



University of Belgrade  
Technical Faculty in Bor



Chamber of Commerce  
and Industry of Serbia

# XV International Mineral Processing & Recycling Conference



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

<b>PLENARY LECTURES</b>	<b>1</b>
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
<b>SESSION LECTURES</b>	<b>41</b>
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
<b>WORKSHOP PAPERS</b>	<b>95</b>
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
<b>PAPERS</b>	<b>133</b>
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 $\text{LiCoO}_2$	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 <sub>x</sub> AND NO <sub>x</sub> 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
<b>ABSTRACTS</b>	<b>607</b>
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
<b>ADVERTISING MATERIALS</b>	<b>619</b>
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

## APPLICATION OF VIKOR METHOD FOR SELECTION OF COLLECTOR IN PORPHYRY COPPER ORE FLOTATION

Z. Štirbanović<sup>1#</sup>, R. Stanojlović<sup>1</sup>, J. Sokolović<sup>1</sup>, D. Stanujkić<sup>1</sup>,  
N. Ćirić<sup>2</sup>, I. Miljanović<sup>3</sup>, G. Popović<sup>4</sup>

<sup>1</sup> University of Belgrade, Technical Faculty in Bor, Bor, Serbia

<sup>2</sup> Zijin Bor Copper d.o.o, Copper Mine Majdanpek, Majdanpek, Serbia

<sup>3</sup> University of Belgrade, Faculty of Mining and Geology, Belgrade, Serbia

<sup>4</sup> University Business Academy in Novi Sad, Faculty of Applied Management,  
Economics and Finance, Belgrade, Serbia

**ABSTRACT** – The selection of appropriate flotation collector is of the crucial importance especially for the complex ores like porphyry copper ores that are distinguished with lower copper grades and higher pyrite content. In this paper are presented the results of selection of flotation collector for porphyry copper ore from “Severni Revir” ore deposit in Copper Mine Majdanpek. The selection was performed between two collectors (Z11 and AP3404) with 3 different dosages (25; 35; 45 g/t) and their mixture with SKIK in different mass ratio. The VIKOR method was applied for the rating of 10 alternatives by 5 criteria: mass yield, copper grade in concentrate, sulfur grade in concentrate, copper recovery, and collector expenses (dosage and price). Based on the results of the analysis, alternative A8 which represents the mixture of three collectors Z11, AP3404, and SKIK with following dosage 20+8+8 g/t was selected as the best alternative.

**Keywords:** Porphyry Copper Ore, Flotation, Collector, Selection, VIKOR Method.

### INTRODUCTION

The main characteristics of porphyry copper ore deposits are large quantities with lower copper grade, as well as high content of pyrite [1]. Pyrite as iron sulfide mineral is often associated with copper minerals and it is difficult to achieve their efficient separation especially if pyrite is activated with copper ions [2].

One of the ways to provide good selectivity of copper minerals from pyrite is to select appropriate flotation collector which will provide good floatability of copper minerals and efficient selectivity towards pyrite and other sulfide minerals.

Xanthates are mostly used collectors in copper flotation and they can be applied alone or in combination with other collectors, such as dithiophosphates or thionocarbamates, which are normally used for flotation of secondary copper minerals or in the case when flotation is performed at lower pH [3].

The selection of an appropriate collector is essential for the efficiency of the flotation process [4]. Certain minerals have similar properties in terms of floatability, so it is necessary to select a suitable collector that has a selective effect and that enables their efficient separation [5]. The selection of collectors in copper flotation is in close

---

<sup>#</sup> corresponding author: [zstirbanovic@tfbor.bg.ac.rs](mailto:zstirbanovic@tfbor.bg.ac.rs)

correlation with the nature and appearance of copper minerals and other sulfides that are associated with them. Recovery of useful components as well as flotation time is also recognized as important parameters when choosing a collector [6-8]. Since the collectors are organic compounds, their impact on both human health and the environment can be very large [9-11], so it is necessary to take this aspect into account as well. The price and consumption of the collector always have an influence when choosing, because economic profitability is very important.

As can be seen, there are a large number of factors that have an impact and should be taken into account when choosing the optimal collector to be used in the flotation of a porphyry copper ores. Precisely for these reasons, it is necessary to apply some of the methods that will facilitate the process of selection the flotation collector, such as multi criteria decision making (MCDM) methods.

MCDM methods present very efficient tool which can simplify selection process when large number of criteria is involved, and for that reason are being used for selection in various areas of life, science and industry. Therefore, these methods have also found applications in mineral processing in recent years, starting from selection of equipment [12,13], technologies [14,15], reagents [16, 17], etc.

In this paper are presented the results of selection of flotation collector for porphyry copper ore from "Severni Revir" ore deposit in Copper Mine Majdanpek.

## METHODOLOGY

Rougher flotation tests were carried out on of porphyry copper ore samples from "Severni Revir" ore deposit in Copper Mine Majdanpek and the influence of different collectors and their dosages on flotation indicators were investigated [18].

The data obtained in the study were used for the selection of the most appropriate collector for flotation of porphyry copper ore from this ore deposit. The selection was performed between two collectors (Z<sub>11</sub> and AP3404) with 3 different dosages (25; 35; 45 g/t) and their mixture with SKIK in different mass ratio (Table 1).

**Table 1** Alternatives for the selection of flotation collector

Alternative	Collector	Dosage
A <sub>1</sub>	Z <sub>11</sub>	25 g/t
A <sub>2</sub>	Z <sub>11</sub>	35 g/t
A <sub>3</sub>	Z <sub>11</sub>	45 g/t
A <sub>4</sub>	AP3404	25 g/t
A <sub>5</sub>	AP3404	35 g/t
A <sub>6</sub>	AP3404	45 g/t
A <sub>7</sub>	Z <sub>11</sub> +AP3404	20+16 g/t
A <sub>8</sub>	Z <sub>11</sub> +AP3404+SKIK	20+8+8 g/t
A <sub>9</sub>	Z <sub>11</sub> +AP3404+SKIK	18+10+8 g/t
A <sub>10</sub>	Z <sub>11</sub> +AP3404+SKIK	18+12+6 g/t

Criteria that were used for selection and their weights are given in Table 2.



**Table 2** The weights of selection criteria

Criteria	Weight
C <sub>1</sub> – Mass yield (%)	0.1
C <sub>2</sub> – Copper grade in concentrate (%)	0.2
C <sub>3</sub> – Sulfur grade in concentrate (%)	0.15
C <sub>4</sub> – Copper recovery (%)	0.35
C <sub>5</sub> – Collector expenses (dosage and price)	0.2

The ratings of alternatives in relation to the selected criteria are shown in Table 3.

**Table 3** The ratings of alternatives in relation to the selected criteria

	C <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>	C <sub>4</sub>	C <sub>5</sub>
	max	max	min	max	min
A <sub>1</sub>	16.39	1.39	19.87	83.45	3
A <sub>2</sub>	14.63	1.55	21.58	83.06	4
A <sub>3</sub>	15.61	1.42	22.72	81.19	5
A <sub>4</sub>	14.08	1.54	15.99	79.43	5
A <sub>5</sub>	14.44	1.58	17.92	83.57	6
A <sub>6</sub>	17.31	1.32	20.32	83.70	7
A <sub>7</sub>	14.82	1.55	22.83	84.14	6
A <sub>8</sub>	15.26	1.52	24.81	84.96	4
A <sub>9</sub>	14.88	1.50	21.92	81.76	5
A <sub>10</sub>	14.09	1.57	23.43	81.03	6

The selection was made by using VIKOR method.

### **VIKOR method**

The VIKOR method was proposed by Opricovic and Tzeng in 2004 [19], and it can be also mentioned as a prominent and often used MCDM method. VIKOR means Multicriteria Optimization and Compromise Solution (VIsekriterijumska optimizacija i KOmpromisno Resenje, in Serbian).

The procedure of evaluating alternatives using the VIKOR method can be explained using the following steps:

**Step 1.** Determine the best  $x_j^*$  and worst  $x_j^-$  value for each criterion as follows:

$$x_j^* = \begin{cases} \max_j x_{ij} & j \in \Omega_{max} \\ \min_j x_{ij} & j \in \Omega_{min} \end{cases}, \text{ and} \quad (1)$$

$$x_j^- = \begin{cases} \min_j x_{ij} & j \in \Omega_{max} \\ \max_j x_{ij} & j \in \Omega_{min} \end{cases} \quad (2)$$

where  $x_{ij}$  denotes rating of alternative  $i$  in relation to criterion  $j$ ,  $\Omega_{max}$  and  $\Omega_{min}$  denote set of maximization and minimization criteria, respectively.

**Step 2.** Determine average  $S_i$  and group  $R_i$  score for each alternative as follows:

$$S_i = \sum_{j=1}^n w_j (x_j^* - x_{ij}) / (x_j^* - x_j^-), \text{ and} \quad (3)$$

$$R_i = \max_j [w_j (x_j^* - x_{ij}) / (x_j^* - x_j^-)], \quad (4)$$

where  $w_j$  denotes the weight of criterion  $j$ .

**Step 3.** Determine the overall ranking index  $Q_i$  as follows:

$$Q_i = \nu \frac{(S_i - S^*)}{(S^- - S^*)} + (1 - \nu) \frac{(R_i - R^*)}{(R^- - R^*)}, \quad (5)$$

where:  $S_j$  and  $R_j$  denotes the average and the worst group score of alternative  $i$ , respectively,  $S^* = \min_i S_i$ ,  $S^- = \max_i S_i$ ,  $R^* = \min_i R_i$ ,  $R^- = \max_i R_i$ , and  $\nu$  is significance of the strategy, which value is usually set to be 0.5.

**Step 4.** Rank the alternatives, sorting by the value  $Q_i$  in decreasing order. The alternative with the minimum value of  $Q_i$  is the most appropriate alternative.

## RESULTS AND DISCUSSION

In this numerical illustration two collectors with three different dosages and their mixtures, shown in Table 1, are evaluated. Ten alternatives, shown in Table 1, were evaluated based on the five criteria shown in Table 2. Table 2 also shows the weights of the criteria.

The ratings of the alternatives in relation to the criteria are shown in Table 3. The optimization directions of the criteria are also shown in Table 3.

The best and worst value for each criterion, determined using Eq. (1) and Eq. (2) are shown in Table 4.

**Table 4** The best and worst value for each criterion

	C <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>	C <sub>4</sub>	C <sub>5</sub>
	max	max	min	max	min
$x_j^*$	17.31	1.58	15.99	84.96	3
$x_j^-$	14.08	1.32	24.81	79.43	7

Based on the data from Table 3 and Table 4, the average  $S_i$  and group  $R_i$  score for each alternative were determined, using Eq. (3) and Eq. (4). The calculated values are shown in Table 5. Table 5 also shows the overall ranking index  $Q_i$ , calculated using Eq. (5) and  $\nu = 0.5$ , as well as the ranks of each considered alternatives.

From Table 5, it can be seen that the alternative denoted as  $A_8$  was selected as the most acceptable alternative. Alternative  $A_8$  represents the mixture of three collectors  $Z_{11}$ , AP3404, and SKIK with following dosage 20+8+8 g/t. As it can be seen from Table 3, the copper recovery rate obtained with this mixture was the highest 84.96%. Mass yield and copper grade in concentrate were 15.26% and 1.52% respectively, which were not the

highest obtained values but also not the lowest. The sulfur content in the concentrate was the highest indicating lower selectivity but since the weight of this criterion was not very high it did not influence the overall ranking of alternative A<sub>8</sub>. Considering all it can be concluded that the criterion C<sub>4</sub>, i.e. copper recovery had the most influence during selection of flotation collector by application of VIKOR method which was expected since it was assigned the highest weight.

**Table 5** The overall ranking index and rank of considered alternatives

	$S_i$	$R_i$	$Q_i$	Rank
A <sub>1</sub>	0.336	0.146	0.097	3
A <sub>2</sub>	0.371	0.120	0.096	2
A <sub>3</sub>	0.629	0.239	0.752	8
A <sub>4</sub>	0.581	0.350	0.920	10
A <sub>5</sub>	0.360	0.150	0.142	4
A <sub>6</sub>	0.553	0.200	0.551	7
A <sub>7</sub>	0.418	0.150	0.233	5
A <sub>8</sub>	0.310	0.150	0.065	1
A <sub>9</sub>	0.540	0.203	0.536	6
A <sub>10</sub>	0.633	0.249	0.780	9

## CONCLUSION

Flotation collectors play very important role in flotation process of complex ores such as porphyry copper ores that are distinguished with lower copper grades and higher pyrite content, thus it is important to select collector which will provide good selectivity of copper minerals from pyrite. By selection of appropriate flotation collector, good floatability of copper minerals and efficient selectivity towards pyrite and other sulfide minerals can be achieved.

During the selection large number of criteria should be taken into consideration, making the selection process difficult. Therefore, the solution to the problem can be application of MCDM methods which can simplify selection process when large number of criteria is involved.

The selection of flotation collector for porphyry copper ore from "Severni Revir" ore deposit in Copper Mine Majdanpek was the aim of the study which results are presented in this paper. Two collectors (Z11 and AP3404) with 3 different dosages (25; 35; 45 g/t) and their mixture with SKIK in different mass ratio were applied for rough flotation tests and the results obtained were then used as the base for the selection. The VIKOR method was applied for the rating of 10 alternatives by 5 criteria: mass yield, copper grade in concentrate, sulfur grade in concentrate, copper recovery, and collector expenses (dosage and price). Based on the results of the analysis, alternative A<sub>8</sub> which represents the mixture of three collectors Z11, AP3404, and SKIK with following dosage 20+8+8 g/t was selected as the best alternative. The criterion C<sub>4</sub>, i.e. copper recovery was recognized as the most influential during the selection of flotation collector by the VIKOR method which was not surprising since it was assigned the highest weight.

## ACKNOWLEDGEMENT

*The authors would like to acknowledge the Ministry of Science, Technological Development and Innovation of the Republic of Serbia for the financial support of scientific research at the University of Belgrade, Technical Faculty in Bor according to the contract with registration number 451-03-47/2023-01/200131.*

## REFERENCES

1. Wills, B., Finch, J. (2016) Wills' mineral processing technology: An introduction to the practical aspects of ore treatment and mineral recovery. 8th Ed., Elsevier Science: New York, USA.
2. Mu, Y., Peng, Y., Lauten, R.A. (2016) The depression of copper-activated pyrite in flotation by biopolymers with different compositions. *Minerals Engineering*, 113, 96-97.
3. Bulatovic, S.M. (2007) Handbook of Flotation Reagents: Chemistry, Theory and Practice. Volume 1: Flotation of Sulfide Ores, Elsevier.
4. Kawatra, S.K. Flotation Fundamentals, [http://www.chem.mtu.edu/chem\\_eng/faculty/kawatra/Flotation\\_Fundamentals.pdf](http://www.chem.mtu.edu/chem_eng/faculty/kawatra/Flotation_Fundamentals.pdf)
5. Ignatkina, V.A. (2011) Selection of Selective Collectors for Flotation of Minerals with Similar Flotation Properties. *Russian Journal of NonFerrous Metals*, 52 (1), 1-7.
6. Ackerman, P.K., Harris, G.H., Klimpel, R.R., Aplan, F.F. (1987) Evaluation of Flotation Collectors for Copper Sulfides and Pyrite, I. Common Sulfhydryl Collectors. *International Journal of Mineral Processing*, 21, 105-127.
7. Ackerman, P.K., Harris, G.H., Klimpel, R.R., Aplan, F.F. (1987) Evaluation of Flotation Collectors for Copper Sulfides and Pyrite, II. Non-Sulfhydryl Collectors. *International Journal of Mineral Processing*, 21, 129-140.
8. Ackerman, P.K., Harris, G.H., Klimpel, R.R., Aplan, F.F. (1987) Evaluation of Flotation Collectors for Copper Sulfides and Pyrite, III. Effect of Xanthate Chain Length and Branching. *International Journal of Mineral Processing*, 21, 141-156.
9. Chen, S., Gong, W., Mei, G., Zhou, Q., Bai, C., Xu, N. (2011) Primary biodegradation of sulfide mineral flotation collectors. *Minerals Engineering*, 24, 953-955.
10. Chockalingam, E., Subramanian, S., Natarajan, K.A. (2003) Studies on biodegradation of organic flotation collectors using *Bacillus polymyxa*. *Hydrometallurgy*, 71, 249-256.
11. Deo, N., Natarajan, K.A. (1998) Biological removal of some flotation collector reagents from aqueous solutions and mineral surfaces. *Minerals Engineering*, 11 (8), 717-738.
12. Štirbanović, Z., Stanujkić, D., Miljanović, I., Milanović, D. (2019) Application of MCDM methods for flotation machine selection. *Minerals Engineering*, 137, 140-146.
13. Sitorus, F., Brito-Parada, P.R. (2020) Equipment selection in mineral processing - A sensitivity analysis approach for a fuzzy multiple criteria decision making model. *Minerals Engineering*, 150, 106261.
14. Stanujkic, D., Kazimieras Zavadskas, E., Karabasevic, D., Milanovic, D., Maksimovic, M. (2019) An approach to solving complex decision-making problems based on IVIFNs: A case of comminution circuit design selection. *Minerals Engineering*, 138, 70-78.
15. Magdalinović, N., Štirbanović, Z., Stanujkić, D., Sokolović, J. (2021) Selection of copper-pyrite flotation circuit design by applying the Preference Selection Index

- Method.In: Proceedings of XIV International Mineral Processing and Recycling Conference. Belgrade, Serbia, Proceedings, 136-141.
16. Kostović, M., Gligorić, Z. (2015) Multi-criteria decision making for collector selection in the flotation of lead–zinc sulfide ore. *Minerals Engineering*, 74, 142-149.
  17. Kursunoglu, S., Kursunoglu, N., Hussaini, S., Kaya, M. (2021) Selection of an appropriate acid type for the recovery of zinc from a flotation tailing by the analytic hierarchy process. *Journal of Cleaner Production*, 283, 124659.
  18. Sokolović, J., Stanojlović, R., Andrić, Lj., Štirbanović, Z., Ćirić, N. (2019) Flotation studies of copper ore Majdanpek to enhance copper recovery and concentrate grade with different collectors. *Journal of Mining and Metallurgy, Section A: Mining*, 55 (1), 53–65.
  19. Opricovic, S., Tzeng, G.H. (2004) Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. *European Journal of Operational Research*, 156 (2), 445-455.