University of Belgrade
Technical Faculty in Bor
Mining and Metallurgy
Institute Bor

56th International October Conference on Mining and Metallurgy

PROCEEDINGS

Editors:
Ljubiša Balanović
Dejan Tanikić

22-25 October 2025,
Bor Lake, Serbia

University of Belgrade
Technical Faculty in Bor
Mining and Metallurgy
Institute Bor

56th International October Conference on Mining and Metallurgy

PROCEEDINGS

Editors:
Ljubiša Balanović
Dejan Tanikić

IOC 2025
International October Conference

22-25 October 2025,
Bor Lake, Serbia

PROCEEDINGS,

56th INTERNATIONAL OCTOBER CONFEERNCE

on Mining and Metallurgy

Editors:

Prof. dr Ljubiša Balanović

Prof. dr Dejan Tanikić

University of Belgrade - Technical Faculty in Bor

Technical Editors:
MSc Miljan Marković
MSc Kristina Božinović
University of Belgrade - Technical Faculty in Bor

Proceedings cover design:
MSc Aleksandar Cvetković,
University of Belgrade - Technical Faculty in Bor

Publisher: University of Belgrade - Technical Faculty in Bor

For the publisher: Dean Prof. dr Dejan Tanikić

Circulation: 200 copies

Publication Place, Year: Bor, 2025

Printed by "*GRAFIKA GALEB DOO" NIŠ, 2025*

CIP - Каталогизација у публикацији Народна библиотека Србије, Београд

622(082)(0.034.2)
669(082)(0.034.2)

INTERNATIONAL October Conference on Mining and Metallurgy (56 ; 2025 ; Bor Lake)
Proceedings [Elektronski izvor] / 56th International October Conference on Mining and Metallurgy - IOC 2025, 22-25 October, 2025, Bor Lake, Serbia ; [organized by] University of Belgrade, Technical Faculty in Bor and Mining and Metallurgy Institute Bor ; editors Ljubiša Balanović, Dejan Tanikić. - Bor : University of Belgrade, Technical Faculty, 2025 (Niš : Grafika Galeb). - 1 USB fleš memorija ; 1 x 1 x 5 cm

Sistemski zahtevi: Nisu navedeni. - Nasl. sa naslovne strane dokumenta. - Tiraž 200. - Preface / Ljubiša Balanović. - Bibliografija uz svaki rad.

ISBN 978-86-6305-164-5

a) Рударство -- Зборници b) Металургија -- Зборници

COBISS.SR-ID 177493257

Bor Lake, Serbia, October 22-25, 2025

The conference is financially supported by
The Ministry of Science, Technological
Development and Innovation
of the Republic of Serbia

Platinum Donors

HBIS SERBIA

SERBIA ZIJIN MINING

Gold Sponsor

DPM METALS

Gold Donors

SERBIA ZIJIN COPPER DOO BOR

Sevojno VALJAONICA BAKRA COPPER MILL

Silver Donor

MC LABOR

Exhibitions

indemak®

Labtim

KRUG
KRUG INTERNATIONAL LTD.

MERIS

Altium

metalurg

FUGRO

ANALYSIS
LABORATORY EQUIPMENT

LOLA INSTITUT

Tescan

μikrolux
www.mikrolux.hr

Trokuttest Group
Srbija

novos
partnership through science

Ruirui Tech

MDPI

ВИНАРИЈА МАНАСТИРА
БУКОВО

Donor of official opening

Epiroc

Friends of the Conference

MESSER
Gases for Life

CHINA-SERBIA
JOINT LABORATORY
ON GREEN STEEL
MANUFACTURING
HBIS and University of Belgrade

THE FOUNDATION
'B.SC. ENG. BOŠKO INJAC'

SCIENTIFIC COMMITTEE

Prof. Dr Dejan Tanikić, University of Belgrade, Technical Faculty in Bor (Serbia) - president
Prof. Dr Nada Štrbac, University of Belgrade, Technical Faculty in Bor (Serbia) - vice-president
Prof. Dr Radoje Pantović, University of Belgrade, Technical Faculty in Bor (Serbia) - vice-president
Dr Ana Kostov, Mining and Metallurgy Institute Bor (Serbia) - vice-president

Prof. Dr Milan Antonijevic, University of Belgrade, Technical Faculty in Bor (Serbia)
Prof. Dr Hasan Avdušinović, University of Zenica, Faculty of Engineering and Natural Sciences (Bosnia and Herzegovina)
Dr Ana Alil, University of Belgrade, Institute of Chemistry, Technology and Metallurgy (Serbia)
Prof. Dr Ljubiša Balanović, University of Belgrade, Technical Faculty in Bor (Serbia)
Prof. Dr Farzet Bikić, University of Zenica, Faculty of Engineering and Natural Sciences (Bosnia and Herzegovina)
Prof. Dr Grozdanka Bogdanović, University of Belgrade, Technical Faculty in Bor (Serbia)
Prof. Dr Pavel Broz, Masaryk University, Faculty of Science, Department of Chemistry (Czech Republic)
Dr Mile Bugarin, Mining and Metallurgy Institute Bor (Serbia)
Prof. Dr Ilhan Bušatlić, University of Zenica, Faculty of Engineering and Natural Sciences (Bosnia and Herzegovina)
Prof. Dr Nicanor Cimpoesu, Gheorghe Asachi Technical University from Iasi (Romania)
Prof. Dr Mira Cocić, University of Belgrade, Technical Faculty in Bor (Serbia)
Dr Vladan Ćosović, University of Belgrade, Institute of Chemistry, Technology and Metallurgy (Serbia)
Prof. Dr Pasquale D. Cavaliere, University of Salento, Department of Innovation Engineering (Italy)
Prof. Dr Kemal Delijić, University of Montenegro, Faculty of Metallurgy and Technology (Montenegro)
Prof. Dr Nikhil Dhawan, Indian Institute of Technology, Department of Metallurgical and Materials Engineering (India)
Prof. Dr Savas Dilibal, Istanbul Gedik University, Department of Mechatronics Engineering (Turkey)
Prof. Dr Aleksandar Dimitrov, Ss. Cyril and Methodius University in Skopje, Faculty of Technology and Metallurgy (Republic of North Macedonia)
Prof. Dr Natalija Dolić, University of Zagreb, Faculty of Metallurgy (Croatia)
Prof. Dr Yong Du, Central South University Changsha (China)
Prof. Dr Luis Filipe Malheiros, University of Porto, Faculty of Engineering (Portugal)
Prof. Dr Almaida Gigović-Gekić, University of Zenica, Faculty of Engineering and Natural Sciences (Bosnia and Herzegovina)
Prof. Dr Mirko Gojić, University of Zagreb, Faculty of Metallurgy (Croatia)
Prof. Dr Adam Grajcar, Silesian University of Technology, Department of Engineering Materials and Biomaterials (Poland)
Prof. Dr Vesna Grekulović, University of Belgrade, Technical Faculty in Bor (Serbia)
Prof. Dr Daniela Grigorova, University of Chemical Technology and Metallurgy, Faculty of Metallurgy and Material Science (Bulgaria)
Prof. Dr Stojan Groudev, University of Mining and Geology "Saint Ivan Rilski" (Bulgaria)
Prof. Dr Dragoslav Gusković, University of Belgrade, Technical Faculty in Bor (Serbia)
Prof. Dr Tomaš Havlik, Institute of Recycling Technologies, Faculty of Materials, Metallurgy and Recycling, Technical University of Kosice (Slovakia)
Prof. Dr Karl Heinz Spitzer, Technical University of Clausthal, Institute for Metallurgy (Germany)
Dr Slavomír Hredzák, Institute of Geotechnics of the Slovak Academy of Sciences (Slovakia)
Prof. Dr Svetlana Ivanov, University of Belgrade, Technical Faculty in Bor (Serbia)
Prof. Dr Dejan Ivezić, University of Belgrade, Faculty of Mining and Geology (Serbia)
Mirjam Jan-Blažić, Slovenian Foundryen Society (Slovenia)
Prof. Dr Dominika Jendrzejczyk-Handzlik, AGH University of Science and Technology in Kraków, Faculty of Non-Ferrous Metals (Poland)
Prof. Dr Željko Kamberović, University of Belgrade, Faculty of Technology and Metallurgy (Serbia)
Prof. Dr György Kaptay, University of Miskolc, Faculty of Materials and Metallurgical Engineering (Hungary)
Dr Vladan Kašić, Institute for Technology of Nuclear and other Mineral Raw Materials (Serbia)

ORGANIZING COMMITTEE

Prof. Dr Ljubiša Balanović, Full Professor (UB TF Bor) – president

Prof. Dr Radoje Pantović, Full Professor (UB TF Bor) – vice-president

Dr Ana Kostov, Principal Research Fellow (MMI Bor) – vice-president

Dr Ivana Marković, Full Professor (UB TF Bor)

Prof. Dr Jovica Sokolović, Full Professor (UB TF Bor)

Dr Maja Nujkić, Associate Professor (UB TF Bor)

Dr Žaklina Tasić, Associate Professor (UB TF Bor)

Dr Milan Gorgievski, Full Professor (UB TF Bor)

Dr Ana Radojević, Associate Professor (UB TF Bor)

Dr Тања Калиновић, Associate Professor (UB TF Bor)

Dr Dejan Petrović, Associate Professor (UB TF Bor)

Dr Jelena Ivaz, Associate Professor (UB TF Bor)

Dr Anđelka Stojanović, Associate Professor (UB TF Bor)

Dr Uroš Stamenković, Assistant Professor (UB TF Bor)

Dr Jasmina Petrović, Assistant Professor (UB TF Bor)

Dr Vladimir Nikolić, Assistant Professor (UB TF Bor)

Milan Nedeljković, Assistant (UB TF Bor)

Milijana Mitrović, Assistant (UB TF Bor)

Marina Marković, Assistant (UB TF Bor)

Kristina Božinović, Assistant (UB TF Bor)

Milica Zdravković, Assistant (UB TF Bor)

Miljan Marković, Assistant (UB TF Bor)

Pavle Stojković, Assistant (UB TF Bor)

Avram Kovačević, Assistant (UB TF Bor)

Sandra Vasković, English Lecturer (UB TF Bor)

Oliver Marković, IT service (UB TF Bor)

Bojana Janković, Accountant (UB TF Bor)

LIST OF REVIEWERS

Prof. Dr Ridvan Yamanoglu, Kocaeli University (Turkey)
Prof. Dr Peizhong Feng, School Materials Science and Physics, China University of Mining and Technology (China)
Prof. Dr Srećko Stopić, IME Process Metallurgy and Metal Recycling, RWTH Aachen University (Germany)
Prof. Dr Nebojiša Tadić, University of Montenegro - Faculty of Metallurgy and Technology (Montenegro)
Dr Aleksandra Mitovski, Engineering Dobersek GmbH (Germany)
Prof. Dr Žarko Radović, University of Montenegro - Faculty of Metallurgy and Technology (Montenegro)
Prof. Dr Ljubiša Balanović, University of Belgrade - Technical Faculty in Bor (Serbia)
Prof. Dr Milan Gorgievski, University of Belgrade - Technical Faculty in Bor (Serbia)
Prof. Dr Jan Vreštal, Masaryk University, Centre for Nanotechnology and Microtechnology (Czech Republic)
Prof. Dr Claire Utton, University of Sheffield, Department of Materials Science and Engineering (UK)
Prof. Dr Marija Petrović Mihajlović, University of Belgrade - Technical Faculty in Bor (Serbia)
Doc. Dr Jelena Ivaz, University of Belgrade - Technical Faculty in Bor (Serbia)
Prof. Dr Radoje Pantović, University of Belgrade - Technical Faculty in Bor (Serbia)
Prof. Dr Miodrag Banješević, University of Belgrade - Technical Faculty in Bor (Serbia)
Dr Danijel Kržanović, Mining and Metallurgy Institute Bor (Serbia)
Dr Predrag Stolić, University of Belgrade - Technical Faculty in Bor (Serbia)
Dr Vladan Marinković, Mining and Metallurgy Institute Bor (Serbia)
Prof. Dr Saša Stojadinović, University of Belgrade - Technical Faculty in Bor (Serbia)
Doc. Dr Ana Simonović, University of Belgrade - Technical Faculty in Bor (Serbia)
Doc. Dr Dejan Petrović, University of Belgrade - Technical Faculty in Bor (Serbia)
Dr Dragana Medić, University of Belgrade - Technical Faculty in Bor (Serbia)
Prof. Dr Milan Trumić, University of Belgrade - Technical Faculty in Bor (Serbia)
Prof. Dr Jovica Sokolović, University of Belgrade - Technical Faculty in Bor (Serbia)
Prof. Dr Ivana Marković, University of Belgrade - Technical Faculty in Bor (Serbia)
Prof. Dr Maja Trumić, University of Belgrade - Technical Faculty in Bor (Serbia)
Dr Dejan Todorović, Institute for Technology of Nuclear and Other Minerel Raw Materials (Serbia)
Prof. Dr Zoran Štirbanović, University of Belgrade - Technical Faculty in Bor (Serbia)
Prof. Dr Vesna Grekulović, University of Belgrade - Technical Faculty in Bor (Serbia)
Prof. Dr Dejan Tanikić, University of Belgrade - Technical Faculty in Bor (Serbia)
Prof. Dr Dominika Jendrzejczyk-Handzlik, AGH University of Science and Technology in Kraków, Faculty of Non-Ferrous Metals (Poland)
Prof. Dr Grozdanka Bogdanović, University of Belgrade - Technical Faculty in Bor (Serbia)
Prof. Dr Dragan Manasijević, University of Belgrade - Technical Faculty in Bor (Serbia)
Prof. Dr Milan Radovanović, University of Belgrade - Technical Faculty in Bor (Serbia)

PREFACE

On behalf of the Organizing Committee, it is a great honor and pleasure to welcome all esteemed participants of the **56th International October Conference on Mining and Metallurgy (IOC 2025)**, scheduled to take place at **Bor Lake, Serbia**, from **October 22nd to 25th, 2025**.

The collaborative efforts of the University of Belgrade – Technical Faculty in Bor and the Mining and Metallurgy Institute Bor have once again brought together academia, industry, and research institutions to organize this year's IOC. Our focus remains firmly set on presenting the latest research achievements and technological advancements in geology, mining, metallurgy, materials science, technology, environmental protection, and other engineering disciplines.

This year's conference program is rich and diverse, featuring **4 plenary lectures, 4 invited lectures, 158 full papers, and 6 abstracts**. The proceedings reflect the contributions of authors from **19 countries**: Austria, Bosnia and Herzegovina, Bulgaria, Canada, China, Croatia, Germany, Hungary, India, Mexico, Montenegro, Poland, Romania, Russia, Serbia, Slovakia, Slovenia, Turkey, and the United Kingdom. Among the submitted papers, eight young researchers under the age of 35 have qualified to participate in the "**MDPI Young Researcher Award**" competition, further emphasizing the conference's commitment to supporting and recognizing excellence among the new generation of scientists and engineers.

We are also delighted to host the **9th International Student Conference on Technical Sciences (ISC 2025)**, running in parallel with IOC 2025. The student conference brings together young researchers from Serbia and the wider region, with **one plenary** and **50 student papers** presented, offering an invaluable opportunity for the next generation of scientists and engineers to share their ideas and discuss the future of their disciplines with experts. The "**Professor Dragana Živković Best Student Paper Award**" will be presented to the most outstanding student contribution based on originality, research quality, and presentation.

The Organizing Committee expresses its deepest gratitude to all who have supported this event. Our General Sponsor is the Ministry of Science, Technological Development, and Innovation of the Republic of Serbia. We are especially grateful to our Platinum Donors, HBIS Serbia and Serbia Zijin Mining, as well as our Gold Sponsor, DPM Metals Inc., and our Gold Donors, Copper Mill Sevojno and Serbia Zijin Copper Bor. This year, the conference is also supported by the Silver Donor, "MC LABOR" d.o.o. Beograd.

We proudly host a diverse exhibition, featuring Indemak, Labtim SE d.o.o., MERIS d.o.o., Krug International LTD, Altium International d.o.o., Metalurg Foundry Ltd., Fugro Germany Land GmbH, Analysis d.o.o., Lola institut, Tescan and Mikrolux d.o.o., Trokuttest Serbia, Novos d.o.o., Changsha Rui Rui Technology Co., Ltd., MDPI and the Winery of Bukovo Monastery. The official opening of the conference has been supported by Epiroc Srbija a.d.. Finally, we warmly acknowledge our Friends of the Conference: Messer Tehnogas AD Belgrade, the China-Serbia Joint Laboratory on Green Steel Manufacturing, and the Foundation B.Sc. Boško Injac.

We sincerely thank all authors, committees, reviewers, speakers, and chairpersons for their invaluable contributions to shaping IOC 2025. We are confident that the conference will once again serve as a alive platform for scientific exchange, professional networking, and the promotion of sustainable development in mining, metallurgy, and related fields.

On behalf of the 56th IOC Organizing Committee,
Prof. dr Ljubiša Balanović

TABLE OF CONTENTS

Plenary Lectures

Invited Lectures

Conference Papers

Geology and Mining

Extractive Metallurgy and Process Innovations

Alloys, Composites, and Advanced Materials

Technology and Energy

Environmental Protection, Remediation and Risk Assessment

Industrial Management, Digitalization and Quality Control

Abstracts

DOI: 10.5937/IOC25659G

Original scientific paper

EQUILIBRIUM AND THERMODYNAMIC ANALYSIS OF THE ADSORPTION OF COPPER IONS ON SUNFLOWER HULLS

Milan Gorgievski[1a], Marina Marković[1b], Miljan Marković[1c], Vesna Grekulović[1d], Nada Štrbac[1e], Kristina Božinović[1f], Milica Zdravković[1g]

[1] Technical Faculty Bor, University of Belgrade, V.J. 12, 19210 Bor, Serbia
[1a] mgorgievski@tfbor.bg.ac.rs, 0000-0002-9899-719X
[1b] marina.markovic@tfbor.bg.ac.rs, 0009-0007-7553-6423
[1c] mmarkovic@tfbor.bg.ac.rs, 0000-0002-4734-1481
[1d] vgrekulovic@tfbor.bg.ac.rs, 0000-0001-6871-4016
[1e] nstrbac@tfbor.bg.ac.rs, 0000-0003-4836-1350
[1f] kbozinovic@tfbor.bg.ac.rs, 0000-0002-9834-448X
[1g] mzdravkovic@tfbor.bg.ac.rs, 0000-0001-9488-9151

Abstract

This paper presents the equilibrium and thermodynamic study of the adsorption of copper ions on sunflower hulls. The results of the equilibrium analyses showed that Temkin's isothermal model was the best fit the analysed data. The calculated thermodynamic data showed that the sorption reaction is not spontaneous at the given temperatures, that the process is endothermic and that there is a reduced randomness at the solid-solution interface.

Keywords: *copper ions, sunflower hulls, isotherms, thermodynamic*

1. INTRODUCTION

The contamination of water bodies with heavy metals, mainly from the metallurgical and mining industries and battery production, has become a serious problem. Due to their toxicity, heavy metals in wastewater threaten global ecosystems and global health. However, they are also valuable resources that should be recycled. For this reason, but above all for environmental reasons, the development of highly efficient methods for the treatment of industrial wastewater contaminated with heavy metals is very important [1, 2].

One of the most promising methods for treating industrial wastewater with low concentrations of metal ions is adsorption using natural adsorbents, known as "biosorption". This process has several advantages over conventional technologies, such as the use of inexpensive and sustainable materials, the metabolic independence of the process, the effective utilization of waste materials and the high removal efficiency even at low heavy metal concentrations [3].

2. EXPERIMENTAL

The sunflower hulls were first ground and sieved on a set of laboratory sieves, and the fraction -1+0.4 mm was used for the adsorption experiments. Before the adsorption experiments, the sunflower hulls were rinsed with distilled water. Stock solutions of Cu^{2+} ions were prepared with $CuSO_4 \cdot 5H_2O$ from LACHEMA (Czech Republic).

3. RESULTS AND DISCUSSION

3.1 Adsorption isotherms

Adsorption isotherms represent the amount of adsorbed material as a function of the equilibrium concentration after adsorption at a constant temperature [4].

Langmuir isotherm model

Langmuir isotherm model assumes monolayer adsorption on a homogeneous surface. It also assumes that there are no interactions between the adsorbed molecules [5]. In non-linear form, the Langmuir adsorption isotherm model can be expressed as follows [6]:

$$q_e = q_m K_L \frac{C_e}{1+K_L C_e} \tag{1}$$

where: C_e is the equilibrium concentration of metal ions in the solution (mg dm^{-3}); q_e is the equilibrium adsorption capacity, defined as the mass of metal ions per unit mass of adsorbent when the system is at equilibrium (mg g^{-1}); q_m (mg g^{-1}) and K_L (dm^3 mg^{-1}) are constants related to the adsorption capacity and the energy or net enthalpy of adsorption.

Freundlich isotherm model

Freundlich isotherm model is based on the assumption that the surface energy of the adsorbent is heterogeneous and that the stronger binding sites are occupied first. It is also assumed that the binding strength decreases as the degree of site occupation increases [7]. This model can be expressed by the following equation [8]:

$$q_e = K_F C_e^{1/n} \tag{2}$$

where: C_e is the equilibrium concentration of metal ions (mg dm^{-3}); q_e is the equilibrium adsorption capacity (mg g^{-1}); K_F is the Freundlich equilibrium constant (dm^3 g^{-1}). 1/n is the heterogeneity factor and n is a measure of the deviation from linearity of adsorption.

Temkin isotherm model

Temkin isotherm model takes into account the interaction of adsorbent and adsorbate and is based on the assumption that the free adsorption energy is a function of the surface coverage, i.e. that the adsorption energy of the molecules decreases linearly with the degree of surface coverage [9].

The Temkin isotherm is represented by the following equation [10]:

$$q_e = \frac{RT}{b}\ln\left(K_T C_e\right) = B\ln\left(K_T C_e\right) \tag{3}$$

where: T is the absolute temperature (K); R is the universal gas constant (8.314 J mol^{-1} K^{-1}); K_T is the equilibrium binding constant (dm^3 mg^{-1}); b is the change in adsorption energy (kJ mol^{-1}); C_e is the equilibrium concentration of the metal ion (mg dm^{-3}); $RT/b = B$ is the Temkin constant related to the heat of adsorption (kJ mol^{-1}).

Adsorption isotherms of copper ions on sunflower hulls

In order to obtain the adsorption isotherm data, experiments were carried out in which 0.5 g of sunflower hulls were brought into contact with 50 mL of copper ion solution, with initial concentrations ranging from 0.05 to 0.3 mg dm^{-3}. The stirring time was 60 minutes. The suspension was then filtered and the copper concentration in the filtrate was determined.

In this work, three of the most common models of the adsorption isotherm in the literature, the Langmuir model, the Freundlich model, and the Temkin model, were used to fit the experimental data of the adsorption of copper ions on sunflower hulls. The obtained results are shown in Figure 1.

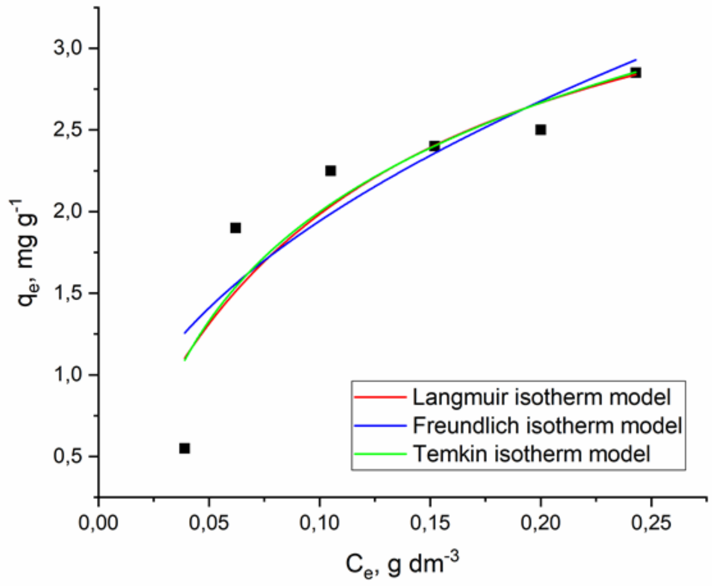

Figure 1. Isotherm data for the adsorption of copper ions on sunflower hulls

Table 1. Isotherm parameters for the adsorption of copper ions on sunflower hulls

Model	Parameters	Values
Langmuir isotherm model	K_L, dm^3 mg^{-1}	9.537
	$q_{e,exp}$, mg g^{-1}	2.850
	q_m, mg g^{-1}	4.064
	R^2	0.838
Freundlich isotherm model	K_F	5.637
	1/n	0.463
	R^2	0.987
Temkin isotherm model	B, J mol^{-1}	0.964
	K_T, dm^3 mg^{-1}	79.397
	R^2	0.988

Based on the values of the correlation coefficients given in Table 1, it can be concluded that Temkin isotherm model shows the best agreement with the experimental data (R^2 = 0.988) and is the best model to describe the equilibrium of adsorption of Cu^{2+} ions on sunflower hulls in the observed concentration range.

3.2 Adsorption thermodynamic

The thermodynamic parameters required to determine the spontaneity and feasibility of adsorption, such as the change in Gibbs free energy, the change in enthalpy and the change in entropy, are easy to determine because adsorption is a temperature-dependent process [11].

To determine the thermodynamic parameters, 0.5 g of adsorbent was brought into contact with 50 mL of a solution of copper ions with a concentration of 0.2 g dm^{-3}, at temperatures of 25 °C, 30 °C and 35 °C, for 60 minutes. The suspension was then filtered and the concentration of copper ions in the resulting filtrate was determined.

The thermodynamic parameters of the adsorption were calculated using the following equation [12, 13]:

$$K_c = \frac{C_A}{C_S} \tag{4}$$

$$\ln K_c = \frac{\Delta S^0}{R} - \frac{\Delta H^0}{RT} \tag{5}$$

$$\Delta G^0 = -RT \ln K_c \tag{6}$$

$$\Delta G^0 = \Delta H^0 - T\Delta S^0 \tag{7}$$

where: K_C is the equilibrium constant; C_A is the concentration of the adsorbed substance at equilibrium (mol dm^{-3}); C_S is the equilibrium concentration of the metal ions in solution (mol dm^{-3}); ΔG^0 is the Gibbs free energy (kJ mol^{-1}); R is the universal gas constant (J mol^{-1} K^{-1}); T is the temperature (K); ΔH^0 is the enthalpy change (kJ mol^{-1}); ΔS^0 is the entropy change (J mol^{-1} K^{-1}).

Figure 2 shows the dependence of $lnK_c=f(1/T)$. Based on the given dependence and the experimental data, the thermodynamic parameters of the adsorption process of copper ions on sunflower hulls were calculated and given in Table 2.

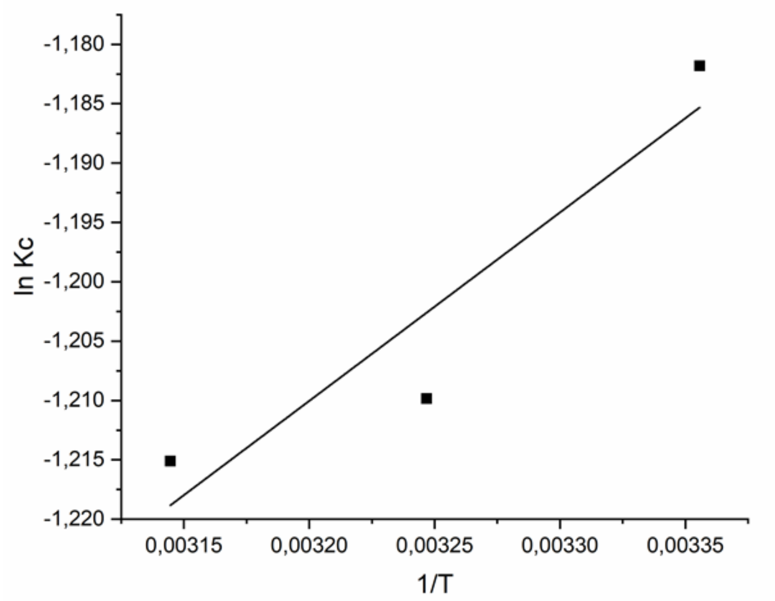

Figure 2. Thermodynamic dependence (ln Kc = f(1/T)) for the adsorption of copper ions on sunflower hulls

Table 2. Thermodynamic parameters of the adsorption process of copper ions on sunflower hulls

T (K)	ΔG^0 (kJ mol^{-1})	ΔH^0 (kJ mol^{-1})	ΔS^0 (J mol^{-1} K^{-1})
298	2.928	0.158	-1.718
303	3.098		
308	3.212		

The values obtained for the change in Gibbs free energy show that the Gibbs free energy increases with increasing temperature. Positive values of the change in Gibbs free energy indicate that there is an energy barrier for the adsorption of copper ions and that the sorption reaction does not occur spontaneously at the given temperatures. A positive ΔH^0 value indicates that the process is endothermic and a negative ΔS^0 value indicates that there is reduced randomness at the interface between the solid and solution [14].

4. CONCLUSIONS

The adsorption of copper ions on sunflower hulls was investigated and presented in this paper. The equilibrium analysis was performed using Langmuir's isothermal model, Freundlich's isothermal model and Temkin's isothermal model. Temkin's isothermal model fits the analysed data best. This model assumes that the adsorption energy of the molecules decreases linearly with the degree of surface coverage. The calculated thermodynamic data (ΔG^0, ΔH^0 and ΔS^0) show that the sorption reaction does not occur spontaneously at the specified temperatures, but is favoured at lower temperatures, that the process is endothermic and that decreased randomness is present at the solid-solution interface.

ACKNOWLEDGEMENTS

The research presented in this paper was done with the financial support of the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, within the funding of the scientific research work at the University of Belgrade - Technical Faculty in Bor, according to the contract with registration number 451-03-137/2025-03/200131.

REFERENCES

[1] L. Fang, L. Li, Z. Qu, H. Xu, J. Xu, N. Yan, J. Hazard. Mater., 342 (2018) 617–624.
[2] Z. Xu, Q. Zhang, X. Li, X. Huang, Chem. Eng. J., 429 (2022) 131688.
[3] H.I. Syeda, I. Sultan, K.S. Razavi, P.S. Yap, J Water Process. Eng., 46 (2022) 102446.
[4] P. Ehiomogue, I.I. Ahuchaogu, I.E. Ahaneku, Acta Tech. Corviniensis – Bull. Eng., XIV (2021) 87-96.
[5] R. Farouq, N.S. Yousef, Int. J. Chem. Eng. Appl., 6 (5) (2015) 319-324.
[6] X. Chen, Information, 6 (1) (2015) 14-22.
[7] R.I. Yousef, B. El-Eswed, A.H. Al-Muhtaseb, Chem. Eng. J., 171 (3) (2011) 1143-1149.
[8] P.S. Kumar, S. Ramalingam, C. Senthamarai, M. Niranjanaa, P. Vijayalakshmi, S. Sivanesan, Desalination, 261 (1-2) (2010) 52–60.
[9] R.I.A. Ahad, S. Goswami, M.B. Syiem, 3 Biotech, 7 (2) (2017).
[10] Sh. Shahmohammadi-Kalalagh, H. Babazadeh, A.H. Nazemi, M. Manshouri, Caspian J. Environ. Sci., 9 (2) (2011) 243-255.
[11] A. Ebelegi, N. Ayawei, D. Wankasi, Open J. Phys. Chem., 10 (2020) 166-182.
[12] P. Rahnama Haratbar, M. Nasiri, A. Ghaemi, Iran. Polym. J., 32 (2023) 929–946.
[13] A. Ozcan, E.M. Oncu, A.S. Ozcan, Colloids Surf. A: Physicochem. Eng. Asp., 277 (2006) 90-97.
[14] L.Y. Lee, X.J. Lee, P.C. Chia, K.W. Tan, S. Gan, J. Taiwan Inst. Chem. Eng., 45 (4) (2014) 1764-1772.