University of Belgrade,
Technical Faculty in Bor

Chamber of Commerce
and Industry of Serbia

XVI International Mineral Processing & Recycling Conference

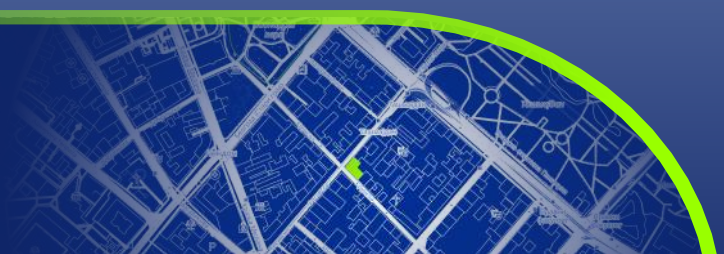
2025 IMPRC

INTERNATIONAL MINERAL PROCESSING & RECYCLING CONFERENCE

Proceedings

Editors:
Zoran ŠTIRBANOVIĆ
Milan TRUMIĆ

28-30 May 2025
Belgrade, Serbia



University of Belgrade,
Technical Faculty in Bor

Chamber of Commerce
and Industry of Serbia

XVI International Mineral Processing & Recycling Conference

2025 IMPRC
INTERNATIONAL MINERAL PROCESSING & RECYCLING CONFERENCE

Proceedings

Editors:
Zoran ŠTIRBANOVIĆ
Milan TRUMIĆ

28 – 30 May 2025, Belgrade, Serbia

XVI International Mineral Processing & Recycling Conference

PUBLISHER:
University of Belgrade, Technical Faculty in Bor

FOR THE PUBLISHER:
Dean: Prof. Dr Dejan Tanikić, University of Belgrade, Technical Faculty in Bor

EDITORS:
Prof. Dr Zoran Štirbanović, University of Belgrade, Technical Faculty in Bor
Prof. Dr Milan Trumić, University of Belgrade, Technical Faculty in Bor

TECHNICAL EDITORS:
Dr Vladimir Nikolić, University of Belgrade, Technical Faculty in Bor
MSc Dragana Marilović, University of Belgrade, Technical Faculty in Bor
MSc Katarina Balanović, University of Belgrade, Technical Faculty in Bor

PROCEEDINGS COVER DESIGN:
MSc Aleksandar Cvetković, University of Belgrade, Technical Faculty in Bor

PRINTED BY:
Grafika Galeb, Niš, Serbia
Printed: 200 copies

PUBLICATION YEAR:
2025

==========

CIP - Каталогизација у публикацији
Народна библиотека Србије, Београд

622.7(082)
502.131.1:628.477.6(082)
628.477.6(082)

INTERNATIONAL Mineral Processing and Recycling Conference (16 ; 2025 ; Belgrade)
Proceedings / XVI International Mineral Processing and Recycling Conference, IMPRC, 28 – 30 May 2025, Belgrade, Serbia ; editors Zoran Štirbanović, Milan Trumić. - Bor : University of Belgrade, Technical Faculty, 2025 (Niš : Grafika Galeb). - XIX, 706 str. : ilustr. ; 25 cm

Na vrhu nasl. str.: Chamber of Commerce and Industry of Serbia. - Tiraž 200. -
Bibliografija uz svaki rad.

ISBN 978-86-6305-158-4

а) Руде -- Припрема -- Зборници б) Отпадне материје -- Одрживи развој – Зборници в) Отпадне материје -- Рециклажа -- Зборници

COBISS.SR-ID 168462601 -ID 114566153

==========

GENERAL SPONSOR

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

GOLD SPONSORS

ZiJin SERBIA ZIJIN COPPER DOO BOR

ZiJin SERBIA ZIJIN MINING

SILVER SPONSORS

EMJM PROMISE

Erasmus Mundus Joint Master in Sustainable Mineral and Metal Processing Engineering

minerals

metals an Open Access Journal by MDPI

HBIS SERBIA

RUDNIK

EXHIBITORS

BSI BALTIC SCIENTIFIC INSTRUMENTS

GLOBAL MET TECH

KRUG

KRUG INTERNATIONAL LTD.

novos partnership through science

FRIENDS OF THE CONFERENCE

PRO FORCE SERBIA

SCIENTIFIC COMMITTEE

ORGANIZING COMMITTEE

Prof. Dr Zoran Štirbanović, University of Belgrade, Technical Faculty in Bor, President
Prof. Dr Milan Trumić, University of Belgrade, Technical Faculty in Bor
Prof. Dr Grozdanka Bogdanović, University of Belgrade, Technical Faculty in Bor
Prof. Dr Jovica Sokolović, University of Belgrade, Technical Faculty in Bor
Prof. Dr Maja Trumić, University of Belgrade, Technical Faculty in Bor
Dr Vladimir Nikolić, University of Belgrade, Technical Faculty in Bor Secretary
Dr Miroslav Ignjatović, Chamber of Commerce and Industry of Serbia
MSc Dragana Marilović, University of Belgrade, Technical Faculty in Bor
MSc Katarina Balanović, University of Belgrade, Technical Faculty in Bor
MSc Ivana Ilić, University of Belgrade, Technical Faculty in Bor
MSc Tamara Gavrilović, University of Priština – Kosovska Mitrovica
MSc Oliver Marković, University of Belgrade, Technical Faculty in Bor
MSc Dragan Milenković, University of Belgrade, Technical Faculty in Bor
MSc Sandra Vasković, University of Belgrade, Technical Faculty in Bor
BSc Vera Ražnatović, Chamber of Commerce and Industry of Serbia
Dobrinka Trujić, University of Belgrade, Technical Faculty in Bor

LIST OF REVIEWERS

Prof. Dr Georgios Anastassakis, National Technical University of Athens (Greece)
Prof. Dr Pablo Brito-Parada, Imperial College London (United Kingdom)
Prof. Dr Milan Trumić, University of Belgrade, Technical Faculty in Bor (Serbia)
Prof. Dr Srećko Stopić, RWTH Aachen University (Germany)
Prof. Dr Grozdanka Bogdanović, University of Belgrade, Technical Faculty in Bor (Serbia)
Prof. Dr Ljubiša Andrić, University of Belgrade, Technical Faculty in Bor (Serbia)
Prof. Dr Jovica Sokolović, University of Belgrade, Technical Faculty in Bor (Serbia)
Prof. Dr Zoran Štirbanović, University of Belgrade, Technical Faculty in Bor (Serbia)
Prof. Dr Maja Trumić, University of Belgrade, Technical Faculty in Bor (Serbia)
Dr Radmila Marković, Mining and Metallurgy Institute Bor (Serbia)
Dr Jelena Petrović, Mining and Metallurgy Institute Bor (Serbia)
Dr Stefan Đorđijevski, Mining and Metallurgy Institute Bor (Serbia)
Dr Vesna Conić, Mining and Metallurgy Institute Bor (Serbia)
Dr Ivana Jelić, Vinča Institute of Nuclear Sciences (Serbia)
Prof. Dr Maja Nujkić, University of Belgrade, Technical Faculty in Bor (Serbia)
Prof. Dr Ivana Marković, University of Belgrade, Technical Faculty in Bor (Serbia)
Prof. Dr Marija Petrović-Mihajlović, University of Belgrade, Technical Faculty in Bor (Serbia)
Prof. Dr Žaklina Tasić, University of Belgrade, Technical Faculty in Bor (Serbia)
Prof. Dr Radoje Pantović, University of Belgrade, Technical Faculty in Bor (Serbia)
Prof. Dr Snežana Milić, University of Belgrade, Technical Faculty in Bor (Serbia)
Dr Ljiljana Avramović, Mining and Metallurgy Institute Bor (Serbia)
Prof. Dr Przemyslaw Kowalczuk, Norwegian University of Science and Technology (Norway)
Prof. Dr Alexandre Chagnes, Université de Lorraine (France)
Prof. Dr Aleksandar Nikoloski, Murdoch University (Australia)
Dr Dragana Medić, University of Belgrade, Technical Faculty in Bor (Serbia)
Prof. Dr Ljubiša Balanović, University of Belgrade, Technical Faculty in Bor (Serbia)
Prof. Dr Juan M. Menéndez Aguado, University of Oviedo (Spain)
Dr Hector Muñiz Sierra, Institute of Chemical Process Fundamentals of the Czech Academy of Sciences (Czech Republic)
Dr Vladimir Nikolić, University of Belgrade, Technical Faculty in Bor (Serbia)
Dr Dragana Božić, Mining and Metallurgy Institute Bor (Serbia)
Dr Marija Šljivić-Ivanović, Vinča Institute of Nuclear Sciences (Serbia)
Dr Dragan Radulović, Institute for Technology of Nuclear and Other Mineral Raw Materials (Serbia)
Prof. Dr Maria Sinche Gonzalez, University of Oulu (Finland)
Prof. Dr Kerstin Forsberg, KTH Royal Institute of Technology (Sweden)
Dr Srđan Stanković, University of Belgrade, Faculty of Biology (Serbia)
Prof. Dr Igor Miljanović, University of Belgrade, Faculty of Mining and Geology (Serbia)
Prof. Dr Milena Kostović, University of Belgrade, Faculty of Mining and Geology (Serbia)
Dr. Yu Yuexian, Xi'an University of Science and Technology (China)
Dr. Yunfeng Song, Central South University (China)
Prof. Bojan Marinkovic, Pontifical Catholic University of Rio de Janeiro (Brazil)

TABLE OF CONTENTS

XVI International Mineral Processing and Recycling Conference
28-30 May 2025, Belgrade, Serbia

DOI: 10.5937/IMPRC25119N Original research article

ANODE NANOMATERIAL RECOVERED FROM SPENT BATTERIES FOR PEROXIDE-ASSISTED CRYSTAL VIOLET PHOTOCATALYTIC DEGRADATION

Vladan Nedelkovski[#], 0000-0001-7724-1118,
Dragana Medić, 0000-0001-9980-5949,
Aleksandar Cvetković, 0009-0003-5184-6874,
Sonja Stanković, 0000-0003-0745-5422,
Žaklina Tasić, 0000-0001-6544-1980,
Milan Radovanović, 0000-0002-5175-6022,
Snežana Milić, 0000-0002-5000-9156,
University of Belgrade, Technical Faculty in Bor, Bor, Serbia

ABSTRACT – This study explores the photocatalytic degradation of Crystal Violet (CV) using anode nanomaterials recovered from spent nickel-metal hydride (NiMH) batteries, activated by hydrogen peroxide (H_2O_2). The research focuses on the potential application of recycled perovskite-based materials, such as Lanthanum Cobalt Oxide ($LaCoO_3$), Nickel Oxide (NiO), and Cerium Dioxide (CeO_2), for the efficient removal of organic dyes from textile industry wastewater. Structural characterization via X-ray diffraction (XRD) confirmed the presence of crystalline phases with high crystallinity, essential for photocatalytic activity. Photocatalytic experiments were conducted under UV-A light (λ = 395 nm) at pH 5.5, demonstrating a degradation efficiency of 99.52% within 60 minutes. The reaction followed pseudo-first-order kinetics, with a significant increase in efficiency over time. These findings highlight the potential of using recycled battery materials as sustainable and effective photocatalysts for wastewater treatment, offering a promising solution to mitigate environmental contamination caused by synthetic dyes and other persistent organic pollutants.

Keywords: Anode Material, Perovskites, Crystal Violet, Photocatalysis.

INTRODUCTION

Textile industry wastewater is a significant source of environmental contamination due to its high concentration of organic pollutants, particularly synthetic dyes. These dyes are known for their chemical stability and resistance to biodegradation, making their removal from water bodies a major challenge. The uncontrolled discharge of such pollutants into aquatic ecosystems leads to severe consequences, including reduced water quality, disruption of aquatic life, and long-term ecological imbalances [1].

In 2020, it was estimated that approximately 200,000 tons of organic dyes were released into textile industry wastewater, posing a substantial environmental threat. The accumulation of these persistent contaminants not only affects aquatic organisms but

[#] corresponding author: vnedelkovski@tfbor.bg.ac.rs

also compromises human health through the contamination of drinking water sources. The widespread presence of dye pollutants in industrial effluents highlights the urgent need for effective and sustainable wastewater treatment methods to mitigate their adverse effects on ecosystems and environmental quality [2].

Traditional methods for dye removal from wastewater are often inefficient or economically unsustainable, driving the search for alternative approaches based on advanced oxidation processes (AOPs) [3]. Hydroxyl radicals generated during AOP exhibit strong oxidative properties, enabling them to degrade complex organic molecules into smaller, environmentally benign compounds such as water and carbon dioxide [4].

Photocatalytic degradation is one of the most promising solutions for breaking down organic pollutants, utilizing photocatalysts that, in the presence of light, generate reactive oxygen species capable of decomposing complex molecules into smaller, environmentally friendly products [5]. Special attention in recent years, has been given to the use of recycled materials, such as perovskite materials similar to the cathode materials that can be obtained from waste batteries [6, 7]. These materials can serve as a very efficient catalyst for dye degradation when activated by hydrogen peroxide.

This paper presents the efficiency of photocatalytic degradation of crystal violet using anode material from spent nickel-metal hydride (NiMH) batteries in combination with hydrogen peroxide. The aim is to examine the degradation kinetics, reaction mechanisms, and the potential application of this method in wastewater treatment.

EXPERIMENTAL

Sample Preparation

The examined sample originated from a discarded battery of an unidentified manufacturer. To ensure safe handling and prevent short circuits, the battery was first disassembled after fully discharging its six individual cells. The discharge process was carried out using a laboratory-made apparatus equipped with a 5.5 Ω resistive wire, enabling controlled discharging of the battery samples.

A hacksaw was used to remove the cell terminals, followed by a longitudinal cut to systematically separate the plastic casing, metal casing, anode, cathode, and separator. The anodic material was subjected to thermal treatment at 580°C for 10 minutes, facilitating its detachment from the current collector. Anodic material was finely ground using an agate mortar and pestle. To maintain sample integrity and prevent cross-contamination, meticulous cleaning of the equipment was performed between uses.

RESULTS AND DISCUSSION

X-ray Diffraction Analysis

XRD analysis was conducted via Rigaku MiniFlex 600 (Japan) to characterize the structural properties of the anode material derived from waste batteries and assess its suitability as a photocatalyst for the degradation of Crystal Violet. The diffraction patterns provide insights into the crystalline phases present, potential impurities, and any structural modifications resulting from material processing. The XRD pattern of anode material is shown in Figure 1.

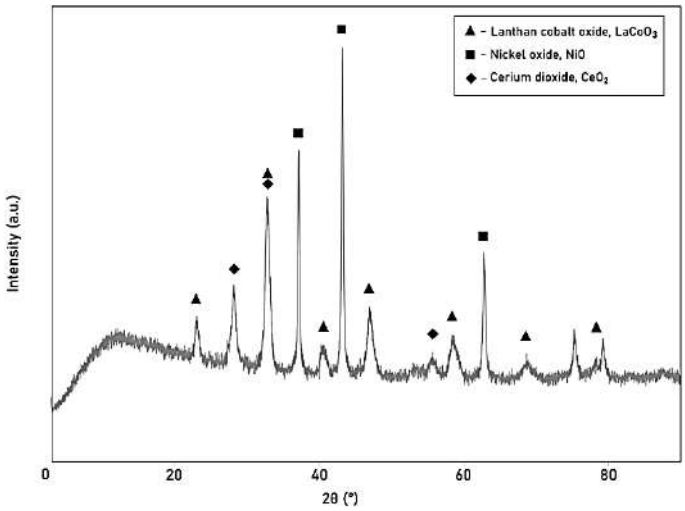


Figure 1 XRD analysis of anode material

The X-ray diffraction (XRD) pattern shown in Figure 1., reveals the crystalline phases present in the analyzed sample, confirming the presence of multiple components. The identified peaks correspond to Lanthanum Cobalt Oxide ($LaCoO_3$), Nickel Oxide (NiO), and Cerium Dioxide (CeO_2), as indicated by the reference diffraction patterns. The presence of $LaCoO_3$ suggests that the anode material retains its perovskite structure, which is crucial for its potential photocatalytic applications [6].

XRD pattern of analyzed material presented a high-intensity peak at 32.7°, which might be associated with planes (110) and/or (104), corresponding to hexagonal crystal symmetry with an R3c space group, assuming angles a=b=90° and y = 120°, further allowing for calculation of crystal lattice constants [8].

The size of crystallites was assessed using the Scherrer equation: $D = 0.9\lambda / \beta \cos\theta$, where D denotes the crystallite size, λ represents the X-ray wavelength (1.5418 Å), θ corresponds to the Bragg diffraction angle, and β signifies the full width at half maximum (FWHM) of the diffraction peak. To evaluate the crystallite size of the sample, the peak broadening of the (024) reflection of the $LaCoO_3$ phase at $2\theta = 46.9°$ was analyzed [8].

Crystal lattice constants for the $LaCoO_3$ phase are determined as a=b≈5.47 Å (hexagonal system) and c≈13.39Å, while crystallite size calculated from the (024) peak is approximately 8.84 nm. The volume cell is determined to be V≈346.8 $Å^3$.

Based on characteristic peaks and confirmed planes (111) and (002), crystal lattice constants for NiO in the cubic system are determined as a=b=c≈4.18 Å, while the crystallite size calculated from the (002) peak is approximately 34.8 nm. The unit cell volume is determined to be V≈73.1$Å^3$.

Crystal lattice constants for CeO_2 in the cubic system are determined as a=b=c≈ 5.45 Å, while the crystallite size calculated from the (111) peak is approximately 11.0 nm. The unit cell volume is determined to be V≈161.9 $Å^3$.

The strong and sharp diffraction peaks could indicate a high degree of crystallinity, suggesting that the material possesses well-ordered structural characteristics [9]. The presence of NiO and CeO_2 as additional phases might contribute to enhanced catalytic properties [10]. These structural insights are essential for understanding the material's reactivity and effectiveness in the photocatalytic degradation of CV when activated with hydrogen peroxide.

Photocatalytic Degradation and Kinetics

Degradation experiments were carried out using a previously prepared 20 ppm crystal violet solution to investigate photocatalytic properties, and accessed via CGOLDENWALL 721 UV-VIS spectrophotometer (China). The experiments were performed with exposure to UV-A light (λ = 395 nm), with the addition of peroxide in order to modify the pH. The collected data were analyzed using a pseudo-first-order model, expressed as [11]:

$$\ln\left(\frac{C_0}{C_t}\right) = kt \tag{1}$$

Here, C_0 and C_t denote the concentrations of the model compound at the initial time (zero) and at time t, respectively, while k represents the rate constant of the reaction. Figure 2(a) illustrates the degradation efficiency of the CV with the addition of H_2O_2. The relationship between $\ln(C_0/C_t)$ and the irradiation time t is presented in Figure 2(b), showing a linear trend. The rate constants for the reaction were determined by calculating the slopes of the $\ln(C_0/C_t)$ versus time plots.

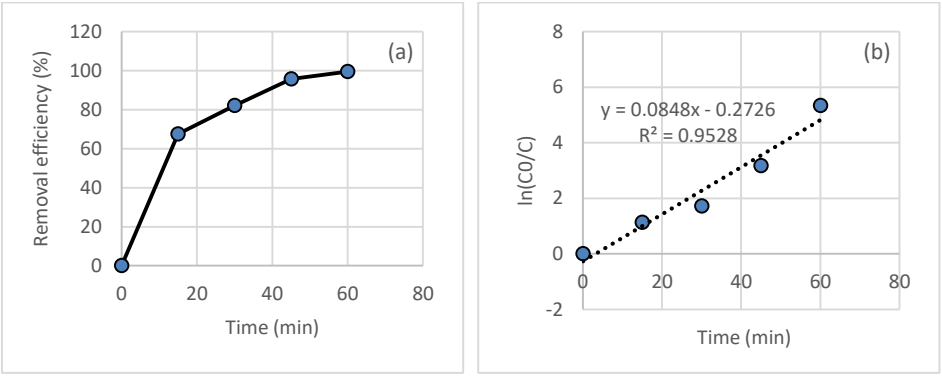


Figure 2 (a) Photocatalytic degradation efficiency of crystal violet, (b) Kinetic curve

The photocatalytic process shows a significant increase in efficiency over time. At 15 minutes, the degradation efficiency is 67.57%, reaching 99.52% at 60 minutes, indicating near-complete degradation of CV. CV degradation follows pseudo-first-order kinetics, which is typical for photocatalytic reactions.

In conclusion, the combination of this anode material and H_2O_2 demonstrates high efficiency in degrading CV, following pseudo-first-order kinetics. Most of the dye is degraded within the first 45 minutes, and near-complete removal is achieved within 60 minutes. This suggests that the anodic material is a promising candidate for the effective removal of CV from wastewater.

CONCLUSION

This study has shown that the combination of recycled anode material and H_2O_2 is highly effective in breaking down complex organic molecules, such as CV, into environmentally benign compounds. The use of recycled materials, such as perovskite-based anode nanomaterials, offers a sustainable and cost-effective approach to wastewater treatment. By repurposing waste from spent batteries, this method not only addresses the issue of environmental contamination caused by synthetic dyes but also contributes to the circular economy by reducing electronic waste. The findings suggest that these materials have significant potential for large-scale applications in industrial wastewater treatment, particularly in the textile industry, where dye pollution is a major concern.

In conclusion, this study highlights the feasibility of using recycled anode nanomaterials as efficient photocatalysts for the degradation of organic dyes. The combination of these materials with H_2O_2 under UV light provides a promising solution for the removal of persistent pollutants from wastewater, offering both environmental and economic benefits. Further research could explore the optimization of reaction conditions and the application of this method to other types of organic pollutants, paving the way for broader implementation in environmental remediation technologies.

ACKNOWLEDGEMENT

The research presented in this paper was done with the financial support of the Ministry of Education, Science and Technological Development 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 number 451-03-137/2025-03/200131.

REFERENCES

1. Ebrahimi, R., Yetilmezsoy, K., Maleki, A., Puttaiah, S.H., Rezaee, R., Hossienzadeh, K., Daraei, H., Safari, M., Shahmoradi, B., Ghanbari, R., Jafari, A. (2019) Effects of doping zinc oxide nanoparticles with transition metals (Ag, Cu, Mn) on photocatalytic degradation of Direct Blue 15 dye under UV and visible light irradiation. Journal of Environmental Health Science and Engineering, 17(1), 479–492.
2. Druzian, D.M., Oviedo, L.R., Wouters, R.D., Loureiro, S.N., Ruiz, Y.P.M., Galembeck, A., Pavoski, G., Espinosa, D.C.R., Dos Santos, C., Dos Santos, J.H.Z., Silva, W.L.D. (2023) A bimetallic nanocatalyst from carbonaceous waste for crystal violet degradation. Materials Chemistry and Physics, 297, 127455.
3. Mirzaei, A., Chen, Z., Haghighat, F., & Yerushalmi, L. (2017). Removal of pharmaceuticals from water by homo/heterogonous Fenton-type processes – A review. Chemosphere, 174, 665–688.

4. Salehi, K., Daraei, H., Teymouri, P., Shahmoradi, B., Maleki, A. (2015) Cu-doped ZnO nanoparticle for removal of reactive black 5: application of artificial neural networks and multiple linear regression for modeling and optimization. Desalination and Water Treatment, 57(46), 22074–22080.
5. Khan, S., Noor, T., Iqbal, N., Yaqoob, L. (2024) Photocatalytic dye degradation from textile wastewater: A review. ACS Omega, 9(20), 21751–21767.
6. Latsiou, A., Konstantinou, I., Bairamis, F., Lykos, C. (2022) Synthesis and characterization of $LaCo_xNi_{1-x}O_3$ perovskites as heterogeneous catalysts for phenolics degradation by persulfate activation. Journal of Chemical Technology & Biotechnology, 97(12), 3467–3480.
7. Christensen, B.H., Deganello, F., La Parola, V., Boffa, V., Jørgensen, M.K., Østergaard, M.B. (2023) Thermocatalytic performance of $LaCo_{1-x}NixO_{3-\delta}$ perovskites in the degradation of Rhodamine B. Catalysts, 13(2), 325.
8. Islam, M., Jeong, M.-G., Jung, H.-G., Ghani, F. (2015) Micro emulsion synthesis of LaCoO3 nanoparticles and their electrochemical catalytic activity. Journal of Electrochemical Science and Technology, 6(4), 121–130.
9. Shaban, Y., Alharbi, N.A. (2022) Sunlight-mediated photocatalytic removal of phenanthrene from wastewater using carbon-doped zinc oxide (C-ZnO) nanoparticles. Environmental Science and Pollution Research, 29(31), 47818–47831.
10. Atzori, L., Cutrufello, M.G., Meloni, D., Cannas, C., Gazzoli, D., Monaci, R., Sini, M.F., Rombi, E. (2017) Highly active NiO-CeO2 catalysts for synthetic natural gas production by CO_2 methanation. Catalysis Today, 299, 183–192.
11. Sliem, M.A., Salim, A.Y., Mohamed, G.G. (2018) Photocatalytic degradation of anthracene in aqueous dispersion of metal oxides nanoparticles: Effect of different parameters. Journal of Photochemistry and Photobiology A: Chemistry, 371, 327–335.

9 788663 051584