



УНИВЕРЗИТЕТ У БАЊОЈ ЛУЦИ
UNIVERSITY OF BANJA LUKA
ТЕХНОЛОШКИ ФАКУЛТЕТ
FACULTY OF TECHNOLOGY



PROCEEDINGS

OCTOBER 21-22, 2022

ACADEMY OF SCIENCES AND ARTS
OF THE REPUBLIC OF SRPSKA,
BANJA LUKA, REPUBLIC OF SRPSKA, B&H

INTERNATIONAL SCIENTIFIC CONFERENCE

XIV OF CHEMISTS,
CONFERENCE TECHNOLOGISTS AND
ENVIRONMENTALISTS
OF REPUBLIC OF SRPSKA

XIV CONFERENCE OF CHEMISTS, TECHNOLOGISTS AND
ENVIRONMENTALISTS OF REPUBLIC OF SRPSKA

BOOK OF PROCEEDINGS

Publisher:

University in Banjaluka, Faculty of Technology

Editorial board:

Borislav Malinović, PhD, dean

Design and computer processing

Pero Sailović, PhD

MSc Marina Rakanović

MSc Đorđe Vujčić

CIP - Каталогизacija у публикацији
Народна и универзитетска библиотека
Републике Српске, Бања Лука

66(082)
661:663/664(082)
502(082)

CONFERENCE of Chemists, Technologists and Environmentalists
of Republic of Srpska (14 ; 2023)

[Book of proceedings] : international scientific conference /
XIV Conference of Chemists, Technologists and Environmentalists
of Republic of Srpska ; [editorial board Borislav Malinović]. - Banja
Luka : University in Banjaluka, Faculty of Technology, 2023 ([S.l. :
s.n.]). - 313 стр. ; 24 cm

Библиографија уз сваки рад.

ISBN 978-99938-54-98-2

COBISS.RS-ID 137637377

Organizing Committee:

PhD Pero Sailović, president, PhD Darko Bodroža, general secretary, M.Sc Maja Milijaš secretary, M.Sc Dajana Dragić, M.Sc Branka Ružičić, M.Sc Marina Rakanović, M.Sc Maja Katić, Sanda Pilipović, M.Sc Nebojša Gorgi, Biljana Vasić, Sanja Novaković, M.Sc Jovanka Kotur

Students: Vladimir Ivković, Jovan Savić, Nevena Janjić, Bojana Milinković, Danijela Lazić

Scientific Committee:

Dr Božana Odžaković, president, University of Banja Luka, **B&H**, Dr Nada Štrbac, co-president, University of Belgrade, **Serbia**, Dr Borislav Malinović, University of Banja Luka, **B&H**, Dr Vlada Veljković, University of Niš, **Serbia**, Dr Todor Vasiljević, Victoria University Melbourne, **Australia**, Dr Sanja Mahović-Poljačak, University of Zagreb, **Croatia**, Dr Csaba Horvath, University Obuda, Budapest, **Hungary**, Dr Mihail Kochubovski, University of Skopje, **Macedonia**, Dr Massimiliano Fenice, Universityt Della Tuscia, **Italy**, Dr Georgij Petriaszwili, Warshav University of Technology, **Poland**, Dr Mira Vukcević, University of Monte Negro, **Monte Negro**, Dr Ondrej Panák, University of Pardubice, **Czech Republic**, , Dr Pospiech Matej, University of Veterinary and Pharmaceutical Sciences, Brno, **Czech Republic**, , Dr Dani Dordevic, University of Veterinary and Pharmaceutical Sciences, Brno, **Czech Republic**, Dr Iskren Spiridonov, University of Chemical Technology and Metallurgy, **Bulgaria**, Dr Laura Benea, West University of Timisoara, **Romania**, Dr Savvas G. Vassiliadis, University of Piraeus, **Greece**, Dr Helena Prosen, University of Ljubljana, **Slovenia**, Dr Srecko Stopic, RWTH University Aachen, **Germany**, Dr Maria Iosune Cantalejo, UPNA, **Spain**, Dr Jurislav Babić, University of Osijek, **Croatia**, Dr Svetozar Milosavić, University of Kosovska Mitrovica, **Serbia**, Dr Petar Uskoković, University of Belgrade, **Serbia**, Dr Mitja Kolar, University of Ljubljana, **Slovenia**, Dr Dragiša Savić, , University of Niš, **Serbia**, Dr Dragan Vujadinović, University of East Sarajevo, **B&H**, Dr Biljana Pajin, University of Novi Sad, **Serbia**, Dr Sead Čatić, University of Tuzla, **B&H**, Dr Husein Vilić, University of Bihać, **B&H**, Dr Sanjin Gutić, University of Sarajevo, **B&H**, Dr Goran Trbić, University of Banja Luka, **B&H**, Dr Milica Balaban, University of Banja Luka, **B&H**, Dr Ljiljana Vukić, University of Banja Luka, **B&H**, Dr Ljiljana Topalić-Trivunović, University of Banja Luka, **B&H**, Dr Slavica Sladojević, University of Banja Luka, **B&H**, Dr Pero Dugić, University of Banja Luka, **B&H**, Dr Zoran Kukrić, University of Banja Luka, **B&H**, Dr Slavica Grujić, University of Banja Luka, **B&H**, Dr Milorad Maksimović, University of Banja Luka, **B&H**, Dr Branka Rodić-Grabovac, University of Banja Luka, **B&H**, Dr Rada Petrović, University of Banja Luka, **B&H**, Dr Dragana Grujić, University of Banja Luka, **B&H**, Dr Svjetlana Janjić, University of Banja Luka, **B&H**, Dr Zora Levi, University of Banja Luka, **B&H**, Dr Ladislav Vasilišin, University of Banja Luka, **B&H**

NOTE:

The authors have full responsibility for the originality and content of thier own papers



УНИВЕРЗИТЕТ У БАЊОЈ ЛУЦИ
UNIVERSITY OF BANJA LUKA
ТЕХНОЛОШКИ ФАКУЛТЕТ
FACULTY OF TECHNOLOGY



International scientific conference

"XIV CONFERENCE OF CHEMISTS, TECHNOLOGISTS AND ENVIRONMENTALISTS OF REPUBLIC OF SRPSKA"

under the auspices of



MINISTRY OF SCIENTIFIC AND TECHNOLOGICAL DEVELOPMENT, HIGHER EDUCATION AND INFORMATION SOCIETY

MINISTRY OF AGRICULTURE, FORESTRY AND WATER MANAGEMENT



ACADEMY OF SCIENCES AND ARTS OF THE REPUBLIC OF SRPSKA

SPONSORS

OPTIMA GROUP and OIL RAFINERY MODRIČA

HOFSTETTER ENVIRONMENTAL SRL

SINEX LABORATORY

PREHTEH d.o.o.

DESTILACIJA ad

EAST CODE d.o.o.

MUNICIPALITY OF ČELINAC

J.P. DEP-OT

ASSOCIATION OF TECHNOLOGY ENGINEERS OF REPUBLIC OF
SRPSKA

EM PLUS d.o.o.

KESO GRADNJA d.o.o.

MARKWAY d.o.o.

EURO-LAB V d.o.o.

EKO-EURO TIM d.o.o.

MB-IMPEX d.o.o.

TRGO FORTUNA PLUS d.o.o.

EURO-INSPEKT d.o.o.

ABC PROJEKT d.o.o.

ŠTAMPARIJA PETROGRAF

CSK PRINT

CONTENTS

GENERAL AND APPLIED CHEMISTRY	5
SYNTHESIS AND ANTIPROLIFERATIVE ACTIVITY OF NITRO AND AMINO SUBSTITUTED BENZIMIDAZOLES AND BENZOTHIAZOLES.....	6
Marijana Hranjec, Livio Racané, Ida Boček, Leentje Persoons, Dirk Daelmans	
PHOTOLYSIS OF NADOLOL IN THE AQUATIC ENVIRONMENT: INSIGHTS INTO THE EFFECT OF BICARBONATES.....	15
Andrijana Vukojević, Maria M. Savanović, Stevan Armaković, Svetlana Pelemiš, Sanja J. Armaković	
CAN E-CIGARETTES BE A THREAT TO ENVIRONMENT: HEAVY METALS ANALYSIS IN E-CIGARETTES FILTERS	21
Dijana Mihajlović, Nemanja Lončar, Ana Đurić, Bojana Đekanović, Dijana Jelić	
COMPARISON OF THREE EXTRACTION PROCEDURES FOR QUANTIFICATION OF Cu, Mn, Ni, Pb AND Zn IN THE PLANTS	27
Dijana Mihajlović, Vesna Antunović	
ANTIPROLIFERATIVE AND ANTIBACTERIAL ACTIVITY <i>IN VITRO</i> OF AMIDINO SUBSTITUTED 2-NAPHTHYLBENZAZOLES	33
Livio Racané, Lucija Ptiček, Marijana Hranjec, Leentje Persoons, Dirk Daelmans, Mihailo Banjananc, Vedrana Radovanović	
SOLVATOCHROMIC PROPERTIES OF NEWLY SYNTHESIZED ARYL AZO PYRIDONE DYES	42
Borko Matijević, Gorana Mrđan, Dušan Mijin, Jelena Lađarević, Suzana Apostolov, Đeđi Vaštag	
CHEMICAL ENGINEERING	50
BIOBASED UNSATURATED POLYESTER RESINS REINFORCED WITH NATURAL FILLERS	51
Olga Pantić, Vesna Panić, Sanja Savić, Maja Marković, Melina Kalagasidis Krušić, Pavle Spasojević	
POSSIBILITIES OF CROSSLINKING SILICONE MATERIALS IN EXCESS OF CROSSLINKER WITH TWO TYPES OF FILLERS	56
Darko Manjenčić, Marko Paić, Vesna Cvijetinović, Vladan Mičić, Anja Manjenčić, Duško Kostić, Pero Dugić	
PHOSPHATE GLASSY FERTILIZERS	62
Vladimir S. Topalović, Jelena D. Nikolić, Srdjan D. Matijašević, Veljko V. Savić, Marija S. Djošić, Ana M. Vujošević, Snežana R. Grujić	
CHEMICAL TECHNOLOGY	67
MINEROLOGICAL AND CHEMICAL CHARACTERIZATION OF CLAY FROM THE ZAGONI SITE MUNICIPALITY OF BRATUNAC	68
Dragana Kešelj, Dragica Lazić, Zoran Petrović, Nebojša Vasiljević	
THE PHOTOSTABILITY AND DYEING ABILITY OF SOME ANTHRAQUINONE REACTIVE DYES FOR COTTON AND PAPER.....	75
Polya Miladinova, Dimitrina Todorova	
COMPARATIVE ANALYSIS OF BLEACHING OF SUNFLOWER OIL WITH COMMERCIAL BLEACHING EARTH AND BENTONITE POWDER ACTIVATED WITH SULFURIC ACID	83
Zoran Petrović, Jelena Mihajlović, Sabina Begić, Dragana Kešelj, Zorica Stojanović, Amir Fazlić	
BIOTECHNOLOGY	95
THE IMPACT OF pH VALUE AND TEMPERATURE ON POLYPHENOL RECOVERY, ANTIOXIDANT CAPACITY AND PHYSICAL PROPERTIES OF SERPYLLI HERBA'S WASTE EXTRACTS.....	96
Aleksandra A. Jovanović, Predrag M. Petrović, Mina Volić, Nataša Obradović, Bojana Balanč, Radoslava Pravilović, Branko M. Bugarski	
THE POSSIBILITY OF ANTIBIOTIC AZALOMYCIN B PRODUCTION BY COMBINING BENZOYL HYDRAZONE DERIVATIVES AND WASTE RAPESEED OIL GLYCEROL	105

Jovan Ćirić, Slavica Ilić, Sandra Konstantinović, Đorđe Lazarević, Marko Živković, Nikola Stanković

FOOD TECHNOLOGY 109

RED WINE COLOR AND STABILITY AS FUNCTION OF SIZE AND CONTENT OF SILICA GEL PARTICLES 110
Tanja Šaran, Dragan Vujadinović, Zoran Petković, Milan Vukić, Vesna Gojković, Vladimir Tomović

THE SEASONAL VARIATIONS OF BIOCHEMICAL COMPOSITION OF COW'S MILK ON THE SOUTHERN SERBIA TERRITORY 118
Jovan Ćirić, Slavica Ilić, Aleksandar Veličković, Ivan Stojković, Dragana Stanisavljević, Nebojša Milosavljević

THE EFFECTS OF ADDITION OF FLAXSEED TO THE CHARACTERISTICS OF BREAD 122
Gordana Jovanović, Ana Vasić, Ljubica Mijić, Ana Matić, Bojan Damnjanović

HABITS OF FLUID INTAKE WITH STUDENTS 128
Dragana Ilić Udovičić, Ana Matić, Danijela Damnjanović, Aleksandra Vasić

QUALITY CONTROL AND FOOD SAFETY 134

THE CONTENT OF TOTAL IRON IN *Urtica dioica* L. FROM DIFFERENT LOCALITIES IN SERBIA 135
Jelena Đuričić Milanković, Kosana Popović, Mirjana Antonijević Nikolić, Bojana Milutinović, Danijela Damnjanović, Dragana Ilić Udovičić

THE PRESENCE OF PHOSPHATE IN MEAT PRODUCTS FROM THE MARKET OF REPUBLIC OF SRPSKA 143
Biljana Pećanac, Dragan Brenjo

TEXTILE ENGINEERING 151

OPTIMIZATION OF THE CLASSICAL DYEING PROCESS OF PES KNITWEAR 152
Marija Kodrić, Suzana Đorđević, Nevena Tomić, Dragan Đorđević

INFLUENCE OF KNIT PATTERN ON DIMENSIONAL STABILITY OF KNITTED FABRICS 159
Sandra Stojanović, Dušan Trajković, Jelka Geršak, Miodrag Đorđević

GRAPHIC ENGINEERING AND DESIGN 166

A METHOD OF RANKING RESPONDENTS ACCORDING TO SENSE OF COLOR DIFFERENCES 167
Zoran Gazibarić, Predrag Živković, Vladimir Cviljušac, Miloš Ljubojević

AN OVERVIEW OF VARIOUS POSSIBILITIES OF 3D PRINTING TECHNIQUES IN THE PRODUCTION OF FLEXOGRAPHIC PRINTING PLATES 176
Sandra Dedijer, Nemanja Kašiković, Magdolna Pal, Živko Pavlović, Gojko Vladić, Ivana Tomić, Bojan Banjanin

CONTEMPORARY APPLICATIONS OF PULP MOULDED PACKAGING 184
Gojko Vladić, Nemanja Kašiković, Živko Pavlović, Stefan Đurđević, Gordana Bošnjaković, Teodora Gvoka

INFLUENCE OF THE SUBSTRATE ON THE PERMANENCE OF PRINTING INK 190
Branka Ružičić, Mladen Stančić, Đorđe Vujčić, Milijana Milić

REMARKS ABOUT PRINTING AUTOMATION 194
Thomas Hoffmann Walbeck, Živko Pavlović

ENVIRONMENTAL ENGINEERING AND ECOLOGY 199

DEPOSITION OF GOETHITE AND FERRIHYDRITE ONTO EXPANDED VERMICULITE SURFACE: CHEMICAL PROPERTIES AND POTENTIAL APPLICATION 200
Mladen Bugarčić, Aleksandar Jovanović, Aleksandar Marinković, Jovana Bošnjaković, Miroslav Sokić, Ana Radosavljević Mihajlović, Milan Milivojević

REMOVAL OF XENOBIOTICS FROM WASTEWATERS USING PHOTOLYSIS UNDER SUN-LIGHT IRRADIATION: EXPERIMENTAL APPROACH AND PROCESS DESIGN 206

Aleksandar Jovanović, Mladen Bugarčić, Nataša Knežević, Jovana Bošnjaković, Jelena Lukić, Antonije Onjia, Aleksandar Marinković

SOLAR STABILITY OF COMMERCIAL PESTICIDES THAT CONTRIBUTE TO THE QUALITY OF GRAPES AND FRUITS..... 211

Maria M. Savanović, Aleksandra Jovanoski Kostić, Andrijana Vukojević, Stevan Armaković, Jelena Kalajdžić, Biserka Milić, Mladen Kalajdžić, Svetlana Pelemiš, Sanja J. Armaković

COMPARATIVE ASSESSMENT OF ZINC IONS SORPTION AND RETENTION BY PROSPECTIVE UNCONVENTIONAL SOIL ADDITIVES 217

Ivana Smičiklas, Marija Egerić, Mihajlo Jović

A GREEN ADSORBENT BASED ON WHEAT STARCH FOR REMOVAL OF SELECTIVE ORGANIC POLLUTANTS FROM AQUEOUS SOLUTIONS 225

Nataša Karić, Marija Vukčević, Marina Maletić, Mirjana Ristić, Aleksandra Perić-Grujić, Katarina Trivunac

EFFECT OF ALKALI MODIFICATION ON ADSORPTION EFFICIENCY OF FLY ASH 231

Nataša Karić, Sara Živojinović, Marija Vukčević, Marina Maletić, Aleksandra Perić-Grujić, Katarina Trivunac

USE OF AGRICULTURAL WASTE AS RAW MATERIALS FOR OBTAINING GLASS AND GLASS-CERAMICS: A REVIEW 237

Vladimir S. Topalović, Jelena D. Nikolić, Veljko V. Savić, Srdjan D. Matijašević, Marija S. Djošić, Snežana N. Zildžović, Snežana R. Grujić

PHOTOCATALYTIC DECOMPOSITION OF DIFENOCONAZOLE FROM WASTEWATERS 242

Jovana Bošnjaković, Nataša Knežević, Srećko Manasijević, Aleksandar Jovanović, Mladen Bugarčić, Aleksandar Marinković

UTILIZATION OF CONSTRUCTION MATERIAL AND UNSATURATED RESIN FROM WASTE PET AS A STABILIZER FOR DESORBED METAL ION Pb^{2+} 247

Nataša Knežević, Jovana Bošnjaković, Aleksandar Jovanović, Mladen Bugarčić, Srećko Manasijević² Aleksandar Marinković

BIOCHAR AS EFFICIENT TOOL FOR SOIL AMMENDMENT 252

Zorica Lopičić, Anja Antanasković, Tatjana Šošarić, Vladimir Adamović, Marina Orlić, Jelena Petrović, Jelena Avdalović

A STUDY OF PV SYSTEM APPLICATION ON THE SUSTAINABLE DEVELOPMENT IN SERBIA 258

Dragana Todorović, Slavica Jovanović, Tijana Kevkić, Marija Stojanović Krasić, Nenad Milojević, Branko Drljača

TIME AND SEASONAL VARIATIONS OF PARTICULATE MATTER (PM) AND GASEOUS POLLUTANTS CONCENTRATIONS IN AMBIENT AIR OF VALJEVO, SERBIA 265

Jelena Đuričić Milanković, Dragana Đorđević, Slavica Ilić

ORGANIC BIO-DEGRADABLE WASTE IN FRUIT PRODUCTION 275

Milica Đeković Šević, Zoranka Malešević, Milan Šević, Tamara Bartošek

MATERIAL SCIENCE AND METALLURGY 283

SIMULATION OF THE IMPACT OF PREHEATING TEMPERATURE ON RAILWAY ALUMINOTHERMIC WELDING 284

Gvozden Jovanović, Vaso Manojlović, Miroslav Sokić, Alen Delić, Milorad Gavrilovski

OTHERS 291

STUDY OF ISOTHERMAL, KINETIC, AND THERMODYNAMIC PARAMETERS FOR SORPTION OF VANADIUM 292

Tamara T. Tadić, Bojana M. Marković, Aleksandra B. Nastasović, Ljiljana T. Suručić, Zvezdana P. Sandić, Antonije E. Onjia

REMOVAL OF LINDANE FROM AQUEOUS SOLUTION BY GLYCIDYL METHACRYLATE BASED CHELATING MACROPOROUS COPOLYMER: KINETICS AND MECHANISM..... 300

Tamara T. Tadić, Bojana M. Marković, Mila V. Ilić, Aleksandra B. Nastasović, Antonije E. Onjia

THE USE OF SOFT FOOD AS A VEHICLE FOR DRUG DELIVERY TO PEDIATRIC POPULATION – EFFECTS
ON DISSOLUTION OF PROPRANOLOL 307

Maja Mirjanić, Aneta Stojmenovski, Biljana Gatarić, Nataša Bubić Pajić, Anđelka Račić

Original scientific article

STUDY OF ISOTHERMAL, KINETIC, AND THERMODYNAMIC PARAMETERS FOR SORPTION OF VANADIUM

Tamara T. Tadić¹, Bojana M. Marković¹, Aleksandra B. Nastasović¹, Ljiljana T. Suručić², Zvezdana P. Sandić³, Antonije E. Onjia⁴

¹University of Belgrade - Institute of Chemistry, Technology and Metallurgy, Njegoševa 12, 11000 Belgrade, Serbia

²Faculty of Medicine, University of Banja Luka, Save Mrkalja 14, 78000 Banja Luka, Republic of Srpska, B&H

³University of Banja Luka, Faculty of Natural Science and Mathematics, Mladena Stojanovića 2, 78000 Banja Luka, Republic of Srpska, B&H

⁴Faculty of Technology and Metallurgy, University of Belgrade, Karnegijeva 4, 11000 Belgrade, Serbia

Abstract

This study evaluated the equilibrium, kinetics, and thermodynamics of vanadium sorption from aqueous solution onto nanocomposite functionalized with diethylene triamine in batch conditions. The effects of temperature, solution pH, and initial concentration of vanadium were examined. The maximum sorption capacity of vanadium on the tested sorbent was achieved at pH 6. The sorption capacity increased with increasing temperature and initial concentration. The equilibrium adsorption data were analyzed using Langmuir, Freundlich, Temkin, Jovanovic, Toth, Sips, Khan, and Redlich–Peterson isotherm models. The kinetics data were studied using pseudo-first-order, pseudo-second-order, the fractional power, Elovich, and Avrami models. A non-linear fitting method was used to compare the best fitting of the equilibrium and kinetic data. The sorption equilibrium data were best represented by the Langmuir, Khan, Toth, and Redlich–Peterson isotherms. The adsorption kinetics was estimated to follow the pseudo-second-order kinetic model. The mechanism of vanadium sorption was analyzed with intra-particle, Bangham, Boyd, and liquid film diffusion models. It was observed that the sorption process was controlled by the film-diffusion as well as the pore-diffusion. Thermodynamic parameters (change of standard enthalpy (ΔH°), standard entropy (ΔS°), and standard free energy (ΔG°)) suggested that the sorption of vanadium onto functionalized nanocomposite was a spontaneous and endothermic process.

Keywords: sorption, vanadium, kinetics, isotherms, thermodynamics.

Introduction

Vanadium (V) is a transition element that exists in several oxidation states in the range from +2 to +5, while tetravalent and pentavalent vanadium are the most commonly used forms (Ścibior et al., 2020). Due to its good physicochemical properties, vanadium is widely used in many industries such as petrochemical, electrochemical, and metallurgical industries (Luo et al., 2017). It plays an important role in contemporary science thanks to its application in producing ceramics, alloys, glasses, and redox batteries (Dakroury et al., 2022; Peng, 2019). An important source of vanadium is represented by minerals, such as vanadinite, patronite and carnotite (Luo et al., 2017). Also, it is used in steel production to improve strength, malleability, and resistance (Ścibior et al., 2020). The rapid growth of the industry has resulted in environmental pollution by vanadium. At the trace level, V has positive effects on plants and algae. On the other hand, huge amounts of V could be released into the environment through industry, contaminating wastewater, groundwater, and soils (Rivas et al., 2019; Ścibior et al., 2020). Vanadium compounds toxicity increase with increasing valence. Through the

food chain, vanadium could reach the human body and cause various health diseases and disorders (Barceloux & Barceloux, 1999). During the production of heat and electricity, exposure to vanadium occurs. Much attention has been focused on the removal of vanadium pollution. Various methods have been employed for removing vanadium from aqueous solutions, such as solvent extraction, sorption, chemical precipitation, and ion exchange (Li et al., 2011; Mthombeni et al., 2015). Among the mentioned methods, sorption is the most economical and effective method due to its flexibility, low cost, simple operation, and high efficiency. Various natural and synthetic materials have been used as sorbents for the removal of vanadium from aqueous solutions, such as natural soil colloids (Luo et al., 2017), di-2-ethylhexyl phosphoric acid (Li et al., 2011), amine extracts (Yang et al., 2016), polymers (Rivas et al., 2019), etc.

In this work, nanocomposite functionalized with diethylene triamine was used as a sorbent for the removal of vanadium. The effects of initial pH value, operative temperature, and initial concentration of vanadium in solution onto sorption capacity were investigated. In addition, the isotherms, kinetics, and thermodynamics of the sorption process were discussed.

Materials and Methods

In the present study, all the chemicals were analytical reagent grade. A stock solution of vanadium (100 mg/dm^3) was prepared by dissolving a NH_4VO_3 (Merck, Germany) in deionized water (Milli-Q Millipore, conductivity $18 \text{ M}\Omega/\text{cm}$). The batch sorption experiments were performed in 100 ml erlenmeyer flasks by contacting 10 g/L of sorbent with a certain concentration of vanadium solution. The effects of process parameters on sorption capacity were investigated by varying initial pH values (3 - 8), initial concentration of the metal solution ($1 - 100 \text{ mg/dm}^3$), and temperature (298 - 343 K). The residual vanadium concentration in the aqueous solution was determined by ICP-OES (Thermo Scientific iCAP 6500, USA). All experiments were repeated in duplicate. Based on obtained results, the kinetic, isotherm, and thermodynamic parameters were determined. The sorption capacity at a given time (Q_t , mg/g) and at equilibrium (Q_e , mg/g) were calculated using equations 1 and 2, respectively:

$$Q_t = \frac{(C_0 - C_t)V}{m} \quad (1)$$

$$Q_e = \frac{(C_0 - C_e)V}{m} \quad (2)$$

where C_0 (mg/dm^3) is the initial concentration of vanadium solution, C_t (mg/dm^3) and C_e (mg/dm^3) are the concentrations of vanadium solutions at time t , and at equilibrium, respectively, V (dm^3) is the volume of the aqueous phase, and m (g) is the mass of the sorbent.

Results and discussion

The pH value of vanadium solution is a very important parameter of the sorption process because it affects the surface chemistry of the sorbent and vanadium ions specification. The effect of pH values of vanadium solution on sorption capacity was investigated in an initial pH range between 3 and 8 at $T = 298 \text{ K}$ using 10 g/dm^3 sorbent dose for 60 min. It was observed from Figure 1a that as the initial pH value was increased, the capacity of vanadium sorption increased and the maximum sorption capacity was reached at pH 6. With a further increase in the initial pH value, the sorption capacity decreased. It is known that the dominant form of vanadium at pH lower than 4 is VO^{2+} , while neutral and anionic forms exist at pH above 4 (Guzmán et al., 2002). At pH around 6, amino groups on nanocomposite were protonated, thus, the interaction between anionic forms of vanadium and active

sites of sorbent was more efficient. The influence of initial metal concentration was examined at $\text{pH} = 6$, $T = 298 \text{ K}$ for 60 min. The increase of initial vanadium concentration from 1 to 100 mg/dm^3 resulted in an increase in sorption capacity from 0.07 mg/g to 4.97 mg/g (Figure 1b). This can be accounted to the increase in the number of vanadium ions to the constant amount of active sites on the sorbent. To investigate the effect of temperature, the sorption capacity was determined at 298, 310, 329, and 343 K -at pH value 6, with a sorbent dose of 10 g/dm^3 for 60 min. The results are presented in Figure 1c. As can be seen, the sorption capacity slightly increases with increasing the temperature. The observed behavior can be attributed to the increase in the rate of diffusion of vanadium ions to the active sites on the sorbent (Atsar et al., 2021).

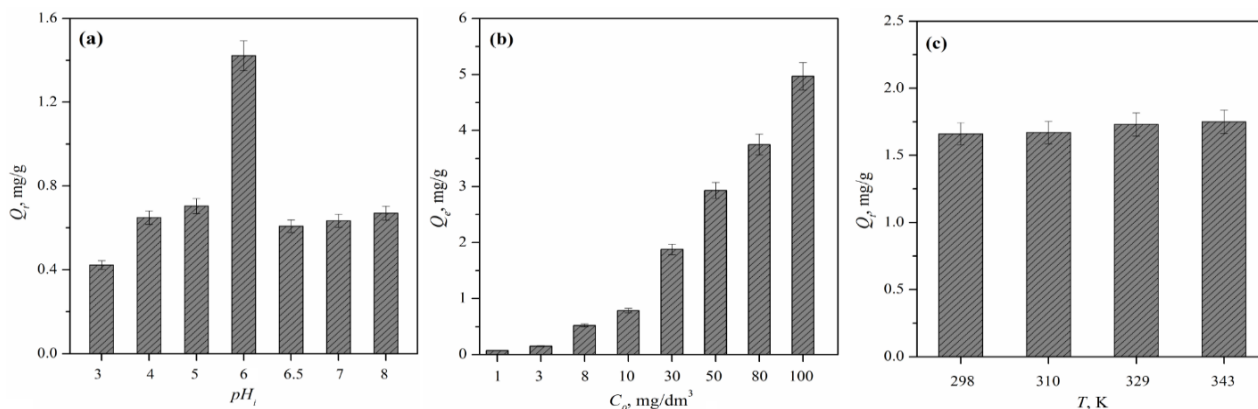


Figure 1. Effect of (a) initial pH, (b) initial concentration and (c) temperature on the sorption capacity of vanadium

To examine the binding interaction between sorbent and vanadium ions, experimental data at equilibrium were analyzed using two-parameters models, namely Langmuir, Freundlich, Temkin, and Jovanovic as well as three-parameters isotherms, namely Redlich-Peterson, Sips, Toth and Khan (Marković et al., 2014; Nastasović et al., 2022). The non-linear regression was used for fitting the curves by applying the Microsoft Excel Solver function. The isotherm models were analyzed using three statistical error functions, namely coefficient of determination (R^2), the sum of square error (SSE), and Chi-square (χ^2) (Kuetze et al., 2020). The obtained parameters for two-parameters and three-parameters isotherm models are presented in Tables 1 and 2, while isotherm fitting curves are portrayed in Figure 2.

With maximal R^2 and minimal SSE and χ^2 , the Langmuir model better described the experimental data compared to other two-parameters isotherm models, indicating monolayer sorption and the homogenous nature of sorbent. All three-parameters isotherm models showed good agreement with experimental data since their R^2 values were high (≥ 0.993). The obtained results indicate that three-parameters isotherms better describe the sorption process than two-parameters models. Also, it can be seen that the Redlich-Peterson and Khan isotherm models have the same and maximal R^2 value (0.994) and minimal values of SSE and χ^2 (0.097 and 0.035, respectively), indicating that sorption of vanadium was a hybrid process and does not follow ideal monolayer adsorption.

Table 1. Parameters of two-parameters isotherm models for the sorption of vanadium onto amino-functionalized nanocomposite

Isotherm model	Parameter	Value	R ²	SSE	χ ²
Langmuir	K_L , L/mg	0.02	0.992	0.066	0.094
	$Q_{max,L}$, mg/g	8.63			
Freundlich	K_F , L ⁿ mg ¹⁻ⁿ /g	0.27	0.988	0.093	0.042
	n	1.37			
Temkin	b_T , kJ/mol	1.45	0.943	1.053	3.451
	K_T , L/mg	0.27			
Jovanovic	K_J , L/g	0.02	0.991	0.104	0.152
	$Q_{max,J}$, mg/g	7.63			

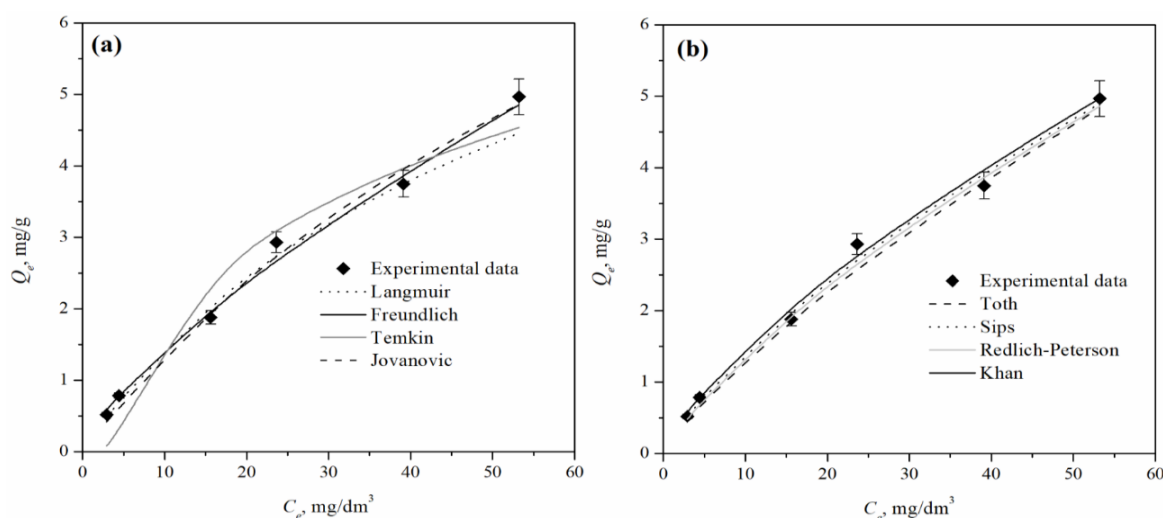


Figure 2. Predicted curve non-linear fits for the (a) two-parameter and (b) three-parameter isotherms of vanadium sorption by amino-functionalized nanocomposit

Table 2. Parameters of three-parameters isotherm models for the sorption of vanadium onto amino-functionalized nanocomposite

Isotherm model	Parameter	Value	R ²	SSE	χ ²
Redlich-Peterson	A , L/g	0.32	0.994	0.097	0.035
	B , L/mg	0.50			
	g	0.40			
Sips	$Q_{m,s}$, mg/g	28.86	0.993	0.100	0.036
	$K_S \cdot 10^3$, L/mg	2.76			
Toth	β	0.83	0.994	0.103	0.040
	$Q_{m,T}$, mg/g	70.19			
	$K_T \cdot 10^3$, L/g	3.29			
Khan	t	0.42	0.994	0.097	0.035
	$Q_{m,K}$, mg/g	0.76			
	K_K	0.28			
	n_K	0.30			

To investigate the kinetics of the vanadium sorption onto nanocomposite functionalized with diethylene triamine five models were used, namely pseudo-first-order, pseudo-second-order, Elovich, Avrami, and Fractional power kinetic models (Nastasović et al., 2022). The non-linear regression method was used to determine the kinetic parameters. The three statistical error functions (R², SSE, and χ²) were applied to test the best fitting kinetic models. The estimated kinetic parameters are presented in Table 3, while kinetics fitting curves are shown in Figure 3.

Table 3. Kinetic parameters for sorption of vanadium onto amino-functionalized nanocomposite

Kinetic model	Parameter	Value	R ²	SSE	χ ²
Pseudo-first-order	k ₁ , 1/min	0.14	0.787	0.267	0.395
	Q _e ^{cal} , mg/g	1.42			
Pseudo-second-order	k ₂ , 1/min	0.18	0.998	0.001	0.001
	Q _e ^{cal} , mg/g	1.48			
Elovich	α, mg/g min	4.91	0.992	0.004	0.003
	β, g/mg	5.35			
Avrami	k _{AV} , 1/min	0.07	0.997	0.002	0.002
	Q _e ^{cal} , mg/g	10.49			
	n	0.17			
Fractional power	k _{FP} , mg/g min	0.71	0.888	0.076	0.084
	ν, 1/min	0.16			

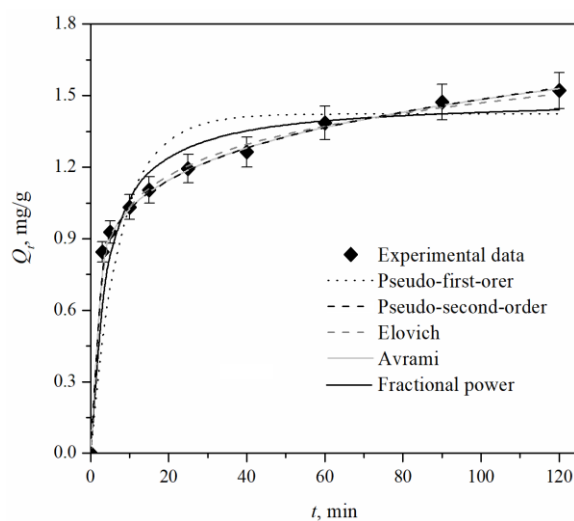


Figure 3. Non-linear kinetic models fitting for sorption of vanadium by nanocomposite functionalized with diethylene triamine

Based on statistical error functions presented in Table 3, the non-linear model of pseudo-second order is best suited to describe the sorption of vanadium. The Q_e^{calc} value (1.48 mg/g) from the pseudo-second-order was close to the Q_e^{exp} value (1.52 mg/g), meaning that chemisorption plays an important role in the vanadium sorption onto amino-functionalized nanocomposite.

The liquid film diffusion, intra-particle diffusion, Bangham, and Boyd models (Nastasović et al., 2022) were used to understand the sorption mechanism. The results are presented in Figure 4 and Table 4. As can be seen from obtained results, the high values for R² for liquid film diffusion, intra-particle diffusion, Bangham, and Boyd models, as well as multilinear intra-particle diffusion plot, suggest the simultaneous influence of film and pore diffusion onto vanadium sorption by the investigated sorbent.

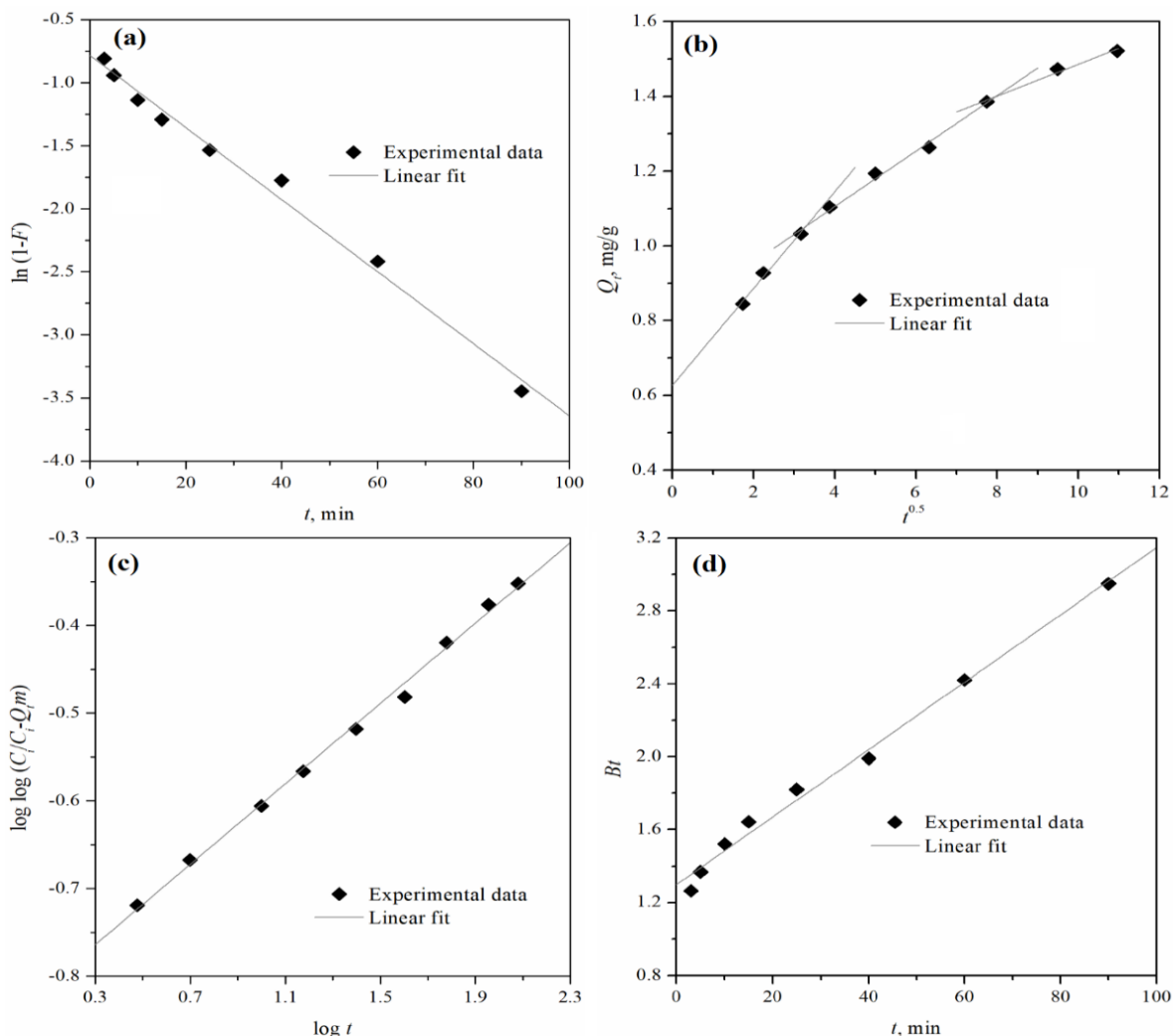


Figure 4. Linearized plots of (a) liquid film diffusion, (b) intra-particle diffusion, (c) Bangham and (d) Boyd models for the sorption of vanadium onto nanocomposite functionalized with diethylene triamine

Table 4. Parameters for sorption mechanism of vanadium onto amino-functionalized nanocomposite

Parameters	Values	Parameters	Values
Intra-particle diffusion		Liquid film diffusion	
$k_{id,1}$, mg/g min ^{0.5}	0.13	$k_{LFD} \cdot 10^2$, 1/min	2.86
$C_{id,1}$	0.63	C_{LFD}	-0.79
R_1^2	0.990	R^2	0.990
$k_{id,2}$, mg/g min ^{0.5}	0.07	Bangham model	
$C_{id,2}$	0.81	$k_B \cdot 10^3$, 1/g	0.68
R_2^2	0.992	α	0.23
$k_{id,3}$, mg/g min ^{0.5}	0.04	R^2	0.996
$C_{id,3}$	1.06	Boyd model	
R_3^2	0.987	R^2	0.991

The standard Gibb's free energy change (ΔG°), the standard enthalpy change (ΔH°) and the standard entropy change (ΔS°) were calculated from Van't Hoff equation (Marković et al., 2017). The thermodynamic parameters are given in Table 5. The positive values of ΔS° (0.31 kJ/K mol) typify a high degree of randomness and reversible process. The positive ΔH° value (69.5 kJ/mol) suggests that the sorption is endothermic and chemisorption in nature (Dada et al., 2020). The negative ΔG°

values at all studied temperatures indicate that sorption of vanadium is thermodynamically favourable and spontaneous.

Table 5. Thermodynamic parameters for vanadium sorption by amino-functionalized nanocomposite

T, K	ΔG° (kJ/mol)	ΔH° (kJ/mol)	ΔS° (kJ/Kmol)	$T\Delta S^\circ$ (kJ/mol)
298	-22.98			92.55
313	-26.71			96.28
328	-31.61	69.5	0.31	102.18
343	-36.95			106.53

Conclusion

This study has investigated the possible application of amino-functionalized nanocomposite as sorbent for the removal of vanadium from aqueous solutions. The sorption capacity was dependent on the initial pH value of vanadium solution, temperature as well as initial metal concentration. Isotherms models confirmed that sorption of vanadium was a hybrid process and did not follow ideal monolayer adsorption. The sorption followed the pseudo-second-order kinetics model, as confirmed by statistical error functions. The mechanism investigation has shown that intra-particle diffusion was not the only rate-limiting step. Thermodynamic parameters suggested that the sorption of vanadium onto functionalized nanocomposite was a spontaneous, thermodynamically favourable, and endothermic process.

Acknowledgment: This work was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Grants No. 451-03-68/2022-14/200026 and 451-03-68/2022-14/200135).

References

- Atsar, F. S., Kukwa, D., Wuana, R. A. & Arwenyo, B. (2021). Kinetics and thermodynamic studies: Adsorption of Pb, Cr and Ni ions from spent lubrication oil (SLO) using acid modified clay. *American Journal of Analytical Chemistry*, 12(5), 109–120. <https://doi.org/10.4236/ajac.2021.125009>
- Barceloux, D. G. & Barceloux, D. (1999). Vanadium. *Journal of Toxicology: Clinical Toxicology*, 37(2), 265–279. <https://doi.org/10.1081/CLT-100102425>
- Dada, A. O., Adekola, F. A., Odebunmi, E. O., Dada, F. E., Bello, O. M., Akinyemi, B. A., Bello, O. S. & Unukoro, O. G. (2020). Sustainable and low-cost *Ocimum gratissimum* for biosorption of indigo carmine dye: kinetics, isotherm, and thermodynamic studies. *International journal of phytoremediation*, 22(14), 1524–1537. <https://doi.org/10.1080/15226514.2020.1785389>
- Dakroury, G. A., El-Shazly, E. A. A., Eliwa, A. A., Mubark, A. E. & El-Azony, K. M. (2022). Utilization of titanium nanocomposites as prospective materials for recycling of vanadium (V) from waste solutions. *Journal of Molecular Liquid*, 366, 120170. <https://doi.org/10.1016/j.molliq.2022.120170>
- Guzmán, J., Saucedo, I., Navarro, R., Revilla, J. & Guibal, E. (2002). Vanadium interactions with chitosan: Influence of polymer protonation and metal speciation. *Langmuir*, 18(5), 1567–1573. <https://doi.org/10.1021/la010802n>
- Kuete, I.-H. T., Tchuifon, D. R. T., Ndifor-Angwafor, G. N., Kamdem, A. T. & Anagho, S. G. (2020). Kinetic, isotherm and thermodynamic studies of the adsorption of thymol blue onto powdered activated carbons from *Garcinia cola* nut shells impregnated with H₃PO₄ and KOH: Non-linear regression analysis. *Journal of Encapsulation and Adsorption Sciences*, 10, 1–27. <https://doi.org/10.4236/jeas.2020.101001>

- Li, X., Wei, C., Deng, Z., Li, M., Li, C. & Fan, G. (2011). Selective solvent extraction of vanadium over iron from a stone coal/black shale acid leach solution by D2EHPA/TBP. *Hydrometallurgy*, 105, 359–363. <https://doi.org/10.1016/j.hydromet.2010.10.006>
- Luo, X., Yu, L., Wang, C., Yin, X., Mosa, A., Lv, J. & Sun, H. (2017). Sorption of vanadium (V) onto natural soil colloids under various solution pH and ionic strength conditions. *Chemosphere*, 169, 609–617. <https://doi.org/10.1016/j.chemosphere.2016.11.105>
- Marković, B. M., Stefanović, I. S., Hercigonja, R. V., Pergal, M. V., Marković, J. P., Onjia, A. E. & Nastasović, A. B. (2017). Novel hexamethylene diamine-functionalized macroporous copolymer for chromium removal from aqueous solutions. *Polymer International*, 66(5), 679–689. <https://doi.org/10.1002/pi.5306>
- Marković, D. D., Lekić, B. M., Rajaković-Ognjanović, V. N., Onjia, A. E. & Rajaković, Lj. V. (2014). A new approach in regression analysis for modeling adsorption isotherms. *The Scientific World Journal*. 2014, 930879. <https://doi.org/10.1155/2014/930879>
- Mthombeni, N. H., Mbakop, S. & Onyango, M. S. (2015). Magnetic zeolite-polymer composite as an adsorbent for the remediation of wastewaters containing vanadium. *International Journal of Environmental Science and Development*. 6(8), 602–605. <http://dx.doi.org/10.7763/IJESD.2015.V6.665>
- Nastasović, A., Marković, B., Suručić, Lj. & Onjia, A. (2022). Methacrylate-based polymeric sorbents for recovery of metals from aqueous solutions. *Metals*, 12(5), 814. <https://doi.org/10.3390/met12050814>
- Peng, H. (2019). A literature review on leaching and recovery of vanadium. *Journal of Environmental Chemical Engineering*, 7(5), 103313. <https://doi.org/10.1016/j.jece.2019.103313>
- Rivas, B. L., Espinosa, C. & Sánchez, J. (2019). Application of the liquid-phase polymer-based retention technique to the sorption of molybdenum(VI) and vanadium(V). *Polymer Bulletin*, 76, 539–552. <https://doi.org/10.1007/s00289-018-2397-8>
- Ścibiora, A., Pietrzyk, Ł., Plewa, Z. & Skiba, A. (2020). Vanadium: Risks and possible benefits in the light of a comprehensive overview of its pharmacotoxicological mechanisms and multi-applications with a summary of further research trends. *Journal of Trace Elements in Medicine and Biology*, 61, 126508. <https://doi.org/10.1016/j.jtemb.2020.126508>
- Yang, X., Zhang, Y., Bao, S. & Shen, C. (2016). Separation and recovery of vanadium from a sulfuric-acid leaching solution of stone coal by solvent extraction using trialkylamine. *Separation and Purification Technology*, 164, 49–55. <https://doi.org/10.1016/j.seppur.2016.03.021>