



University of Belgrade
Technical Faculty in Bor



Chamber of Commerce
and Industry of Serbia

XV International Mineral Processing & Recycling Conference



Proceedings

Editors:
Jovica Sokolović
Milan Trumić

17-19 May
2023

Belgrade
SERBIA



University of Belgrade,
Technical faculty in Bor

Chamber of Commerce
and Industry of Serbia

XV International Mineral Processing & Recycling Conference



Proceedings

Editors:
Jovica Sokolović
Milan Trumić

17 – 19 May 2023, Belgrade, Serbia

XV International Mineral Processing & Recycling Conference

PUBLISHER:

University of Belgrade, Technical Faculty in Bor

FOR THE PUBLISHER:

Dean: Prof. Dr Dejan Tanikić

EDITORS:

Prof. Dr Jovica Sokolović

Prof. Dr Milan Trumić

PROCEEDINGS COVER DESIGN:

Vojislav Jotović

PRINTED BY:

Grafomed - Trade Bor d.o.o., Bor, Serbia

Printed: 200 copies

PUBLICATION YEAR:

2023

=====
CIP - Каталогизacija 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 (15 ; 2023 ; Belgrade)
Proceedings / XV International Mineral Processing and Recycling Conference, IMPRC, 17-19
May 2023, Belgrade, Serbia ; editors Jovica Sokolović, Milan Trumić. - Belgrade : University,
Technical Faculty in Bor, 2023 (Bor : Grafomed Trade). - XII, 634 str. : ilustr. ; 25 cm

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

ISBN 978-86-6305-133-1

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

COBISS.SR-ID 114566153

=====



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

COMMITTEES

Scientific Committee

Prof. Dr Milan Trumić, Serbia, President;
Prof. Dr Grozdanka Bogdanović, Serbia, Vice President;
Prof. Dr Jovica Sokolović, Serbia, Vice President;
Prof. Dr Zhiyong Gao, China;
Prof. Dr Lijie Guo, China;
Prof. Dr Mauricio Torem, Brazil;
Prof. Dr Pablo Brito-Parada, United Kingdom;
Prof. Dr Przemyslaw Kowalczyk, Norway;
Prof. Dr Erin Bobicki, Canada;
Prof. Dr Kazutoshi Haga, Japan;
Dr Maoming Fan, USA;
Dr Aleksandar Janković, Australia;
Prof. Dr Rraghupatruni Bhima Rao, India;
Prof. Dr Junbeum Kim, France;
Prof. Dr Srećko Stopić, Germany;
Prof. Dr Magdalena Regel-Rosocka, Poland;
Prof. Dr Alejandro Rodriguez Pascual, Spain;
Prof. Dr Georgios Anastassakis, Greece;
Prof. Dr Mehmet Polat, Turkey;
Prof. Dr Valery Morozov, Russian Federation;
Prof. Dr Silvie Heviánková, Czech Republic;
Dr Slavomir Hredzak, Slovakia;
Prof. Dr Gabor Musci, Hungary;
Prof. Dr Francisc Popescu, Romania;
Prof. Dr Irena Grigorova, Bulgaria;
Prof. Dr Jakob Lamut, Slovenia;
Prof. Dr Aleksandra Anić Vučinić, Croatia;
Prof. Dr Ilhan Bušatlić, Bosnia & Herzegovina;
Prof. Dr Svjetlana Sredić, Bosnia & Herzegovina;
Prof. Dr Mirjana Golomeova, North Macedonia;
Prof. Dr Aleksandar Jovović, Serbia;
Prof. Dr Milena Kostović, Serbia;
Prof. Dr Željko Kamberović, Serbia;
Prof. Dr Vlada Veljković, Serbia;
Prof. Dr Goran Vujić, Serbia;
Prof. Dr Srđan Rončević, Novi Sad, Serbia;
Prof. Dr Bogdana Vujić, Serbia;

Prof. Dr Marina Stamenović, Serbia;
Prof. Dr Nada Štrbac, Serbia;
Prof. Dr Milan Antonijević, Serbia;
Prof. Dr Zoran Stević, Serbia;
Prof. Dr Dejan Tanikić, Serbia;
Prof. Dr Snežana Šerbula, Serbia;
Prof. Dr Snežana Milić, Serbia;
Prof. Dr Mira Cocić, Serbia;
Prof. Dr Zoran Štirbanović, Serbia;
Prof. Dr Maja Trumić, Serbia;
Prof. Dr Ljubiša Andrić, Serbia;
Asst. Prof. Dr Vladan Milošević, Serbia;
Dr Ivana Smičklas, Serbia;
Dr Miroslav Sokić, Serbia;
Dr Dragan Radulović, Serbia;
Dr Sonja Milićević, Serbia;
Dr Milinko Radosavljević, Serbia;
Dr Mile Bugarin, Serbia;
Dr Zoran Stevanović, Serbia;
Dr Radmila Marković, Serbia;
Dr Miroslav Ignjatović, Serbia.

Organizing Committee

Prof. Dr Jovica Sokolović, President, Serbia;
Prof. Dr Milan Trumić, Serbia;
Prof. Dr Grozdanka Bogdanović, Serbia;
Prof. Dr Zoran Stević, Serbia;
Prof. Dr Zoran Štirbanović, Serbia;
Prof. Dr Maja Trumić, Serbia;
Dr Miroslav Ignjatović, Serbia;
Dr Vladimir Nikolić, Serbia;
MSc Dragana Marilović, Serbia;
MSc Predrag Stolić, Serbia;
MSc Katarina Balanović, Serbia;
MSc Ivana Ilić, Serbia;
MSc Oliver Marković, Serbia;
BSc Vera Ražnatović, Serbia;
BSc Sandra Vasković, Serbia;
Dobrinka Trujić, Serbia.

TABLE OF CONTENTS

PLENARY LECTURES	1
L. Guo, Y. Zhao, Q. Ma, G. Tang, C. Jia, C. Li RESEARCH PROGRESS, TRENDS, AND INNOVATIONS OF DEVELOPMENT ON MINING BACKFILL TECHNOLOGY OF UNDERGROUND METALLIFEROUS MINE	3
V.A. Chanturia, V.V. Morozov, G.P. Dvoichenkova, E.L. Chanturia, Yu. A. Podkamenny INNOVATIVE TECHNOLOGY FOR THE RECOVERY OF ABNORMALLY LUMINESCENT DIAMONDS BASED ON THE USE OF LUMINOPHORE-CONTAINING MODIFIERS	23
G. Vujić N. Maoduš, M. Živančev WTE AS INTEGRATED PART OF CIRCULAR ECONOMY	32
J.C. Gabriel, H. Bo, N. Charpentier, S. Chevrier, Y. Deng, F.Olivier, D. Xia CRITICAL METALS RECOVERY FROM E-WASTE: FROM MICROFLUIDICS HYDROMETALLURGY TO ECONOMICALLY VIABLE PROCESSES	39
SESSION LECTURES	41
F. Nakhaei, I. Jovanović 3D IMAGING AND APPLICATIONS IN MINERAL PROCESSING	43
D. Singh, S. Basu, B. Mishra. R. Bhima Rao NOVEL APPROACHES TO RECOVER TOTAL HEAVY MINERALS FROM DIFFERENT GRADE BEACH SAND DEPOSITS USING GRAVITY CONCENTRATORS	54
M. Trumić, K. Balanović ROLE OF PARTICLE SHAPE IN THE FLOATABILITY OF TONER PARTICLE	64
I. Smičiklas, M. Egerić, M. Jović COPPER SORPTION CAPACITY OF THE SOIL TREATED WITH UNCONVENTIONAL ALKALIZING AGENTS	73
V. Conić, I. Jovanović COPPER ORE BIOLEACHING FROM ECOLOGICAL POINT OF VIEW	79
S. Cvetković, M. Popović, J. Perendija LIFE CYCLE ASSESSMENT AND USE OF NATURAL RESOURCES	89
WORKSHOP PAPERS	95
P. M. Angelopoulos, G. Anastassakis, N. Kountouris, N. Koukoulis, M. Taxiarchou COMBINED USE OF ORGANOSOLV LIGNIN AND XANTHATES ON SPHALERITE FLOTATION FROM MIXED SULPHIDES	97
P. M. Angelopoulos, N. Kountouris, G. Anastassakis, M. Taxiarchou PARTIAL REPLACEMENT OF XANTHATE BY ORGANOSOLV LIGNIN ON PYRITE/ARSENOPYRITE FLOTATION	103
K. Hrůzová, July Ann Bazar, Leonidas Matsakas, Anders Sand, Ulrika Rova, Paul Christakopoulos ORGANOSOLV LIGNIN PARTICLES: A NOVEL GREEN REAGENT THAT INCREASES THE FLOTATION EFFICIENCY OF SULFIDE ORES	109
A. Peppas, D. Skenderas, P.M. Angelopoulos, C. Politi ENVIRONMENTAL BENEFITS OF LIGNIN BASED ECOFRIENDLY SURFACTANTS FOR FLOTATION PROCESSES TOWARDS CURRENT PRACTICES	115

A. Peppas, K. Hurzova, D. Skenderas, C. Politi, L. Matsakas, P.M. Angelopoulos EVALUATION OF BATTERY MINERALS FLOTATION PROCESS ECO FRIENDLINESS UTILISING BIODEGRADABLE LIGNIN REAGENTS	121
A. Peppas, C. Politi, D. Skenderas, P.M. Angelopoulos ENVIRONMENTAL ASSESSMENT OF RARE EARTHS RECOVERY METHOD FROM BAUXITE RESIDUES	126
PAPERS	133
A. Jankovic, M. Sederkennya MODIFIED BOND AND RITTINGER ENERGY-SIZE RELATIONSHIPS FOR LABORATORY FINE GRINDING	135
V. Nikolić, M. Trumić, D. Tanikić OPTIMIZATION OF MICRONIZING ZEOLITE GRINDING USING ARTIFICIAL NEURAL NETWORKS	143
E. Petrakis, K. Komnitsas THE EFFECT OF MICROWAVE RADIATION ON DRY GRINDING KINETICS OF BAUXITE ORE	150
M.H. Tyeb, S. Mishra, A.K. Majumder LSTM AND CNN COMBINATION BASED MODELLING APPROACH FOR PARTITION CURVE PREDICTION IN HYDROCYCLONES	157
I. Jovanović, M.Ž. Trumić, J. Sokolović, M.S. Trumić, J. Nešković DETERMINATION OF LIMITING SETTLING VELOCITY IN THE SLURRY PIPELINE FROM GRINDING PLANT, USING DIFFERENT APPROACHES – A CASE STUDY	163
N. Omarova, R. Sherembayeva, A.Amirkhan, Zh. Ibraybekov, A. Nesipbay FLOTATION OF POLYMETALLIC LEAD-ZINC ORES OF THE BAKALSKOYE DEPOSIT	168
V.A. Chanturiya, I.Zh. Bunin, M.V. Ryazantseva THE APPLICATION OF THE DIELECTRIC BARRIER DISCHARGE (DBD) FOR THE IMPROVEMENT OF THE SEPARATION OF PYRITE AND ARSENOPYRITE	174
V. Ignatkina, A. Kayumov, N. Yergesheva, P. Chernova BASIC SELECTIVE REAGENT REGIMES FOR COMPLEX SULFIDE ORE FLOTATION	179
S. Chaudhuri, S. Maity, S.C. Maji, D. Roy, U.S. Chattopadhyay STUDIES ON THE FLOATABILITY CHARACTERISTICS OF LOW VOLATILE COKING COAL FINES USING X-RAY DIFFRACTION (XRD) ANALYSIS AS A DIAGNOSTIC TOOL	186
V.I. Ryaboi, V.P. Kretov, E.D. Schepeta, I.V. Ryaboi, S.E. Levkovets APPLICATION OF COLLECTOR BTF-15221 IN FLOTATION OF COPPER- AND GOLD - CONTAINING ORES	193
I. Dervišević, A. Dervišević, M. Tomović, J. Galjak COMPARATIVE ANALYSIS OF REAGENTS FOR GOLD EXTRACTION FROM FLOTATION TAILS	202
E.M.S. Silva, A.C. Silva, J.M.B.S. Cabral, P.S. Oliveira, A.F. Nascimento, A.P. Vieira Filho, S.A. Santos TESTS WITH DIFFERENT FLOCCULANTS FOR CHROMIUM ORE TAILINGS	208
C. Ouyang, B. Lv, K. Jia, Y. Yang STUDY ON THE APPLICATION OF HIGH-EFFICIENCY AND ENVIRONMENT-FRIENDLY COPPER COLLECTOR TO ASSOCIATED COPPER IN AN IRON ORE	214
S. Sredić, Lj.Tankosić KINETIC STUDIES OF THE ADSORPTION POLYACRILAMIDE-BASED FLOCCULANTS ON NATURAL GOETHITE, QUARTZ AND CLAY MINERALS	221

G. D. Bogdanović, D. Marilović, B. Nikolić, S. J. Petrović COLUMN LEACHING OF LOW-GRADE COPPER SULFIDE ORE WITH SULFURIC ACID	230
K. Gáborová, M. Achimovičová, M. Hegedüs, O. Šestinová AN INFLUENCE OF MECHANICAL ACTIVATION ON THE COPPER LEACHING KINETICS OF BERZELIANITE	236
D. Medić, I. Đorđević, M. Nujkić, A. Papludis, V. Nedelkovski, S. Alagić, S. Milić USE OF COPPER POWDER AS A REDUCING AGENT IN THE LEACHING PROCESS OF LiCoO_2	242
J. Dimitrijević, S. Jevtić, A. Marinković, M. Simić, M. Koprivica, J. Petrović REMOVAL OF HEAVY METAL IONS FROM MULTIMETALLIC SOLUTION BY MODIFIED OAT STRAW	248
M.R. Rath, A.S. Patra, S. Kiran Kumar, M. Mukherjee, A. Chatterjee, A. Ranjan, A.K. Bhatnagar, A.K. Mukherjee A PROCESS TO DECREASE THE CLAY COATING OF IRON ORE LUMPS & FINES BY THE APPLICATION OF DISPERSANTS	254
H. Kurama, S. Kurama SURFACTANTS AND THEIR FUNCTIONS ON NANO-POWDER SYNTHESIS	262
A. Goryachev, D. Makarov METHODS FOR PROCESSING NATURAL AND ANTHROPOGENIC COPPER- NICKEL RAW MATERIALS IN THE ARCTIC	275
Y. Yuankun, D. Mirović DAM BREACH ANALYSIS USING HEC-RAS: A CASE STUDY OF COPPER AND GOLD "ČUKARU PEKI" MINE DAMS	283
A. Milovanović Brkić, Y. Yuankun, N. Buđelan MANAGEMENT OF FLOTATION TAILINGS AS MINING WASTE ON THE COPPER AND GOLD MINE "CUKARU PEKI"	289
N. Pavlovic, F. Palkovits, A. Hall GEO-STABLE DISPOSAL OF COAL COMBUSTION BYPRODUCTS	297
N. Pavlovic, F. Palkovits, A. Hall TAIL WAGGING THE DOG-WHY INTEGRATED SOLUTIONS ARE BETTER-TAILINGS AND BACKFILL DISPOSAL	303
V. Alivojvodic, N. Petrovnijevic POSITION OF COPPER WITHIN URBAN MINING - RECOVERING POTENTIAL FROM MINE TAILINGS	309
V.Tsitsishvili, N.Dolaberidze, N.Mirdzveli, M.Nijaradze, Z.Amiridze, B.Khutsishvili BACTERIOSTATIC ACTIVITY OF GEORGIAN HEULANDITE ENRICHED WITH BIOLOGICALLY ACTIVE METALS	315
V.Tsitsishvili, M.Panayotova, N.Dolaberidze, N.Mirdzveli, M.Nijaradze, Z.Amiridze, B.Khutsishvili, N.Jakipbekova, S.Sakibayeva THERMAL STABILITY OF NATURAL HEULANDITE-CHABAZITE MIXTURES	321
V.Tsitsishvili, M.Panayotova, N.Dolaberidze, N.Mirdzveli, M.Nijaradze, Z.Amiridze, B.Khutsishvili, N.Klarjeishvili, N.Jakipbekova COMPOSITION OF GEORGIAN AND KAZAKHSTANI NATURAL HEULANDITES	327
S. Matijašević, S. Grujić, V. Topalović, J. Stojanović, J. Nikolić, V. Savić, S. Zildžović NANOCRYSTALLIZATION OF POTASSIUM NIOBIUM GERMANATE GLASSES	333

A.C. Silva, E.M.S. Silva, P.S. Oliveira, A.F. Nascimento, A.P. Vieira Filho, D.B. Carvalho Neto ESTIMATING THE ACCURACY, PRECISION, AND RECALL OF THE HAND-SORTING OF A BRAZILIAN CHROMIUM ORE	338
V.V. Morozov, Y.P. Morozov, G. Zorigt, D. Lodoy, E. Jargalsaikhan, I.V. Pestriak SCANNING FLATBED OPTICAL ORE QUALITY ANALYZER	344
B. B. Tchouffa, N. J. Ndemou, M. G. Frida Ntsama CHARACTERIZATION, ENRICHMENT TEST AND VALORIZATION OF IRON ORE FROM NABEBA (NORTH – CONGO)	350
K. Jia, S. Đorđević, C. Ouyang, B. Lv LABORATORY BENEFICIATION TECHNOLOGY AND DEVELOPMENT RESEARCH ON TITANIUM MAGNETITE ORE	355
D. S. Radulović, V. Jovanović, B. Ivošević, D. Todorović, S. Milićević, M. Marković INVESTIGATION OF THE POSSIBILITY OF VALORIZATION OF TWO BORATE SAMPLES FROM THE DEPOSIT "POBRĐE" – BALJEVAC	361
S. Hredzák, M. Matik, O. Šestinová, A. Zubrik, D. Kupka, S. Dolinská, I. Znamenáčková, M. Sisol, M. Marcin, L. Pašek STUDY OF ORE SAMPLES FROM THE ZLATÉ HORY DEPOSIT (HRUBÝ JESENÍK Mts., SILESIA, CZECH REPUBLIC)	367
J. Sokolović, I. Ilić, D. Krstić COMPARISON OF THE RESULTS OF SEPARATION OF DIFFERENT COALS IN THE ANTHRACITE MINE "VRSKA CUKA"	373
B.R. Reddy, K. Abhishek, J.M. Korath, M.R Rath A COMPUTATIONAL TOOL FOR PREDICTION OF JIG CONCENTRATOR OPERATING PARAMETER TO GET IMPROVED YIELD OF CONCENTRATE	379
I. Jovanović, V. Conić, D. Milanović, F. Nakhaei, S. Krstić RELATIVE PREDICTION ERROR OF FLOTATION INDICES BY ANFIS MODELS	387
Z. Štirbanović, R. Stanojlović, J. Sokolović, D. Stanujkić, N. Čirić, I. Miljanović, G. Popović APPLICATION OF VIKOR METHOD FOR SELECTION OF COLLECTOR IN PORPHYRY COPPER ORE FLOTATION	391
S. Milutinović, Lj. Obradović, S. Petrović S. Magdalinović, I. Svrkota RANKING OF FLOTATION TAILINGS POND IN EASTERN SERBIA USING THE AHP METHOD	398
I. Jovanović, V. Conić, J. Sokolović, D. Kržanović, D. Radulović SIMPLE FUZZY MODELS FOR PREDICTION OF FLOTATION INDICES	404
S. Mishra, M.H. Tyeb, A.K. Majumder DEVELOPMENT OF A VIBRATION SENSOR-BASED ONLINE MONITORING SYSTEM FOR DETECTING ROPING IN HYDROCYCLONES	410
B. Farkaš, A. Hrastov, E. Orbanic THE IMPROVEMENT OF MINERAL PROCESSING – CASE STUDY	416
T. Mohit, P. Patel, P. Kaushal, J. Sahoo, V. Arumuru, B. Deo, M. Jain, R. Manchanda IMPROVED ON-LINE FAILURE PREDICTION METHOD OF COAL INJECTION SYSTEM USED IN A SPONGE IRON ROTARY KILN	423
M. Mikić, R. Rajković, S. Trujić, D. Kržanović, M. Jovanović IMPACT ON THE ENVIRONMENT AND OF THE OPEN MINE AND LANDFILLS IN SOUTH MINING DISTRICT – MAJDANPEK	429

M. Jovanović, D. Kržanović, R. Rajković, M. Mikić, M. Maksimović APPLICATION OF GEOGRIDS IN RECULTIVATION MEASURES AGAINST LAND DEGRADATION	435
V. Gardić, R. Marković, Z. Stevanović, A. Isvoran, T. Marković APPLICATION OF SUSTAINABLE CYCLING MANAGEMENT SYSTEM IN PHYTOREMEDIATION TECHNOLOGY OF CONTAMINATED SOILS	441
D. Đurđević-Milošević, A. Petrović, J. Elez, G. Gagula, V. Kalaba SUSTAINABLE APPROACH TO THE LACTIC ACID PRODUCTION AND ANTIBACTERIAL USE	445
B. Cekova, M. Matlievska, M. M. Puncheva, V. Velkoski, B. Kuzmanovski DIGITALIZATION OF WASTE, WAYS FOR MORE EFFICIENT WASTE MANAGEMENT	451
A. Vasileiadou, S. Zoras, A. Dimoudi INVESTIGATION OF SLAGGING CHARACTERISTICS OF INDUSTRIAL SOLID WASTES	458
A. Vasileiadou, S. Zoras, A. Dimoudi MODELLING OF CO _x AND NO _x EMISSIONS FROM INDUSTRIAL SOLID WASTES COMBUSTION USING ANSYS CHEMKIN PRO	464
Z. Bayer Ozturk, S. Kurama, A. Eser THE USAGE AND EFFECT OF BASALT CUTTING WASTE (BCW) IN CERAMIC GLAZE COMPOSITIONS CONTAINING OPAQUE AND MATT FRIT	470
D. Dinić, S. Stupar, N. Jovanović, M. Tanić, S. Jevtić SYNTHESIS AND CHARACTERIZATION OF POROUS CERAMICS BASED ON COPPER SLAG	480
M. Šišić, Dž. Dautbegović, M. Duraković ANALYSIS OF THE CHARACTERISTICS OF SLAG FROM METALLURGICAL PLANTS IN ZENICA DISPOSED OF INDUSTRIAL WASTE LANDFILL "RACA"	486
Dz. Datubegovic, M. Hasanbasic, M. Sisic, V. Birdahic ANALYSIS OF THE IMPACT OF THE INTRODUCTION OF LARGER CONTAINERS INTO THE WASTE COLLECTION SYSTEM IN THE CITY OF ZENICA	492
N. Bušatlić, I. Bušatlić, A. Halilović, N. Merdić, L. Kovač ENVIRONMENTALLY ACCEPTABLE CEMENTS WITH THE ADDITION OF GRANULATED BLAST FURNACE SLAG	498
A. Stojićević, M. Antić, M. Purić VEGETABLE INDUSTRY BY-PRODUCTS AS RAW MATERIALS IN FUNCTIONAL FOOD PRODUCTION	507
A. Petrović, R. Marković, D. Božić CARBON NANOTUBES AS POTENTIAL MATERIAL FOR WASTEWATER TREATMENT - A REVIEW	514
M. Marić, A. Ivković, B. Ivković, A. Janošević Ležaić, S. Uskoković-Marković, J. Savić, M. Milojević-Rakić, D. Bajuk-Bogdanović REMOVAL OF METHYLENE BLUE FROM AQUEOUS SOLUTIONS USING AN IRON-RICH SOIL	519
R. Marković, V. Gardić, R. Kovačević, Zoran Stevanović, A. Isvoran, V. Marjanović, A. Petrović BOR DISCRIT RIVERS WATERCOURSES CONTAMINATION BY Cu AND Ni IONS	524
P. Kekarjawlekar, N. Kamal, K. Maniyar, B. Deo, P. Nanda, P. Malakar, R. Manchanda DEVELOPING SAFE OPERATING PRACTICES (SOP) FOR POSTCOMBUSTION CHAMBER IN A SPONGE IRON PLANT	530

D. Milošević, M. Radosavljević, S. Polavder, Ž. Praštalo ARRANGEMENT OF FIELDS DEVASTATED BY CONSTRUCTION OF MAIN GAS PIPELINE	536
D. Đurđević-Milošević, A. Petrović, J. Elez, V. Kalaba, G. Gagula ENVIRONMENTAL PROTECTION THROUGH THE RATIONAL USE OF SODIUM HYPOCHLORITE AS A FUNGICIDE	542
G. Kyparissis, A. Goukoudis, G. Papadimas, E. Tasiopoulos, A. Vasileiadou CASE STUDY OF ENERGY SAVING IN A PUBLIC SCHOOL THROUGH THE INSTALLATION OF A PHOTOVOLTAIC SYSTEM ON THE ROOF	548
D. Topalović, J. Marković, M. Jović, S. Dragović, I. Smičiklas THE ARSENIC SORPTION CAPACITY OF DIFFERENT SERBIAN SOILS	554
F. Popescu, M. Zot, E.A. Laza USING SHERPA TOOL FOR ASSESSMENT OF EUROPEAN WATERBORNE TRANSPORT SECTOR IMPACT ON AIR QUALITY	560
A. Stojić, D. Tanikić, E. Požega THE IMPACT OF EXPLOITATION OF PRIMARY AND ALTERNATIVE ENERGY SOURCES ON THE ENVIRONMENT	566
A. Radojević, S. Šerbula, T. Kalinović, J. Milosavljević, J. Kalinović MOBILE PHONES – A VALUABLE COMPONENT OF E-WASTE STREAM	572
K. Janković, M. Stojanović, D. Bojović, A. Terzić, S. Stanković APPLICATION OF COAL COMBUSTION BYPRODUCTS IN SELF-COMPACTING CONCRETE: INFLUENCE ON FLOWABILITY	579
D. Radosavljević, A. Jelić, M. Stamenović IMPACT OF STUDENT MIGRATIONS ON SUSTAINABLE AND TECHNOLOGICAL DEVELOPMENTS OF THE REPUBLIC OF SERBIA	585
D. Radosavljević, A. Jelić, M. Stamenović DEVELOPMENT OF EDUCATION FOR SUSTAINABLE DEVELOPMENT AND MANAGEMENT OF RECYCLABLE WASTE IN THE REPUBLIC OF SERBIA	592
Deependra Singh SUSTAINABLE RECOVERY OF INDIAN PLACER MINERALS-THEIR DISTRIBUTION AND MINERAL ASSEMBLAGES	598
ABSTRACTS	607
M. Tasić, I. Stojković, V. Pavićević, V. Veljković SIMULATION OF HYDRODYNAMIC CAVITATION-ASSISTED BIODIESEL PRODUCTION FROM WASTE COOKING OIL USING ASPEN PLUS	609
A. Jocić, S. Marić, A. Dimitrijević RECOVERY OF METALS FROM INDUSTRIAL EFFLUENTS USING AN IONIC LIQUID-BASED STRATEGY	610
S. Marić, A. Jocić, A. Dimitrijević IONIC LIQUID-BASED TECHNOLOGY FOR METAL RECOVERY FROM ELECTRONIC WASTE	611
J. Vučićević, S. Čupić, M. Jauković, V. Đurđević, M. Stamenović, A. Božić, A. Janićijević CURRENT STATE OF THE QUALITY OF THE LUG RIVER IN THE MUNICIPALITY OF MLADENOVAC	612

D. Žnidarič THE ENERGY CRISIS AND THE EXPLOITATION OF MINERAL RESOURCES IN THE LIGHT OF INCREASING LOADS IN SPACE	613
S. Zeković A NEW GLOBAL CHALLENGES AND REGULATION FOR SUSTAINABLE SPATIAL DEVELOPMENT OF MINING	614
P.M. Angelopoulos, P. Oustadakis, G. Anastassakis, M. Georgiou, N. Kountouris HYDROTHERMAL TREATMENT OF BAUXITE RESIDUE FOR IRON RECOVERY ENHANCEMENT BY MAGNETIC SEPARATION	615
O. Ayoglu, M. Sinche-Gonzalez, M. Moilanen TEXTURAL MINERALOGICAL UNDERSTANDING OF MAGNETITE LIBERATION CONTAINING COPPER INCLUSIONS	616
M. Sinche-Gonzalez MASTER IN MINERAL PROCESING (EMJM-PROMISE) IN THE CONTEXT OF DEMAND OF CRITICAL MATERIALS AND ENERGY TRANSITION	617
ADVERTISING MATERIALS	619
Department for Mineral and Recycling Technologies	621
Serbia Zijin Mining	624
Serbia Zijin Copper	627
Analysis d.o.o.	629
tozero	631
Monicom	632
EMJM-PROMISE	633

REMOVAL OF HEAVY METAL IONS FROM MULTIMETALLIC SOLUTION BY MODIFIED OAT STRAW

J. Dimitrijević^{1#}, S. Jevtić², A. Marinković², M. Simić¹, M. Koprivica¹, J. Petrović¹

¹ Institute for Technology of Nuclear and Other Mineral Raw Materials,
Belgrade, Serbia

² Faculty of Technology and Metallurgy, University of Belgrade, Belgrade, Serbia

ABSTRACT – In this paper, the ability of waste biomass as an adsorbent was investigated. Oat straw was chosen as the starting raw material. In order to improve the adsorption capacity this material was modified with selected deep eutectic solvent (DES). Changes in the structure of the native and modified samples were examined using the SEM analysis. The efficiency of the adsorption of heavy metal ions from a multimetal solution was tested on the modified oat straw. The maximum obtained capacities of lead, copper and zinc ions were 77mg/g, 29.5mg/g and 44.1mg/g, respectively. The obtained results showed that adsorption follows pseudo-second-order kinetics model that imply chemisorption as a rate controlling step.

Keywords: Adsorption, Oat Straw, DES Solution, Biomass Modification.

INTRODUCTION

The rapid technical and technological development in recent years has led to greater use of natural waters and their contamination. Various branches of industry such as pharmaceuticals, mining, mineral processing, production of artificial fertilizers and construction materials, oil refining and ferrous metallurgy are among the main polluters of the environment [1]. On that occasion, heavy metals, organic components, dyes, pesticides, drugs, which have a harmful effect on the environment, enter the waterways. Due to their toxicological and chemical properties, heavy metals represent a major problem for the preservation of the environment. They are toxic, non-degradable in water and soil, subject to bioaccumulation, which leads to reaching the food chain. Heavy metals in smaller quantities are necessary for the normal functioning of the organism, while to a greater extent they cause serious damage or can have a lethal effect. Accordingly, more and more attention is being directed to research related to the preservation of the environment in order to reduce or completely prevent the pollution by heavy metals [1-3].

Different traditional methods such as: sedimentation, oxidation-reduction, ion exchange, coagulation and flotation, membrane filtration and others have been greatly used for the removal of pollutants from waste water [3,4]. Traditional technologies also have disadvantages such as economic profitability due to high operating costs, insufficient selectivity, producing large amount of waste sludge, the increasing

[#] corresponding author: j.dimitrijevic@itnms.ac.rs

attention of the scientific public is focused—in finding more adequate and accessible solutions [4,5].

An increasing number of researches are directed towards the development of alternative remedies for the removal of semi-titanium from water. One of the increasingly applicable alternative methods is biosorption. Biosorption is a technique characterized by high efficiency, accessibility, economic profitability, selectivity and ecological acceptability for the removal of heavy metals from wastewater [1,4,5]. Easily available, cheap, waste natural materials are used, due to their physical and chemical characteristics; they bind pollutants to the surface. In order to increase the additional adsorptive properties, different methods of biomass modification are used to increase the binding surface and the number of active binding sites. Various alkaline and acid modifications are widely used. Recently, there has been an increasing use of environmentally acceptable deep eutectic solvents (DES) as innovative green liquid for the treatment of lignocellulosic biomass, in order to obtain the desired characteristics for potential further application [6,7]. DES solvents consist of hydrogen bond donors and acceptors, which affect biomass degradation, that is, partial or complete degradation of lignin from biomass. The biomass after the interaction with the DES gives a more porous structure in comparison with the native sample [8].

Oat straw is a readily available, inexpensive bio-waste generated after harvesting of oats. Due to the large production of straw after the harvest, are more and more attention is being directed to its further application. Precisely for this reason, in this paper, the modification of oat straw with DES solvent as an adsorbent for liquid metals from water resources was examined. In order to examine the influence of the modification on the sorbent SEM analysis was performed. The paper presents the results obtained after the application of modified oat straw for the removal of lead, copper and zinc from a multi-metallic solution.

EXPERIMENTAL

The oat straw used in this research was obtained after the oat harvest in Banat (a region in Serbia). The straw was collected directly from the field, washed a couple of times to avoid impurities and dried at room temperature. The dried oat straw was ground, sieved and dried to a constant mass at 105°C.

In order to degrade lignocellulose in oat straw, DES solvent was used. The DES solvent is prepared by mixing the ionic liquid choline arginate (IL) and a sufficient amount of urea. The reaction was carried out in a reflux condenser with constant stirring at 40°C [9]. Obtained modified oat straw was dried in a dryer to constant mass and used for further adsorption experiments.

The $\text{Pb}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, $\text{Cu}(\text{NO}_3)_2 \cdot 3\text{H}_2\text{O}$ and $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ were used for the preparation of the working solution. All used chemicals were of analytical grade.

Morphological characteristics of the sample before and after modification were investigated by scanning electron microscopy (SEM) using Jeol JSM-6610LV, at 20 keV. Before recording, the samples were dried at 105°C, impregnated with gold and placed on a carbon.

Adsorption experiments were performed in a batch system. The experiment was carried out at room temperature and pH value 5. The influence of contact time was

tested in different time intervals from 15 to 1440 min. About 0.04 g of modified oat straw and 40 ml of multi-metal solution were added to 100 ml Erlenmeyer flasks. The initial concentrations of lead, zinc and copper were 1mM, 1,5mM and 1.5 mM, respectively. The suspensions were stir on an orbital shaker mixed at room temperature at 250 rpm and filtered. At the end of the adsorption experiment, the metal concentration in the filtrates was measured by the ASS method on a Perkin Elmer 900T.

RESULTS AND DISCUSSION

The morphological characteristics of the material before and after modification were examined with a scanning electron microscope (SEM). Figure 1 shows the results of the analysis. According to the SEM micrograph, it was observed that there was a change in the appearance of the surface of the modified sample. Changes on the surface are caused by degradation of lignocellulose after modification with DES. An increase in the number of channels, voids and pores is observed compared to the relatively smoother appearance of native oat straw. In oat straw, a smaller number of cavities and channels are observed [1,10,11]. Figure 1b, which represents the modified sample, shows numerous cavity channels and a more heterogeneous structure compared to the native sample. The results obtained in this way support the fact that the use of degradability of DES leads to the degradation of lignocellulose. [10] A surface with more pores and channels is more suitable for adsorption due to the easier possibility of ion diffusion, as well as more sites for metal binding.

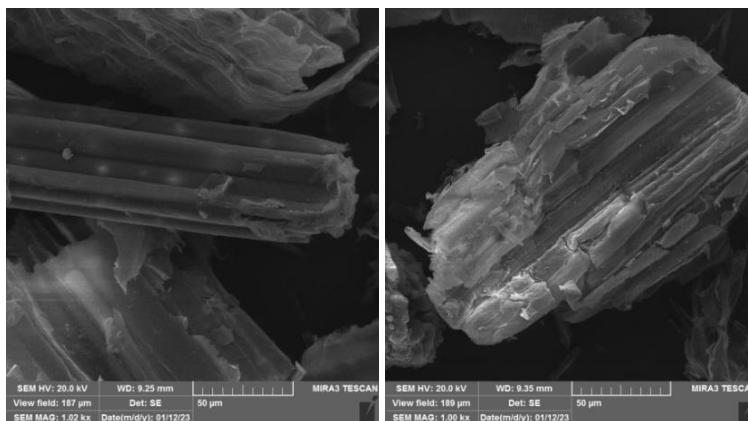


Figure 1 SEM images of oat straw before and after modification with DES

Preliminary adsorption tests revealed that the modified oat straw has a higher affinity for metal ion binding than the native one. Accordingly, the influence of time was examined only on the modified material. The influence of contact time on the adsorption of each metal is shown separately in the Figure 2. The results indicate that with increasing time, the efficiency of removing metal ions from the aqueous solution also increases. After 4 hours, there were no significant changes in the capacity. The maximum capacities for lead, zinc and copper are 77mg/g, 29.5mg/g and 44.1mg/g

respectively. The obtained results indicate that the binding sites on the surface of the adsorbent are filled due to high competition between the site ions in the solution [12]. Similar results were obtained by Cherono et al. [13], which also has a slight trend of decreasing capacity for certain metals after 24 h, which is noticeable here for zinc. The multiple efficiency of metal ion removal was faster on the beginning, which is attributed to the larger number of active sites that become filled over time. Adsorption efficiency is highest for lead ions.

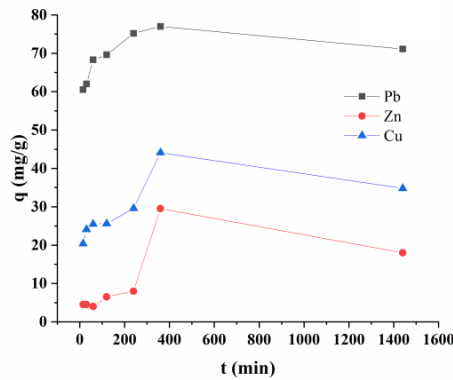


Figure 2 The effect of time during the adsorption of lead, copper and zinc ions using modified oat straw

Figure 3 shows graphs representing the pseudo first and pseudo second kinetic models for the adsorption of lead, copper and zinc metals from a multimetal solution after adsorption of modified oat straw. Based on the obtained results, it can be concluded that the adsorption kinetic for all metals follows pseudo second-order kinetic model. This is supported by the data presented in Table 1. Obtained values (Table 1) suggesting that chemisorption was an important mechanism responsible for the binding of investigated metal ions to the modified oat straw surface [14]. The results obtained during this study support the fact that the modification process with DES was successful.

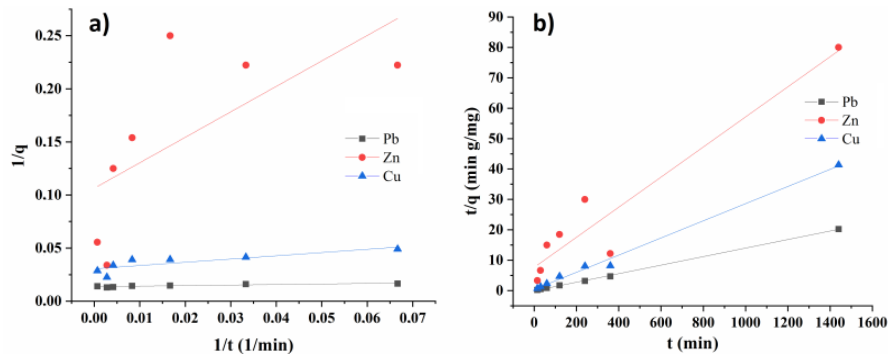


Figure 3 Curves of kinetic adsorption of metals on modified oat straw
a) pseudo first models b) pseudo second models

Table 1 Kinetic parameters

Modified oat straw	Pb	Zn	Cu
$q_{eq, exp}$ [mg/g]	77.00	29.5	44.1
Pseudo-First-Order Model			
$q_{eq, cal}$ [mg/g]	73.42	9.40	32.77
k_1 [1/min]	3.69	22.53	9.99
R^2	0.8055	0.4517	0.6992
Pseudo-Second-Order Model			
$q_{eq, cal}$ [mg/g]	71.38	20.21	35.43
k_2 [g/mg min ⁻¹]	0.2914	0.0065	0.0007
R^2	0.9994	0.9129	0.9939

CONCLUSION

In this work, the possibility of using modified oat straw as a biosorbent for the removal of heavy metals from waste water was investigated. In order to improve the adsorption capacity of oat straw, it was modified with DES solvent. In order to compare the structural characteristics of the material before and after modification, characterization was performed using SEM analysis. Based on the obtained results, it was observed that there are changes in the structure, i.e. degradation of lignocellulose. Adsorption experiments performed on modified oat straw showed that adsorption follows pseudo-second-order kinetics and approaches chemisorption as binding mechanism. Results from this study indicate that competition between ions from multimetal solution for binding sites on adsorbent surface occurs. Besides, under these conditions, the best ability of lead removal was achieved.

ACKNOWLEDGEMENT

The authors are grateful to the Ministry of Science, Technological Development and Innovation of the Republic of Serbia for the financial support (contract no. 451-03-47/2023-01/200023).

REFERENCES

1. Simić, M., Petrović, J., Šoštarić, T., Ercegović, M., Milojković, J., Lopičić, Z., Kojić, M., (2022) A Mechanism Assessment and Differences of Cadmium Adsorption on Raw and Alkali-Modified Agricultural Waste. *Processes*, 10 (10), 1957.
2. Yao Z.Y., Qi J.H., Wang L.H. (2010) Equilibrium, kinetic and thermodynamic studies on the biosorption of Cu(II) onto chestnut shell. *Journal of Hazardous Materials*, 137-143.
3. Solisio C., Al Arni S., Converti A. (2019) Adsorption of inorganic mercury from aqueous solution onto dry biomass of *Chlorella vulgaris*: kinetic and isotherm study, *Environ Technol*, 40, 664-672.
4. Fan, L., Miao, J., Yang, J., Zhao, X., Shi, W., Xie, M., Wang, X., Chen, W., An, X., Luo, H., Ma, D., Cheng, L. (2022) Invasive plant-crofton weed as adsorbent for effective removal of copper from aqueous solution. *Environmental technology & innovation*,

- 26, 102280.
5. Petrović, J., Stojanović, M., Milojković, J., Petrović, M., Šoštarić, T., Laušević, M., Mihajlović, L.M. (2016) Alkali modified hydrochar of grape pomace as a perspective adsorbent of Pb^{2+} from aqueous solution. *Journal of Environmental Management*, 182, 292-300.
 6. Zhang, Y., Meng, Y., Ma, L., Ji, H., Lu, X., Pang, Z., Dong, C., (2021) Production of biochar from lignocellulosic biomass with acidic deep eutectic solvent and its application as efficient adsorbent for Cr (VI). *Journal of Cleaner Production*, 324, 129270.
 7. Xu, H., Dong, C., Wang, W., Liu, Y., Li B., Liu, F. (2023) Machine learning prediction of deep eutectic solvents pretreatment of lignocellulosic biomass. *Industrial Crops and Products*, 196, 116431.
 8. Jose, D., Tawai, A., Divakaran, D., Bhattacharyya, D., Venkatachalam, P., Tantayotai, P., Sriariyanun, M. (2023) Integration of deep eutectic solvent in biorefining process of lignocellulosic biomass valorization. *Bioresource Technology Reports*, 21, 101365.
 9. Wang, Y., Zhang, J.W., Yang, J.Y., Li, M.L., Peng, F., Bian, J. (2022) Efficient fractionation of woody biomass hemicelluloses using cholinium amino acids-based deep eutectic solvents and their aqueous mixtures. *Bioresource Technology*, 354, 127139.
 10. Lai, P., Zhou, H., Niu, Z., Li, L., Zhu, W., Dai, L. (2023) Deep eutectic solvent-mediated preparation of solvothermal carbon with rich carboxyl and phenol groups from crop straw for high-efficient uranium adsorption. *Chemical Engineering Journal*, 457, 141255.
 11. Gollakota, R.K.A., Munagapati, S.V., Shu C.M., Wen, J.C. (2022) Adsorption of Cr (VI), and Pb (II) from aqueous solution by 1-Butyl-3-methylimidazolium bis(trifluoromethylsulfonyl)imide functionalized biomass Hazel Sterculia (*Sterculia Foetida* L.). *Journal of Molecular Liquids*, 350,118534.
 12. Gupta V., Nayak A., Agarwal S., Tyagi I. (2014) Potential of activated carbon from Waste Rubber Tire for the adsorption of phenolics: effect of pre-treatment conditions. *Journal of Colloid and Interface Science*, 417, 420-430.
 13. Cherono F., Mburu Nj., Kakoi B. (2021) Adsorption of lead, copper and zinc in a multi-metal aqueous solution by waste rubber tires for the design of single batch adsorber. *Heliyon*, 7 (11), e08254.
 14. Kakoi B., Kaluli J.W., Ndiba P., Thiong G., (2016) Removal of lead (II) from aqueous solution using natural materials: a kinetic and equilibrium study. *J. Sustain. Res. Eng.*, 3 (3), 53-62.