



**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
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**Belgrade
SERBIA**



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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, Jule 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. Orbanić 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. Goulkoudis, 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. Vučičević, 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



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RANKING OF FLOTATION TAILINGS POND IN EASTERN SERBIA USING THE AHP METHOD

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ABSTRACT – From the aspect of technology, the flotation tailings pond represents a necessary mining facility. From the point of view of the environment, a real danger to the ecological factors of the environment, whether they are in operation or the disposal process has been completed. In this paper, the AHP method was used to rank the tailings ponds in Bor and Majdanpek, so that a clear picture is obtained of which tailings pond should be paid the most attention in terms of taking all preventive measures to prevent accidents.

Keywords: Tailings, Tailings Pond, AHP, MCDM.

INTRODUCTION

Flotation tailings ponds are dynamic structures that continuously evolve during their time of exploitation, and for a good number of years after the end of exploitation [1]. They must be seen as living objects that reflect all-natural events in the environment and all events caused by human activities. Protection of general natural assets is one of man's biggest challenges every day. Exploitation and processing of natural resources such as mineral deposits contribute to the transformation of the natural environment. Several activities designed to maintain balance are undertaken by the concept of integrated order. One of them is the use of comprehensive tailings pond monitoring systems. Despite the monitoring, system crashes still happen.

In Europe, public concern about the risk and potential impacts of existing (operating, inactive, and abandoned) tailings ponds has been growing since recent incidents such as the large-scale tailings spill in Spain in 1998 [2], the Baia Borsa tailings (Romania) contaminated with heavy minerals spilled in March 2000 [3], etc. These and other experiences show that the emphasis should be placed on prevention and not on responding after the incident. By predicting the potential risk, the environmental impact can be reduced and the actual costs optimized.

In the paper [4] a detailed review and re-evaluation of known historical cases of accidents at tailings ponds in Europe and the world was carried out. The main aim of the work was to improve the understanding of tailings pond incidents and to establish relationships and trends based on (known) historical tailings pond accidents in Europe as well as in the world.

In this paper, the AHP method was used to rank the tailings ponds in Bor and Majdanpek, so that a clear picture is obtained of which tailings pond should be paid the

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most attention in terms of taking all preventive measures to prevent accidents at these flotation tailings ponds. The decision that will be made will have a significant impact on the business in terms of achieving technical, environmental, and economic goals.

EXPERIMENTAL

The application of the AHP method is very broad, with the possibility of adaptation to specific circumstances.

In the paper [5] a detailed procedure and definition of the AHP method are given, so in this part of the paper, only the experimental part of the application of this method will be given.

The analyzed area of Eastern Serbia has six flotation tailings ponds, one of which is an accidental tailings pond. The comparison was made for six tailings ponds, namely the Veliki Krivelj tailings pond (Field 0, 1, 2), the RTH tailings pond, and two tailings ponds in Majdanpek (Valja Fundata and the Šaški Potok accidental tailings pond).

The Veliki Krivelj tailings dump is a valley-type tailings dump and occupies space in the former bed of the Kriveljska River. Downstream from the tailings pit is the village of Oštrelj, and upstream is a conveyor system for transporting tailings from the Krivelj mine to the old open pit in Bor and the Veliki Krivelj open pit. This tailing dump consists of three fields. Field 1 was created by closing the valley of the Kriveljska river with two barrier sand dams, upstream dam 1 and downstream dam 2. In 1990, the tailings pond was expanded downstream, occupying additional space in the bed of the Kriveljska river - a new tailings dump or Field 2. To contour the new tailings pond, it was enough to build only one dam - dam 3. To provide adequate space for the further disposal of tailings from the Veliki Krivelj flotation, at the beginning of 2015, the construction of the Zero Field upstream of field 1 was started.

The flotation tailing dump in the area of the old surface mine RTH (after the mine it is a tailings pit and got the name - ore body H) has been in operation since 1985. The tailings pit has the shape of an ellipse with the approximate direction of the central axis east-west.

Since the beginning of the operation of the copper mine in Majdanpek, flotation tailings have been deposited in two tailings ponds - Valja Fundata and Šaški Potok. The tailings pond "Valja Fundata" dates back to 1961 and is the main tailings pond, and it was named after the stream of the same name, Valja Fundata. This tailings pond was formed in the valley of the Valja Fundata stream, which starts immediately in front of the copper flotation in Majdanpek and extends in a southerly direction for about 1300 m, where two new branches flow into it. At a distance of about 1800 m, this valley changes its direction to the west, where it joins another larger branch. Then, at about 2400 m from the flotation, this valley widens considerably and enters a new branch, which eventually ends with a rocky limestone barrier. The original purpose of the "Šaški Potok" tailings pond was to deposit part of the tailings of the supplementary plant in the form of sand from secondary hydro cyclones. As such, this tailing pond has been in operation for several years and about 8.5 Mm³ of flotation tailings were deposited in it, mostly in the central area of the tailings pond. Considering the various difficulties that arose during the operational work of this tailings pond, as well as different conceptions of its purpose and technical construction, after a comprehensive review of the entire situation related to

the disposal of tailings from RBM flotation, it was decided that this tailings pond will serve only for accidental discharges in the future in case of unforeseen downtimes and breakdowns.

The basic criteria for the selection of tailings for this work are:

- Area of the tailings pond (m²) – A larger area of the tailings pond automatically means that the tailings pond is more dangerous.
- Volume of the tailings pond (m³) - The larger the volume of the tailings pond, the less favorable the tailings pond.
- Proximity to surface waters (km) - If surface waters (rivers, streams, etc.) were observed near the tailings dump, their distance from the tailings dump was determined. The closer a river or stream is to a tailings pond, the less favorable the tailings pond is.
- Proximity to agricultural land (km) - If agricultural land was observed near the tailings dump, its distance from the tailings dump was determined. The closer an agricultural land is to a tailings pond, the less favorable the tailings pond is.
- Proximity of protected natural areas (km) - If a protected natural area (cave, etc.) was observed near the tailings dump, its distance from the tailings dump was determined. The closer an area is to a tailings pond, the less favorable the tailings pond is.
- Proximity to cities and settlements (km) - If a settlement was observed near the tailings dump, its distance from the tailings dump was determined. The closer a settlement is to a tailings pond, the less favorable the tailings pond is.

Other criteria, such as harmful and dangerous substances in tailings, stability of dams, environmental protection, economic aspect, etc. were not taken into account in this paper.

RESULTS AND DISCUSSION

The initial decision matrix is shown in Table 1.

Table 1 The initial decision matrix

	Name of tailings pond	Area of the tailings pond (m ²)	Volume of the tailings pond (m ³)	Proximity to surface waters (km)	Proximity to agricultural land (km)	Proximity of protected natural areas (km)	Proximity to cities and settlements (km)
Alternative/ criterion		K1	K2	K3	K4	K5	K6
A1	Veliki Krivelj-Field 0	424,193.00	15,200,000.00	2	1	27	3
A2	Veliki Krivelj-Field 1	2,321,823.00	135,300,000.00	2	1	27	1.5
A3	Veliki Krivelj-Field 2	1,347,567.00	87,500,000.00	2	1	27	1.5
A4	RTH	700,462.00	53,562,878.00	2	0.5	27	1.5
A5	Valja Fundata	4,726,514.00	364,950,000.00	0.5	2	14	1
A6	Šaški potok	365,606.00	21,250,000.00	3.5	2	14	3

The evaluation of six flotation tailings ponds A1, A2, A3, A4, A5, and A6 was carried out based on the six evaluation criteria K1, K2, K3, K4, K5 and K6 that were previously mentioned.

The first step is to define the weighting factors (preference factors) of the considered criteria using Saaty's scale [6], after which their mathematical calculation should be performed. After that, the consistency of the decision maker should be checked [7], which is shown in Table 2, as well as the value of the preference vector. Based on the results, we see that the random CR consistency index is <10%, which satisfies the conditions.

Table 2 Consistencies of the decision maker and the value of the preference vector

	K1	K2	K3	K4	K5	K6	Preference vector	Consistencies of the decision maker	
K1	1	0.33	0.14	0.14	0.14	0.11	0.023105	6.128457338	$\lambda_{\max}$
K2	3	1	0.14	0.14	0.14	0.11	0.034486	6	n
K3	7	7	1	1	1	0.33	0.178521	1.24	RI
K4	7	7	1	1	1	0.33	0.178521	0.025691468	CI
K5	7	7	1	1	1	0.33	0.178521	0.020718925	CR
K6	9	9	3	3	3	1	0.406846	2.071892544	%

The next step in the analysis is the evaluation of alternatives in relation to the defined criteria.

The first sub-criterion to be analyzed is the area of the tailings pond. All necessary input values, as well as preference values and consistency of the decision maker, for the calculation of alternatives according to the criterion of the tailings area are shown in Table 3.

Table 3 Values according to the criterion - tailings area

K1		A1	A2	A3	A4	A5	A6	Preference vector	Consistencies of the decision maker	
424,193.00	A1	1	0.14	0.2	0.33	0.11	1	0.023507614	6.597345816	$\lambda_{\max}$
2,321,823.00	A2	7	1	5	3	0.11	7	0.19744616	6	n
1,347,567.00	A3	5	0.2	1	3	0.11	5	0.091562837	1.24	RI
700,462.00	A4	3	0.33	0.33	1	0.11	3	0.051033157	0.119469163	CI
4,726,514.00	A5	9	9	9	9	1	9	0.612942617	0.096346099	CR
365,606.00	A6	1	0.14	0.2	0.33	0.11	1	0.023507614	9.634609942	%

Calculations are made in the same way for the other sub-criteria shown in Tables 4-8.

Table 4 Values according to the criterion - tailings volume

K2		A1	A2	A3	A4	A5	A6	Preference vector	Consistencies of the decision maker	
15,200,000.00	A1	1	0.14	0.2	0.33	0.11	1	0.023508	6.597346	$\lambda_{\max}$
135,300,000.00	A2	7	1	5	3	0.11	7	0.197446	6	n
87,500,000.00	A3	5	0.2	1	3	0.11	5	0.091563	1.24	RI
53,562,878.00	A4	3	0.33	0.33	1	0.11	3	0.051033	0.119469	CI
364,950,000.00	A5	9	9	9	9	1	9	0.612943	0.096346	CR
21,250,000.00	A6	1	0.14	0.2	0.33	0.11	1	0.023508	9.63461	%

Table 5 Values according to the criterion - Proximity to surface water

K3		A1	A2	A3	A4	A5	A6	Preference vector	Consistencies of the decision maker	
2	A1	1	1	1	1	3	0.14	0.094427	6.051013	$\lambda_{\max}$
2	A2	1	1	1	1	3	0.14	0.094427	6	n
2	A3	1	1	1	1	3	0.14	0.094427	1.24	RI
2	A4	1	1	1	1	3	0.14	0.094427	0.010203	CI
0.5	A5	0.33	0.33	0.33	0.33	1	0.14	0.038999	0.008228	CR
3.5	A6	7	7	7	7	7	1	0.583292	0.822788	%

Table 6 Values according to the criterion - Proximity to agricultural land

K4		A1	A2	A3	A4	A5	A6	Preference vector	Consistencies of the decision maker	
1	A1	1	1	1	3	0.11	0.11	0.052143	6.057498	$\lambda_{\max}$
1	A2	1	1	1	3	0.11	0.11	0.052143	6	n
1	A3	1	1	1	3	0.11	0.11	0.052143	1.24	RI
0.5	A4	0.33	0.33	0.33	1	0.11	0.11	0.025921	0.0115	CI
2	A5	9	9	9	9	1	1	0.408825	0.009274	CR
2	A6	9	9	9	9	1	1	0.408825	0.927384	%

Table 7 Values according to the criterion - Proximity to protected natural areas

K5		A1	A2	A3	A4	A5	A6	Preference vector	Consistencies of the decision maker	
27	A1	1	1	1	1	9	9	0.236925	5.986655	$\lambda_{\max}$
27	A2	1	1	1	1	9	9	0.236925	6	n
27	A3	1	1	1	1	9	9	0.236925	1.24	RI
27	A4	1	1	1	1	9	9	0.236925	0.002669	CI
14	A5	0.11	0.11	0.11	0.11	1	1	0.026149	0.002152	CR
14	A6	0.11	0.11	0.11	0.11	1	1	0.026149	0.215239	%

Table 8 Values according to criteria - Proximity to cities and settlements

K6		A1	A2	A3	A4	A5	A6	Preference vector	Consistencies of the decision maker	
3	A1	1	5	5	5	3	1	0.320217	6.177695	$\lambda_{\max}$
1.5	A2	0.2	1	1	1	3	0.14	0.072662	6	n
1.5	A3	0.2	1	1	1	3	0.14	0.072662	1.24	RI
1.5	A4	0.2	1	1	1	3	0.14	0.072662	0.035539	CI
1	A5	0.33	0.33	0.33	0.33	1	0.14	0.041028	0.028661	CR
3	A6	1	7	7	7	7	1	0.420768	2.866055	%

Table 9 Final report of parameters

Alternative/ criterion	K1	K2	K3	K4	K5	K6	RANK	RANK	Name of tailings pond
A1	0.023508	0.023508	0.094427	0.052143	0.236925	0.320217	6	1	Valja Fundata
A2	0.197446	0.197446	0.094427	0.052143	0.236925	0.072662	2	2	Veliki Krivelj- Field 1
A3	0.091563	0.091563	0.094427	0.052143	0.236925	0.072662	3	3	Veliki Krivelj- Field 2
A4	0.051033	0.051033	0.094427	0.025921	0.236925	0.072662	5	4	Šaški potok
A5	0.612943	0.612943	0.038999	0.408825	0.026149	0.041028	1	5	RTH
A6	0.023508	0.023508	0.583292	0.408825	0.026149	0.420768	4	6	Veliki Krivelj- Field 0
Ki	0.47134	0.32739	0.058321	0.058321	0.058321	0.026306			

Table 9 shows the last step in the application of the AHP method, which is the weighting of the calculated significance coefficients of the alternatives in the choice according to different criteria, and the significance coefficient (preference) of those criteria

CONCLUSION

During the construction of the flotation tailings pond, there are various changes related to the characteristics of the material to be deposited, the method and conditions of transport, deposition, environmental protection, water removal, changes in the groundwater level in the surrounding area, etc. Because of all this, it is impossible to predict all the influencing elements that occur at the beginning of the construction of the tailings pond, so auscultation or observation is necessary.

Based on the results obtained by the AHP analysis, it can be seen that the dangers to people and the environment in the vicinity of the tailings dump mainly depend on the size of the tailings dump, so the Valja Fundat tailings dump is in the first place in terms of risk to the environment. Then comes Veliki Krivelj tailings - Field 1 and Field 2. The other three places are occupied by accidental tailings Šaški Potok in Majdanpek and tailings RTH and Veliki Krivelj - Field 0 in Bor (Table 9.).

The selection of flotation tailings ponds can be based on other criteria, such as stability of dams on flotation tailings ponds, chemical hazard, presence of erosion, etc., and not only on those given in this paper, so different results can be obtained using the AHP method.

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