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Ljubiša Balanović
Dejan Tanikić

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PREFACE

On behalf of the Organizing Committee, it is a great honor and pleasure to welcome all esteemed participants of the 54th International October Conference on Mining and Metallurgy (IOC 2023), scheduled to take place at the picturesque Bor Lake, Serbia, from October18th to 21st 2023.

The collaborative efforts of the University of Belgrade, the Technical Faculty in Bor, and the Mining and Metallurgy Institute Bor have meticulously organized this year's IOC. Our focus remains unwavering on showcasing the latest research findings and advancements in geology, mining, metallurgy, materials science, technology, environmental protection, and other engineering disciplines. Our primary objective is to foster a dynamic environment where academics, researchers, and industry professionals can come together to share their knowledge, experiences, and innovative ideas while exploring opportunities for collaborative research endeavors.

Our conference agenda is rich and diverse, encompassing plenary sessions, engaging invited lectures, technical presentations, enlightening oral and poster sessions, informative technical tours, a diverse exhibition, and memorable social gatherings. At the heart of this event lies our strong commitment to sustainable development within the mining and metallurgy sector. We are dedicated to exploring ecologically conscious methodologies, responsible resource extraction practices, and cutting-edge technologies that reduce the industry's environmental impact and enhance the well-being of local communities.

The conference proceedings comprise 129 papers authored by individuals from universities, research institutes, and industries in 22 countries. We are proud to welcome participants from Bosnia and Herzegovina, Bulgaria, Canada, China, Croatia, Germany, Greece, India, Iran, Kazakhstan, Libya, North Macedonia, Montenegro, Morocco, Romania, Russia, Slovakia, South Africa, Spain, Turkey, United States, and, of course, Serbia.

We are excited to host the 8th International Student Conference on Technical Sciences (ISC 2023) as part of IOC 2023. This event offers students from Serbia and the wider region a unique chance to showcase their research and discuss the future of their fields with experts.

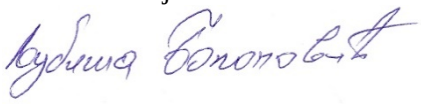
We sincerely thank the Ministry of Science, Technological Development, and Innovation of the Republic of Serbia for their generous financial support. In addition, we express our profound gratitude to all our sponsors, exhibitors, and friends of the Conference for their contributions and unwavering support for playing a pivotal role in ensuring the success of IOC 2023.

We would like to express our heartfelt thanks to all authors, committees, reviewers, speakers, and chairpersons for their invaluable contributions in shaping IOC 2023.

We look forward to welcoming you to the 55th International October Conference on Mining and Metallurgy (IOC 2024), which will be held in October 2024.

On behalf of the 54th IOC Organizing Committee,

Prof. dr Ljubiša Balanović



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APPLICATION OF VIKOR METHOD FOR COMPARISON OF THE WASHABILITY OF COALS

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Abstract
This paper summarizes the results of the comparison of the washability characteristics of three coals (anthracite, brown, and lignite) by the VIKOR method. Based on the float-sink test results, the theoretical values of the coal yield and the quality of the clean coal product were calculated. Two washability parameters, the Index of Washability (IW) and the Near Gravity Material Index (NGMI), as well as the Separability Coefficient (K), were computed, and the results were compared. The results presented in this study indicate that the washability of the anthracite coal is relatively easy at a specific density of 1650 kg/m^3.

***Keywords**: coal, washability, VIKOR, method.*

1. INTRODUCTION

Gravity separation of coal, also known as coal washing or coal beneficiation, is a process for separating coal based on the difference in density between the coal and the impurities (mineral matter) typically associated with the coal.

Washability curves based on laboratory float-sink tests are used to evaluate the coal's washability. This test is used to distribute the coal by density fraction to determine the optimum separation density. The theoretical values of the coal yield and the quality of the clean coal product, i.e. the ash content in the separated coal product, thus depend on the separation density. Washability of coal is affected by a variety of factors, including grain size, ash content, floating and sinking products, and the amount of near-gravity materials [1]. The “index of washability” [2] and “near-gravity material index” [3] have been proposed for comparative analyses of washability characteristics of different coals. The “separability coefficient” [4] is very useful parameter for interpreting separability data in the study of coal washability.

MCDM methods present very efficient tool which can simplify compare coals when large number of criteria is involved. Therefore, in this paper are presented the results of comparison of the washability of three coals (antracihte, brown coal, and lignite) by the VIKOR method. [5]

2. EXPERIMENTAL

2.1. Materials

Raw coal samples were collected from the Vrska Cuka Anthracite Coal Mine, the Bogovina Brown Coal Mine, and the Lubnica Lignite Coal Mine, located in Eastern Serbia. Representative samples were obtained after coning and quartering the collected samples, and afterward they were sieved in order to prepare samples needed for further laboratory float sink tests.

2.2. Float–Sink Test

Float-sink tests were carried out on different coals, and the washability characteristics of coals were investigated. The float-sink tests were performed using zinc-chloride as heavy media at different specific densities ranging from 1300 to 1850 kg/m^3.

All products were analyzed for ash content. Based on the obtained results, the cumulative yield and ash values were computed. According to methodologies by Govindarajan and Rao (1994) [2] and Majumder and Barnwal (2004) [3], the values of the index of washability (IW) and near-gravity material index (NGMI) were calculated. The washability data obtained in the study were used for the comparison of the washability of coals. The comparison was performed between three coals with different washability characteristics. The results of the float-sink analysis of raw coals are shown in Table 1 [3].

Table 1 – Results of the float-sink tests of raw coals

Specific gravity kg/m^3	Vrska Cuka		Bogovina		Lubnica	
	Mass %	Ash %	Mass %	Ash %	Mass %	Ash %
-1300	3.52	1.99	3.93	10.86	20.39	9.85
-1400	54.43	5.90	18.79	12.42	33.55	13.49
-1500	12.91	11.75	20.15	13.55	14.58	27.18
-1600	4.08	22.19	7.95	15.41	7.39	37.61
-1700	2.09	29.28	2.15	27.19	5.01	54.09
-1800	1.49	39.55	1.44	43.51	4.10	68.16
-1850	0.69	47.42	1.24	48.68	2.22	76.67
+1850	20.79	72.65	44.36	55.31	12.75	86.02
∑	100.00	22.34	100.00	33.06	100.00	31.45

Based on the float-sink test results and washability data, it can be noticed that depending on the quality, in the range of separation densities between 1400 and 1800 kg/m^3, the best separation of raw coals was achieved at a separation density of 1650 kg/m^3. At this density, a comparison of coal separability, i.e., washability, and theoretical values of yield and quality of a clean coal product was made using the VIKOR method.

2.3. Methodology

Three alternatives, shown in Table 2, were evaluated based on the six criteria shown in Table 3. Table 4 also shows the weights of the criteria.

Table 2 - Alternatives for the selection of flotation collector

Alternative	Coal Rank	Coal Mine
A_1	Anthracite	Vrska Cuka
A_2	Brown	Bogovina
A_3	Lignite	Lubnica

Criteria that were used for selection and their weights are given in Table 3.

Table 3 - The weights of selection criteria

Criteria	Weight
C_1 – Index of washability (IW)	0.15
C_2 – Near-Gravity Material Index (NGMI)	0.15
C_3 – Separability coefficient (K)	0.15
C_4 – Theoretical value of the mass yield of clean coal (%)	0.20
C_5 – Quality (ash content) of clean coal (%)	0.20
C_6 – Price of clean coal product (EUR/t)	0.15

The ratings of alternatives in relation to the selected criteria are shown in Table 4.

Table 4 - The ratings of alternatives in relation to the selected criteria

	C_1	**C_2**	**C_3**	**C_4**	**C_5**	**C_6**
	max	min	max	max	min	max
A_1	33.23	0.07	2.82	75.99	7.91	114.62
A_2	33.78	0.06	2.45	51.88	13.50	81.10
A_3	40.39	0.12	1.16	78.42	18.66	59.78

The comparison was made by using VIKOR method. The VIKOR method was proposed by Opricovic and Tzeng in 2004 [5], 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 for evaluating alternatives using the VIKOR method was explained in the following steps by Opricovic and Tzeng [5].

3. RESULTS AND DISCUSSIONS

The ratings of the alternatives in relation to the criteria are shown in Table 4. The optimization directions of the criteria are also shown in Table 4. The best and worst values for each criterion are shown in Table 5.

Table 5 - The best and worst value for each criterion

	C_1	**C_2**	**C_3**	**C_4**	**C_5**	**C_6**
	max	max	min	max	min	max
x_j^*	40.39	0.06	2.82	78.42	7.91	114.62
x_j^-	33.23	0.12	1.16	51.88	18.66	59.78

Based on the data from Table 4 and Table 5, the average S_i and group R_i score for each alternative were determined. The calculated values are shown in Table 6. Table 6 also shows the overall ranking index Q_i, and $v = 0.5$, as well as the ranks of each considered alternatives.

Table 6 - The overall ranking index and rank of considered alternatives

	S_i	R_i	Q_i	**Rank**
A_1	0.21	0.150	0.00	1
A_2	0.57	0.200	0.91	2
A_3	0.65	0.200	1.00	3

From Table 6, it can be seen that the alternative denoted as A_1 was selected as the most acceptable alternative. Alternative A_1 represents anthracite coal. As it can be seen from Table 5, the coal yield (C_4) was the highest at 78.42%. Clean coal grade (C_5) was 7.91%, which were the lowest obtained values of ash content. The "index of washability" was the lowest, indicating lower washability, but since the weight of this criterion was not very high, it did not influence the overall ranking of alternative A_1. The "near-gravity material index" has been proposed for comparative analyses of washability characteristics of different coals, and the lowest value was obtained for alternative A_2, which represents brown coal. The "separability coefficient" was the highest for alternative A_1, indicating better separability of the anthracite coal. Considering all this, it can be concluded that the criteria C_4 and C_5, i.e., mass yield ash content of clean coal products, had the most influence during the comparison of coal washability by application of the VIKOR method, which was expected since they were assigned the highest weight.

4. CONCLUSION

Washability of coal plays a very important role in the gravity process of coal, so it is important to select a separation density that will provide good washability and separability of coal from associate minerals. The washability of coal is affected by a variety of factors, including grain size, ash content, floating and sinking products, and the amount of near-gravity materials. The "index of washability", the "near-gravity material index," and the "separability coefficient" are very useful parameters for interpreting separability data in the study of coal washability.

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

The comparison of coals from the Vrska Cuka Anthracite Coal Mine, the Bogovina Brown Coal Mine, and the Lubnica Lignite Coal Mine by the VIKOR method was the aim of the study, presented in this paper. The criteria for comparison were: C_1 – Index of washability (IW), C_2 – Near-Gravity Material Index (NGMI), C_3 – Separability coefficient (K), C_4 – Theoretical values of the mass yield of clean coal (%), C_5 – Quality (ash content) of clean coal (%), and C_6 – Price of clean coal product (EUR/t). Based on the float-sink test results, and the results of the MCDM analyis the anthracite coal was selected as the coal with the best washability.

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