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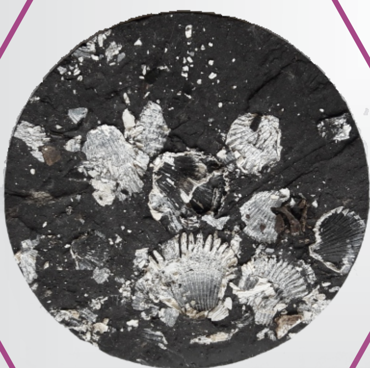

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IMPACT THE CONCENTRATION OF SUSPENDED PARTICLES PM10 ON THE AIR POLLUTION IN THE CITY OF KRALJEVO (SERBIA)

Abstract

This paper analyzes the concentration of PM10 suspended particles in the air sampled from one measuring spot in the downtown area of the City of Kraljevo. The analysis includes 1358 samples (one sample per 24 hours) in the period 2012-2015. Sampling of the ambient air and analysis of samples were carried out by the standard methods. Gravimetric method of analyzed samples has shown that the suspended particle concentration was in the interval of 2.17-405.43 $\mu g/m^3$*. Apart from that, 420 samples, or 30.9% of the analyzed samples, exceeded the limit and tolerance values. As 95% of these cases took place during the heating season, it can be concluded that the manner of heating of the City of Kraljevo plays a dominant role in increased air pollution by the suspended particles PM10. The increased level of air pollution by these particle has a negative impact on human health and eco-system of this City.*

Keywords: *air pollution, suspended particles PM10, gravimetric method*

1 INTRODUCTION

Air pollution by suspended particles includes tiny particles that may be in a solid or liquid aggregate state. Among them, the ones reaching the deepest parts of lungs are of a particular importance, and the diameter of those particles is smaller than 10 µm. These particles are classified into three categories:

1) particles smaller than 10 µm marked as PM10, called the coarse suspended particles,
2) particles smaller than 2.5 µm marked as PM2.5, called the fine suspended particles, and
3) particles smaller than 0.1 µm marked as PM0.1, called the ultra-fine suspended particles [1].

The coarse dispersed particles PM10 usually represent a mixture of smoke, dust, soot, acids, salts and other substances. They may be of urban or rural origin, and they originate from: industrial plants, motor vehicles, boiler room and furnaces for burning of solid fuels, dust from construction sites, landfills and agricultural regions, fire, etc.

The World Health Organization and World Meteorological Organization established the system of monitoring the quality of human environment in order to protect the environment. The Environmental Protection Agency (EPA) labeled the solid particles, sulphur dioxide, carbon monoxide, nitrogen oxides, ozone and heavy metals as the main air pollutants and defined standards for them

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to the aim of of protection the human health and ecosystems. These substances are the primary polluting substances with the varying concentrations in accordance to the weather conditions (concentrations are the highest during autumn and winter), and much more dangerous the secondary polluting substances are created by their interaction [2].

Floating particles of dust, ash, liquid drops of smoke and other condensed gaseous compounds suspended in the air (aerosols) are considered to be the most hazardous air pollutants [3]. Results of the study were conducted in three European countries (Austria, Switzerland and Germany) in which about 75 million people live, indicate that the exposure to respiratory particles accounts for about 40,000 deaths per year [4]. Still, some researcher believe that the increase of suspended particles in the air by 10 $\mu g/m^3$ increases mortality by 0.4-1% [5,6].

Concentration of PM10 suspended particles is monitored in the EU countries as a part of regular monitoring. According to the applicable legislation, the daily mean for concentration of PM10 suspended particles is 50 $\mu g/m^3$, and it may not be exceeded for more than 35 days a year, and the permitted annual mean for PM10 is 40 $\mu g/m^3$ [7,8].

Limit and tolerable values for the PM10 suspended particle fraction in the Republic of Serbia are regulated by the Regulation on Conditions for Monitoring and Requirements for the Air Quality [9]. According to this Regulation, the limit value for PM10 suspended particle fraction in Serbia is 50 $\mu g/m^3$, whereas the tolerable value for the same parameter is 75 $\mu g/m^3$. At the annual level, the value for PM10 suspended particle fraction is 40 $\mu g/m^3$, whereas the tolerable value is 48 $\mu g/m^3$.

As the suspended particles are the main air pollutants, there is a need to monitor them in order to undertake the preventive measures for protection the human health and ecosystems. The analyses of air pollution impact on human health have been performed in certain cities in our country [10,11,12], but there was no detailed research on the national level.

The aim of this paper is to analyze the level of air pollution by suspended particles PM10 in the City of Kraljevo. This City is located at the central part of the Republic of Serbia, at $43^0 43'$ north latitude and $20^0 41'$ east longitude, at the altitude of about 206 m. It is located in a valley between the Vlach, Sumadija and Kopaonik mountain ranges, and lies on three rivers – Ibar, Zapadna Morava and Ribnica. According to the Census of 2011, there are 68,749 inhabitants in the City itself, and 125,488 inhabitants on the whole municipal territory [13].

Concentrations of PM10 suspended particles in 1358 samples sampled almost every day in the period 2012-2015 were determined applying the standard methods. A particular attention was paid to an analysis of samples from a six-month period of heating season in which the concentration of these particles was several times higher than the limit and tolerable values.

2 EXPERIMENTAL PART

Within this paper, the concentrations of PM10 suspended particles at one measuring spot were determined almost every day within four years. The selected measuring spot is in the downtown area of the City of Kraljevo at $43^0 43'21.76''$ north latitude and $20^0 41'33.03''$ east longitude. As there are no industrial plants near the measuring spot, the main source of air pollution is the boiler room of the City Heating Plant, heating both residential and commercial facilities, and it is 300 m distant from the measuring spot. The significant sources of air pollution are also numerous private furnaces and road traffic. The average frequency of vehicles is about 2000 vehicles per hour in both directions. There are two crossroads at a distance of about 150-250 m from the measuring spot. All the streets near the measuring spot are asphalted, they are 5-10 m wide, and their maintenance is at a satisfactory level.

Sampling of the ambient air and laboratory testing were performed by the standard methods [14]. Measuring quality check, manner of processing and presentation of results and evaluation of their reliability and credibility were done in accordance with the stipulated methods of measurement and standard requirements [15].

SEQ47/50 sampler made by Sven Leckel Company from Germany was used for sampling of ambient air, equipped with corresponding air intake pipes and corresponding inputs for sampling of the PM10 suspended particles, directly connected to the Glass fiber filter dia 47/50 mm *Whatman* and the flow control device.

A filter paper of the corresponding size, previously measured on the analytical balance measuring at five decimals, is placed in the sampler. The filter paper should be previously conditioned in a special room in which the constant temperature (20 ± 1)°C and corresponding humidity (45-50)%RH are maintained [14]. After 48 and 72 hours, the filter paper is measured and then transported in a special container and placed into a sampling machine of ambient air.

After passing of air with certain flow through the filter paper during 24 hours, the filter is taken off and transported back in the same container to the lab to be conditioned in the room for measuring of PM10 suspended particles, where it is measured after 48 and 72 hours. Concentration of fraction of PM10 suspended particles is calculated according to the following formula:

$$C\ (\mu g/m^3) = (m_2 - m_1) / F \cdot t$$

where:

C - concentration of the fraction of PM10 suspended particles (µg/m^3);

m_1 - empty filter paper mass (µg);

m_2 - filter paper mass after sampling (µg);

F - flow volume in the ambient conditions (m^3/h), and

t - sampling period (h).

Temperature and humidity are measured by a thermohygrometer and recorded in a computer.

This paper presents the concentrations of PM10 suspended particles in the period 2012-2015, per year and month, their minimum and maximum values, mean values, the number of days above the limit value, and the number of days above the tolerable value.

3 RESULTS AND DISCUSSION

This paper analyzes the results of determining the concentration of PM10 suspended particles that included 1,358 samples (one sample every 24 hours), sampled at the location of the City of Kraljevo in the period 2012-2015.

Results of concentration of these particles in the tested samples were obtained by the gravimetric analysis, and minimum and maximum values, average annual values, and the number of days above limit and tolerable values are presented in Table 1. According to this Table, the minimum concentration of these particles was 2.17 µg/m^3 in 2015, and the maximum value was 405.43 µg/m^3 in 2012. Their average annual values were slightly lower in 2014 - 48.13 µg/m^3, and approximately the same (53.74-53.90 µg/m^3) in 2012, 2013, and 2015.

Table 1 *Annual review the concentrations of suspended particles PM10 in the period 2012-2015*

		PM10 suspended particles			
Year		**2012**	**2013**	**2014**	**2015**
Number of days in the year when measuring was performed		315	335	352	356
X –annual (μg/m^3)		53.90	53.74	48.13	53.82
Min (μg/m^3)		7.97	2.42	7.06	2.17
Max (μg/m^3)		405.43	361.95	319.92	327.17
Above limit value-daily	Number of days	52	45	40	45
	%	16.5	13.4	11.4	12.6
Above tolerable value-daily	Number of days	48	62	52	76

Considering the permitted values of PM10 suspended particles in the air, it may be stated that 30.9% of analyzed samples are above the permitted level, on average. Out of 1,358 analyzed samples, exceeding the permitted value was identified in 420 samples, whereby values were higher than the permitted limit values in 182 samples, and higher than the permitted tolerable values in 238.

In order to establish the influence of season on concentration of PM10 suspended particles in the air, it is believed that it would be of interest to analyze the results of measuring of these particles per month in the period 2012-2015 (Tables 2 and 3). There is an apparent difference in the content of these particles depending on month and year of their measuring. Regarding the similarity of results per season, the discussion of results is simplified and includes one month from every season: January, April, July and October.

Analysis of the results for January indicates that the highest values for the total concentration (3042.51 μg/m^3), the highest maximum daily concentrations (258.69 μg/m^3), the highest mean monthly concentrations (101.42 μg/m^3) as well as the lowest minimum concentrations (16.30 μg/m^3) were recorded in 2015, compared to 2012, 2013 and 2014. In the same month of 2013, 2014, and 2015, a large number of days (20-21) with concentrations of these particles above limit and tolerable values were recorded.

In April of the analyzed period of 2012-2015, the lower concentrations of suspended particles PM10 were recorded than in January. The total monthly concentration of these particles was in the interval of 887.39 - 1008.46 μg/m^3, and the average concentration in the interval of 30.25-36.02 μg/m^3. In the same month of 2012, both minimum (7.97 μg/m^3) and maximum (69.92 μg/m^3) concentrations of these particles were recorded. The number of days above the limit value was recorded in the interval of 2-3 days, and there were no days above the daily tolerable value.

Table 2 *Monthly review the concentrations of suspended particles PM10 in the period January – June from 2012-2015*

Month		**2012**	**2013**	**2014**	**2015**
January	Total ($\mu g/m^3$)	1403.54	2570.19	2633.02	3042.51
	Max ($\mu g/m^3$)	168.47	232.06	210.14	258.69
	Min ($\mu g/m^3$)	31.15	18.11	27.35	16.30
	X-monthly ($\mu g/m^3$)	77.97	91.79	87.77	101.42
	Number of days above limit value	4	5	7	4
	Number of days above tolerable value	7	16	14	16
February	Total ($\mu g/m^3$)	2820.76	1427.26	1996.41	2014.75
	Max ($\mu g/m^3$)	267.21	117.21	185.59	169.93
	Min ($\mu g/m^3$)	41.30	17.39	27.13	31.34
	X-monthly ($\mu g/m^3$)	128.22	52.86	71.30	71.95
	Number of days above limit value	5	14	4	12
	Number of days above tolerable value	15	2	11	7
March	Total ($\mu g/m^3$)	1888.8	1090.10	1332.32	1520.69
	Max ($\mu g/m^3$)	131.15	84.78	91.66	107.24
	Min ($\mu g/m^3$)	36.41	17.39	19.02	16.66
	X-monthly ($\mu g/m^3$)	60.93	38.93	45.94	49.05
	Number of days above limit value	18	3	9	13
	Number of days above tolerable value	6	3	3	2
April	Total ($\mu g/m^3$)	1008.46	965.98	887.39	907.37
	Max ($\mu g/m^3$)	69.92	54.16	59.05	47.83
	Min ($\mu g/m^3$)	7.97	20.10	18.11	12.13
	X-monthly ($\mu g/m^3$)	36.02	34.50	32.87	30.25
	Number of days above limit value	3	2	2	0
	Number of days above tolerable value	0	0	0	0
May	Total ($\mu g/m^3$)	766.71	813.40	642.22	792.12
	Max ($\mu g/m^3$)	49.81	61.17	39.97	38.58
	Min ($\mu g/m^3$)	14.31	12.86	7.06	14.13
	X-monthly ($\mu g/m^3$)	28.40	30.13	22.15	25.55
	Number of days above limit value	0	3	0	0
	Number of days above tolerable value	0	0	0	0
June	Total ($\mu g/m^3$)	679.65	733.91	812.38	687.04
	Max ($\mu g/m^3$)	34.96	46.92	58.51	39.49
	Min ($\mu g/m^3$)	14.67	15.94	18.29	13.40
	X-monthly ($\mu g/m^3$)	23.44	28.23	28.01	22.90
	Number of days above limit value	0	0	1	0
	Number of days above tolerable value	0	0	0	0

Table 3 *Monthly review the concentrations of suspended particles PM10 in the period July – December from 2012-2015*

Month		2012	2013	2014	2015
July	Total (μg/m^3)	813.66	817.59	760.19	956.57
	Max (μg/m^3)	38.58	45.10	40.21	79.52
	Min (μg/m^3)	17.21	2.42	16.12	18.11
	X-monthly (μg/m^3)	29.06	29.20	26.21	31.88
	Number of days above limit value	0	0	0	0
	Number of days above tolerable value	0	0	0	1
August	Total (μg/m^3)	844.89	906.40	839.85	887.63
	Max (μg/m^3)	61.23	43.84	40.39	50.18
	Min (μg/m^3)	12.86	19.38	9.96	11.77
	X-monthly (μg/m^3)	30.17	31.26	27.09	28.63
	Number of days above limit value	4	0	0	1
	Number of days above tolerable value	0	0	0	0
September	Total (μg/m^3)	853.30	782.71	955.29	855.86
	Max (μg/m^3)	41.12	51.99	55.07	53.62
	Min (μg/m^3)	18.29	11.05	17.93	2.17
	X-monthly (μg/m^3)	30.48	27.95	31.84	28.53
	Number of days above limit value	0	1	1	2
	Number of days above tolerable value	0	0	0	0
October	Total (μg/m^3)	1196.06	1700.58	1291.78	1280.88
	Max (μg/m^3)	101.63	115.03	92.02	99.82
	Min (μg/m^3)	14.85	8.69	14.85	10.14
	X-monthly (μg/m^3)	42.72	58.64	44.54	41.32
	Number of days above limit value	7	9	8	4
	Number of days above tolerable value	1	10	3	3
November	Total (μg/m^3)	1596.24	1556.85	1566.34	3394.80
	Max (μg/m^3)	176.08	191.12	109.05	243.11
	Min (μg/m^3)	15.57	16.66	17.57	20.83
	X-monthly (μg/m^3)	59.12	57.66	52.21	113.16
	Number of days above limit value	3	4	5	6
	Number of days above tolerable value	6	6	6	20
December	Total (μg/m^3)	3007.28	4974.19	3334.55	3138.47
	Max (μg/m^3)	405.43	361.95	319.92	327.17
	Min (μg/m^3)	25.54	29.34	12.13	45.65
	X-monthly (μg/m^3)	100.24	160.46	107.57	101.24
	Number of days above limit value	8	4	3	3
	Number of days above tolerable value	13	25	15	27

July of the analyzed period 2012 - 2015 is characterized by significantly lower concentrations of the PM10 suspended particles. Total monthly concentrations of these particles were in the interval of 760.19 - 956.57 μg/m^3, and their average concentration was between 26.21 and 31.88 μg/m^3, whereas only one day above the tolerable value was recorded. In this month, the minimum concentration of 2.49 μg/m^3 was recorded in 2013, and the maximum value of 79.52 μg/m^3 in 2015.

Results for October of the analyzed period 2012-2015 indicate the increase in concentration of PM10 suspended particle concentration compared to July. It is shown by the following parameters: the total concentration of these particles was in the interval of 1196.06-1700.58 μg/m^3; the average concentration was in the interval of 41.32 - 58.64 μg/m^3; the number of days above the limit values was recorded in the interval of 4-9 days; and the number of days above the daily tolerable value was recorded in the interval of 1-10 days. In the same month of 2013, both minimum (8.69 μg/m^3) and maximum (115.03 μg/m^3) concentrations of the analyzed particles were recorded.

Analysis of the contents of PM10 suspended particles in the period 2012-2015 resulted in observation that their total maximum concentration (4974.18 μg/m^3) and their maximum average concentration (160.46 μg/m^3) were recorded in December 2013, and that their total minimum concentration (642.22 μg/m^3), and their minimum average concentration (22.15 μg/m^3) were recorded in May 2014. Apart from that, the largest number of days (18-30) in which the concentration of these particles was above limit and tolerable values, was recorded in December of the analyzed period, whereby the permitted values were not exceeded in June. These results clearly indicate the difference between concentrations of these particles in the heating season months (October, November, December, January, February and March) and off the heating season (April, May, June, July, August and September). This conclusion is supported by a chart presented in Figure 1 showing the mean concentrations of PM10 suspended particles per month in the period 2012-2015.

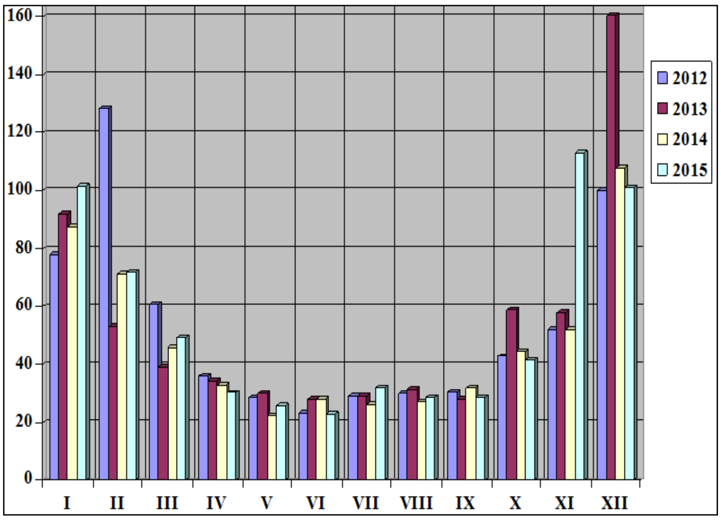

Figure 1 *Average monthly concentrations of suspended particles PM10 in the period 2012-2015*

The presence of the additional source of emission (boiler rooms and individual furnaces) during the heating season significantly influenced the increased concentrations of PM10 suspended particles, and the identified average and maximum values are significantly higher than the values off the heating season. Daily concentrations of the analyzed particles exceeded the limit value in more than 50% measuring during the heating season, and the percentage of measuring with concentrations of this fraction of PM10 suspended particles above the tolerable value is also considerable. Exceeding of limit and tolerable values was recorded during 420 days, out of which 400 days in the period of heating season, and 20 days off the heating season, as presented on a chart in Figure 2. Therefore, PM10 suspended particles significantly impact the air pollution in the City of Kraljevo. It is verified by their maximum concentration of 405.43 μg/m^3 (recorded on 26 December 2012), which is as much as eight times higher than the limit value, and more than five times higher than the tolerable value. As much as 30.9% of the analyzed samples exceed the limit and tolerable values. Out of 420 samples exceeding the limit and tolerable values, as much as 95% are samples from the heating season, and 5% are samples from the period outside of the heating season. These data clearly indicate that the technology of fuel combustion in boiler rooms and individual furnaces influences multiple increase in the content of PM10 suspended particles, thereby influencing the increase at the level of air pollution in the City of Kraljevo.

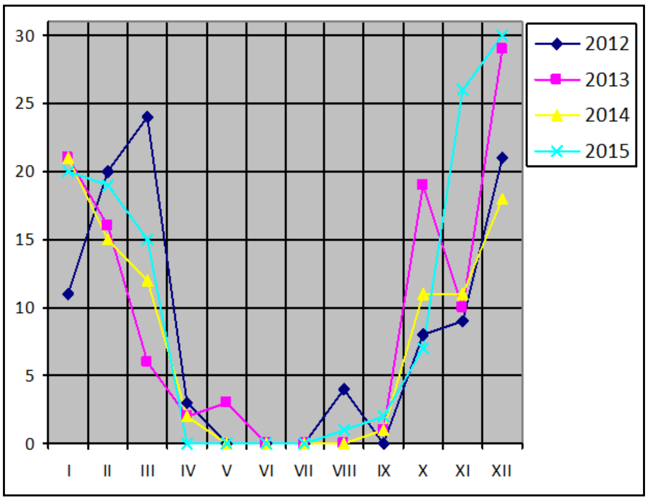

Figure 2 *Monthly review the number of days with PM10 concentrations above the limit value and tolerable value in the period 2012-2015*

Apart from that, frequency of vehicles passing through the center of the City, as well as a large number of heavy vehicles more than 10 years old significantly contributes to the increase of air pollution in this City, all of which complies with the previous studies in this field [16,17].

These results indicate that the issue of air pollution of the City of Kraljevo needs to be considered as a serious one, as a long-term exposure to the action of PM10 suspended particles has a hazardous impact on human health and ecosystem.

CONCLUSION

Analysis of impact of concentration of PM10 suspended particles on air pollution of the City of Kraljevo resulted in the following conclusions:

1) 1,358 samples were analyzed between 2012 and 2015, and the number of samples was from 315 in 2012 to 356 in 2015,

2) Mean annual concentration of PM10 suspended particles was in the interval of 48.13-53.90 $\mu g/m^3$,

3) Minimum concentration of these particles, recorded in September 2015 was 2.17 $\mu g/m^3$, and maximum of 405.43 $\mu g/m^3$ was recorded in December 2012,

4) The number of samples that was above the limit value was in the interval of 40-52, and the number of samples above the tolerable value was in the interval of 48-76,

5) Observed per month, the lowest concentrations of these particles were recorded in June, and the highest in December,

6) Average concentration of these particles in the period of heating season was 75.71 $\mu g/m^3$ and it was significantly higher than the in period off heating season - 28.95 $\mu g/m^3$,

7) The total number of samples above limit and tolerable values was 420, out of which 400 samples in heating and 20 samples off the heating season,

8) PM10 suspended particles coming from boiler rooms and individual furnaces play a leading role in the air pollution of the City of Kraljevo,

9) Exceeding of limit and tolerable value of the suspended particles PM10 in 30.9% of the samples analyzed points to their hazardous impact on the human health and ecosystem of the City of Kraljevo.

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REDISTRIBUTION OF EXCAVATION EQUIPMENT FOR THE PURPOSE OF ACHIEVING THE DESIRED CAPACITY AND IMPROVEMENT THE UTILIZATION TIME OF EQUIPMENT**

Abstract

Minor or greater deviations from the designed technological solutions are mainly due to two reasons: deviation from the design solutions in the previous period as a consequence of organizational factors, and as a consequence of changed parameters of the working environment in relation to those used in the planning and design phase. Ajusting to the newly created situation at the open pit, and in order to ensure a continuous supply of the customer/consumer with the mineral raw materials or fuel, as well as processing (discovery) the new quantities of mineral raw materials that still need to be exploited, it is sometimes convenient to redistribute the equipment at the open pit and adjust the technological parameters of operation to the concrete conditions. In order to improve the effects of equipment operation, reduce the costs and utilize the favorable weather conditions for work at the open pit Gacko - Central Field, a change of designed technology for operation rotor excavator II BTO system and relocation of excavation discontinuous equipment, organized as part of the combined system, has been carried out. This paper presents the technological - organizational measures implemented with the aim of more efficient use the existing excavation and transport capacities.
Keywords: *equipment redistribution, operation technology change, utilization time, OP Gacko*

INTRODUCTION

The Coal Basin Gacko is divided into four exploration exploitation fields: Western, Central, Eastern Exploitation Field and Roof Coal series. The first mass coal exploitation within this basin began in 1978 with the opening of the open pit Gracanica in the western part of Gatacko polje. Exploitation at the open pit Gracanica took place in the Field A, Field B and a part of Field C. Following the break of water into the Field B in 2013, the exploitation continued only from the Field C (Central Field).

The next stage in development the coal mining in the area of the Coal Basic Gacko is the beginning of exploitation in the zone of Roof Coal Series. Considering the existing problems in coal exploitation in a part of Field C, the coal exploitation of the roof

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series has ensured a stable fuel supply of the Thermal Power Plant.

Today, at the open pit Gacko - Central Field, the exploitation is carried out in the central exploitation zone, in which the coal of the main coal seam and the roof exploitation zone are exploited, in which the coal of the roof series is excavated. There is a significant difference in the qualitative coal characteristics within the central and roof exploitation zone. In order to supply coal of the appropriate and uniform quality for the needs of the Thermal Power Plant, the coal amounts excavated in both zones are dynamically coordinated, and their mixing is done on a coal depot of the Thermal Power Plant.

According to the design (The Main Mining Design of the Open Pit Gacko - Central Field for the Capacity of 2.3*10^6 t/year of the Run-of-Mine Coal - the Mining and Metallurgy Institute Bor) for 2017, it is foreseen at the open pit Gacko that the existing front works expand in the south - southeast. Changes of the existing contours of the open pit and their expansion are aimed at achieving the final contour of the open pit in this zone; creating the conditions for coal exploitation in the currently deepest part of the central exploitation zone characterized by high quality and preparition for transfer of rotary excavators of continuous systems to the designed excavation front of the north – south.

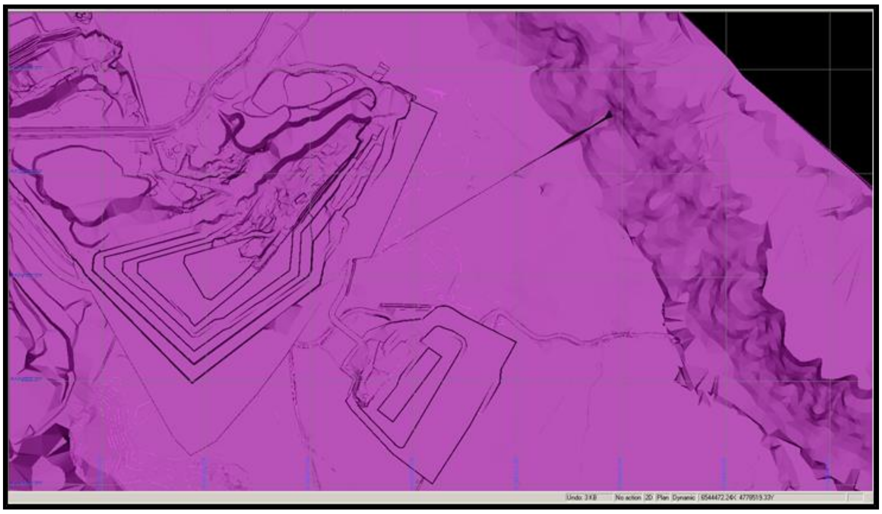

Figure 1 *Designed condition of works from the end of 2017 - View of the Gems program package form*

DESCRIPTION OF THE CONDITION AT THE OPEN PIT AND PROBLEMS

Vertical arrangement of equipment on the southern slope of the open pit is as follows:

- Diskontinuous equipment for excavation the surface quaternary sediments and humus
- I BTO system
- II BTO system
- Comined system
- Coal exploitation system

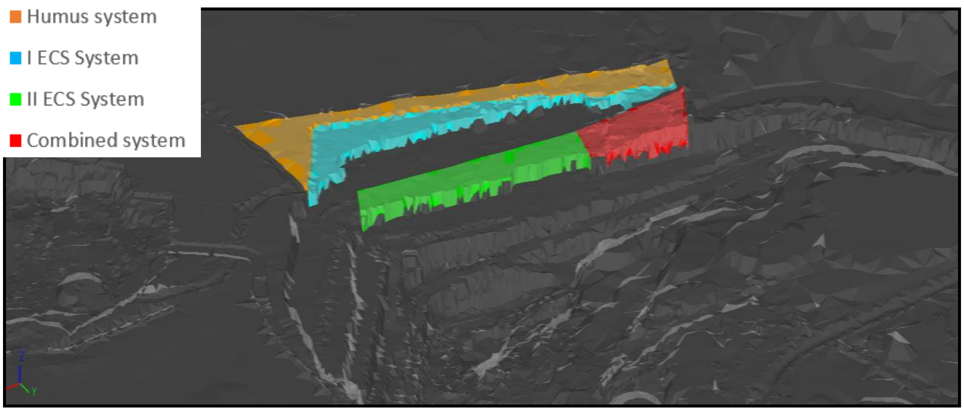

Figure 2 *Schedule of exploitation system at the end of April 2017*

Due to a lack of adequate excavation equipment of surface layers, an external contractor was engaged. Excavation of quaternary sediments is difficult due to the presence of water in them, but also on the terrain surface in the front of works, as they are performed in the area of the old river basin of the Mušnica River, the most important recipient of the Gacko field. The dynamics of quaternary sediment excavation directly affect the work of I BTO system. Humus must be removed separately, primarily because it is intended for remediation. Excavation of these sediments is not performed by a rotary excavator and due to the adverse characteristics in terms of stickiness.

Equipment of the I BTO system (rotor excavator ER 1250 17/1.5, a self-propelled conveyor BRs 1200 and floor conveyor KLM 450) in the excavation zone, is placed at level 926-925. A rotary excavator excavates a floor height of 8-10 m, and the excavated material is deposited by a stacker Ars 1200 depositor on the Large External Landfill. Transport of the excavated material is carried out by the belt conveyors, belt width of 1200 mm.

Equipment of the II BTO system (rotor excavator ER 1250 16/1.5, a self-propelled conveyor P1600 and floor conveyor KLM 500) in the excavation zone is placed at level 909. The rotary excavator excavates a floor height of 15-16, but the height of massif that is provided to be excavated by this system is not the same in all parts of the floor so, in the west part, the floor height exceeds 20 m (Figure 3).

In the zone of the southern slope of the open pit, or in the zone where the excavation works are currently the most intensive, there are also the routes of the BTO coupling conveyors and Combined system. In order for smooth works on extension the southern slope, it is designed that the new conveyor routes are formed by the operation of continuous excavation equipment with minimum participation of discountinuos auxiliary equipment. This implies the operation of rotary excavators in tandem with self-propelled conveyors to form the cross-linking cuts in the slope, with loading on conveyors below the level of standing and with the radial advance of the front. Due to the small dimensions of the site and complicated technological scheme, the time and capacity utilization of the rotor excavators is low. Due to the aforementioned and since the rotor excavator is not able to excavate at places where the floor height exceeds maximum excavation height, the excavation equipment of the combined system, a hydraulic bucket excavator, type PC 2000, is engaged on excavation of these floor parts. The excavated material within the II BTO system is transported by a belt conveyor, 1200 mm wide, and deposited in the excavated area of the Field B by a stacker, type P 1600.

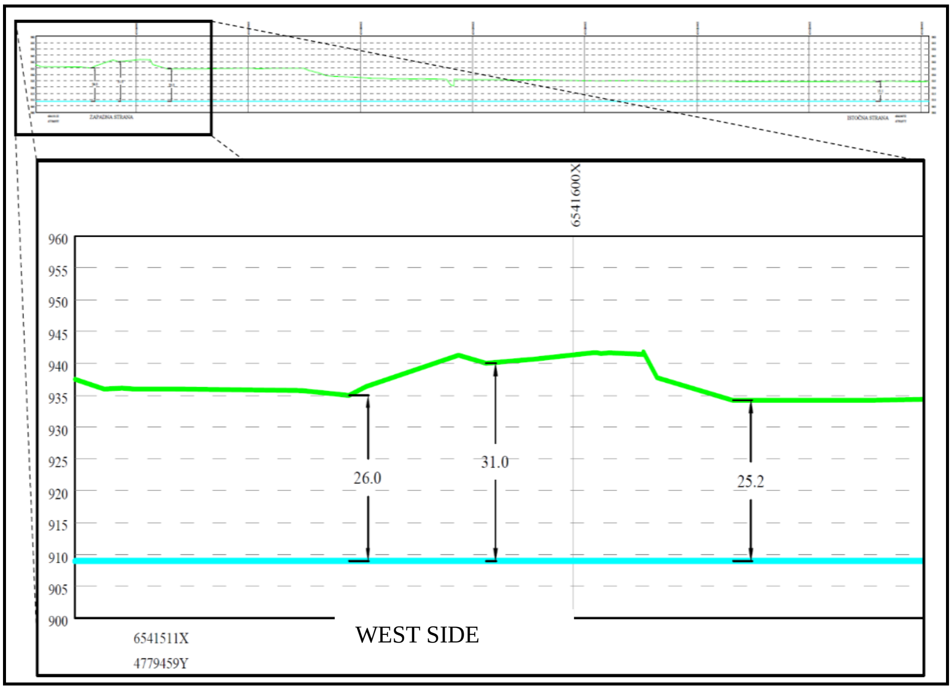

Figure 3 *Longitudinal profile of the II BTO system with maximum heights per individual sections in the western part*

Discontinuous excavation equipment within the Combined system is distributed at many locations - sites. The excavated material from the eastern slope is transported by the trucks to the crusher for waste and after crushing is transported by the 1400 mm wide conveyors to a landfill in the excavated area of the Field B. The hydraulic bucket excavator, type PC 2000, located on the southern slope of the open pit, excavates the material that is transported to a truck and bulldozer landfill, located on the northern slope of the Large Exterior Landfill. This excavator primarily excavates masses on the parts of floor that are higher than the excavation height of the rotor excavator of the II BTO system, participates in excavation of the waste masses in formation the connecting cuts for the BTO conveyors and combined system and parts of floors which the rotary excavator, due to its constructive and technical characteristics, cannot excavate. The work of this hydraulic excavator also forms the level for movement of trucks from the site to the Extenal Landfill.

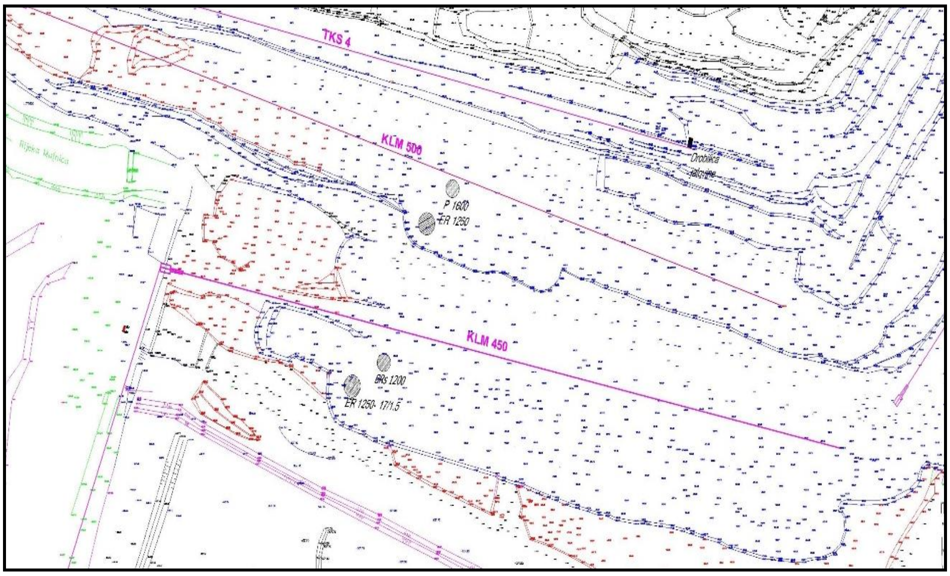

Figure 4 *Situational map of the southern slope of the beginning of April (04/05/2017)*

PROBLEMATICS

At the end of April 2017, the overhaul of the II BTO system was completed. It was anticipated that this excavator would continue its work from the position of its overhauling and continue its progress towards the design solution. This development of works did not come due to the following reasons:

1. Engagement of continuous excavation equipment must be predicted in the conditions in which their capacity will be high.
2. Capacity of a continuous part of the Combined system is not fully utilized due to the characteristics of stacker and a lack of another crusher for waste.
3. Existing sites of a discontinuous excavation equipment are characterized by the cramped working conditions and small lengths of front, and there is a need for a more favorable site of excavation equipment of the Combined system.
4. In order to stabilize the general slope of the landfill, it is necessary to form a floor in a foot of the Large External Landfill.
5. Engagement of a combine Wirtgen SM 2500, due to the specific requirements for corresponding dimensions of the site, is advantageous to form in the southern slope zone, since there are no necessary conditions on the working floores of the east slope (the previous front of works).

Within the limits of expansion the exploitation central zone, the connecting conveyors of BTO and Combined system are located in the southern slope of the open pit. The design envisaged that the new routes of belt conveyor would be made by the operation of rotary excavators with minimum participation of the discontinuous excavation and auxiliary equipment. The operation of rotary excavator, in tandem with the self-propelled conveyor, in a slope, with the narrowed front of works and at the level above the level of conveyor belt, is characterized by the low time and capacitive utilization. Incorporating of a discontinuous equipment in the zones of irrational engagement of the rotor excavator would enable a greater engagement of continuous excavation equipment at locations with more favorable conditions for its operation.

Discontinuous excavation equipment of the Combined system is currently is deployed in many sites. Excavation at the existing sites on the eastern slopeis limited due to the position of higher floores of continuous systems, and on which the current works are not in progress. Therefore, the space for engagement of discontinuous equipment is narrowed, which affects reduction of capacity utilization degree. This is especially significant for the bulk of discontinuos excavation equipment with a bucket capacity of 10-12 m^3.

Overburden that is excavated by the equipment of Combined system is transported to the crusher, and after crushing, it is transported by the belt conveyors to the landfill in the Field B. In case of planned or unplanned downtime of the continuous part of the Combined system, it is convenient to have a storage space for waste deposition, or maintain as operative a discontinuos part. In the previous period, an internal landfill in the Field C had this role. Further disposal on the internal landfill is not possible, so it would be convenient to find a new landfill for overburden that will be deposite by the truck and bulldozer, and with the operation costs being not significantly higher than the combined system costs. One of the causes of frequent delays on the waste crusher are the characteristics of waste that is excavated by the combine Wirtgen SM 2500. The excavated material by the combine has fine granulation and significant adhesion, causing numerous delays ion the wasten the crusher crusher. During the time that is required to clean the crusher, a discontinuous part of the system is operative and, in case of finding a suitable storage space, the time utilization of the system would be significantly improved.

The Combined system at the open pit has a limit on capacity of continuous part of the system, primarily in terms of the stacker capacity. Due to the short transport lengths from the site to the wastew crusher and availability of discontinuous excavation capacities, a discountinuous part of the system currently capaciously exceeds the possibilities of continuous part. It is advantageous to use the available capacity of discontinuous excavation and transport equipment, especially in the period of favorable meteorological conditions.

A continuous disposal of waste is carried out on the Large External Landfill, and the engineering-geological processes are present on the existing slopes of the landfill resulting in instability. Due to this reason, it is necessary to carry out the activities to stabilize the existing slopes by the mass deposition in the landfill foot. This disposal of excavated waste would be done by the masses excavated and transported within a discontinuous part of the Combined system.

In order to avoid longer delays of the Combined system equipment, especially in the period of the year when the largest production is expected and to avoid the costs arising from equipment delay, it is necessary to establish the new worksites for this equipment as soon as possible. One solution that is imposed is to redistribute the existing equipment at the open pit in relation to the design positions within the technological exploitation system in a way that would allow a greater time and capacity utilization (Figure 3).

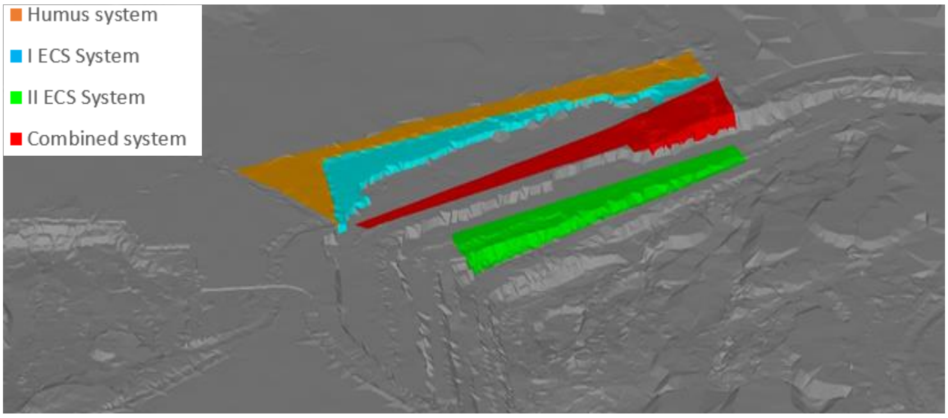

Figure 5 *Proposal of equipment redistribution*

PROBLEM SOLUTION

Upon completion the overhaul of the II BTO system, the rotor excavator and self-propelled transporter should move to the side of conveyor KLM 500 towards the bottom edge of the floor, i.e. in the mining vocabulary "to cross over the belt." This changeover is performed such as the rotory excavator is bypassing the floor conveyor KLM 500 around the return station and comes in a parallel position to the original one. During movement from the initial position to the return station, the rotary excavator excavates a block of 20 m width. After bypassing the return conveyor station, it starts with excavation of a depth floor.

After the rotary excavator of the II BTO system leaves its level, the whole plateau at the level 925-926 m is released, where a part of excavation Combined system equipment can be accommodated. In contrast to the designed equipment layout in this case, a part of discountinuous equipment will work above the rotary excavator of the II BTO system. During the mass excavation by a discountinuous equipment and combine, from this level, the overburden wouls be transported discontinuosly to the external landfill. The most favorable location for this is the space on the northern slope of the Large External Landfill, on the south side of the old old riverbed of the Musnica River. At the same time, the following is carried out:

- Development a floor in a foot of the Large External Landfill in order to stabilize the slope,
- Capacitively relieves a continuous part of the Combined system,
- Increase the degree of capacity utilization of discontinuous equipment of the combined system at the expense of shortening the transport length,
- Formation the landfill for discontinuos equipment of the Combined system in case of delay pn a continuous part of the system.

Plateau on the north side of the KLM 450 conveyor at the level 925-926 has a sufficient width so that it is possible to engage the Wirtgen SM 2500 combine. The excavated overburden with combine will be transported by a truck to the external landfill. This ensures better worksite for a combine and eliminates jams of rakes on the waste crusher due to the material bonding that is excavated by a combine.

TECHNOLOGY OF WORK

After bypassing around the KLM 500 conveyor and installing the equipment to the starting position, it is envisaged that the rotary excavator starts with excavation of deep floor. This implies that the rotry excavator builds a transit ramp, or more precisely, a cut to descend to the level of 895 m. When operating, a longitudinal slope of the ramp must not be greater than 3%, and the floor height will excavated in direct dependance on the equipment capability.

Since the distance between the KLM 500 floor conveyor and edges of the floor varies, the block width also varies. Initially, a rotary excavator excavates a block. Over time, because the conveyor KLM 500 is not installed in parallel to the floor edge, the block is expanded. As the works continue and the rotary excavator goes deeper into the massif, the distance between the rotary excavator, or more precisely the self-propelled conveyor and floor conveyor increases. After a certain time, the arrow of the self-propelled conveyor is not able to hand overthe material on a belt. This situation requires the rotary excavator to be returned and to open a semi-block, to allow unhindered loading of excavated material onto the floor conveyor.

Due to the constructive characteristics of equipment, the rotary excavator will work until it reaches the excavation height of 12m. After that, the standard altitude work will be done in a a block and a semi-block with material unloading above the level of standing.

For the Wirtgen SM 2500 combine, the standard work technology is provided, making the parallel cuts of 2.5 m width on a prepared plateau of 30-40 m wide. After completing the overhaul of the I BTO system and moving the conveyor KLM 450, the plate for combine operation will be expanded. This combine will be provided with a safe worksite for a longer period of time.

Figure 6 *Work of the Combined system equipment at the plateau 925-926*

In addition to the excavator combine on this floor, there is a hydraulic bucket excavator PC 2000. The task is to excavate material from a part of floor that the excavator combine cannot excavate. For this equipment, the technology of work in a deep block with material loading below the standing level in the trucks, type Belaz 75135, is predicted. As the plateau will be expanded, the conditions will be created to open the site for a number of excavators of the Combined system.

The material excavated by the Combined system equipment is deposited on a truck landfill positioned in a foot of the Large External Landfill.

CONCLUSION

Redistribution of equipment and change in the technology of work can be successfully applied in order to improve the working conditions and increase the utilization degree of equipment capacity, all in order to increase the production of useful mineral raw materials and overburden at the open pit. This method of organization is indispensable in cases when a variety of equipment is included in the production process. Due to the maneuverability of discontinuous equipment, it is possible to change the positions of excavation equipment and thus with minimum delays to provide better working conditions such as shorter transport lengths, relieving of transport systems, positioning equipment of higher power at worksites where the working environment is characterized by the increased excavation resistance.

In the case, described as a result of equipment redistribution and change the technology of work, more favorable working conditions of the equipment and increased degree of capacitive utilization of equipment were provided in the period of favorable weather conditions. A necessary prerequisite for these operations is a good knowledge of equipment and working conditions at the open pit.

In the case of unplanned delays and interruptions in the operation of certain parts of the equipment in system (especially discontinuous), it is necessary to define the priorities of work and to redistribute the remaining available equipment based on them. Redistribution should be as efficient and cost-effective as possible. It should also be taken into account that the equipment is not exposed to high loads (large excavation resistances, high slopes of the transport route, overload of transport equipment) achieved by its engagement in parts of the working environment with favorable physical-mechanical characteristics and technological parameters adapted to the constructive kinematics characteristics of the equipment.

If it is not possible to perform a location redistribution of equipment (this is the case for large continuous systems), the next solution is to change the technology of work of the excavation and disposal equipment.

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THE BOND WORK INDEX OF LIMESTONE AND ANDESITE MIXTURES**

Abstract

This paper investigates grinding of mineral mixtures with different grindabilities in the Bond ball mill. Understanding the ore mixture grinding is of great importance in mineral processing. The energy required for crushing and grinding is presented by the Bond work index and is determined by means of Bond grindability test. This paper presents the experimental results of the Bond work index values obtained by the standard method on limestone and andesite samples, as well as composite samples made up from these ore in different weight ratios. Comparatively are shown the Bond work index values that are obtained by the mass fraction of components that make up the composite samples calculation and their differences from the real value. During the Bond work index value determining, changes in the composition of the grinding products and circulating mill charge were monitored.

Keywords: *Bond work index, grinding, circulating charge, composite samples*

INTRODUCTION

Grinding is one of the main industrial processes which burden with the large expenses in the heavy equipment, energy, operation and maintenance. It is necessary to spend the most of energy for ore grinding to the designed size, significantly more than for all the other processes of preparation and concentration. In the mineral processing in terms of energy savings is crucial to understand how the ore mixture with different grindabilities from different deposit parts would grind. Natural minerals and rocks are generally very heterogeneous in their physical characteristics. It is important in the heterogeneous materials comminution to understand how the individual components act separately and, on the other hand, how these components in the mill will affect to each other in order to optimize the grinding process. Further, it is important to understand how ore different mineral components with different grindabilities would react to grinding after their liberation, since different responses of mill load components in the grinding process can lead to formation of adverse granularity for further concentration process.

Ore grindability is represented by the Bond work index value for the purposes of the processes in mineral processing. This value is found in a laboratory Bond ball mill by simulating dry grinding in a closed circuit until the 250% circulating load has been achieved (Magdalinovic, 2003).

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A large number of researchers in their papers deal with various aspects of the mineral mixtures grinding in a ball mill.

Feurstenau and Venkataraman (1988) have performed the grinding experiments in a closed circuit on a quartz and limestone mixture samples. They have shown that it takes 25 two-minute grinding cycles in order to achieve a constant circulating charge, whereby it was constantly changing its, i.e. there is a harder-grinding material concentration in the circulating charge.

Kapur and Feurstenau (1989) have carried out the locked-cycle grinding experiments with a constant grinding time on quartz and limestone samples and their mixtures in different mass portions. They have demonstrated that to achieve the grinding steady state, actually a constant circulating load of single component mill feed needs 3 to 6 grinding cycles, and for mixture of these ingredients up to 35 cycles.

Yan and Eaton (1994) studied the Bond work index changes of ore mixtures as a function of the mixture composition, and found that this value is not the simply weighted - average value for individual component.

Hostels and Avsar (1998) have carried out the experiments by the standard Bond grindability test on samples of clinker and volcanic tuff and their mixtures in various weight ratios. They have shown that the Bond work index value of these components mixtures is greater than the Bond work index of harder components, clinker.

Oner (2000) have conducted a research of clinker and blast furnace slag mixture Bond Work Index in different mass proportions. He found out that these values are always lower than the Bond Index obtained as the mean calculated Bond work index value of mixture components by their mass portion.

Ipek et al. (2005) have carried out the Bond work index measurements by the standard method on samples of quartz, feldspar and kaolin and their binary and ternary mixtures. They have demonstrated that the energy required for comminution is smaller when the mixture components are grinded separately than when they are grinded together as a mixture.

Tavares and Kallemback (2013) on samples of limestone, basalt and copper ore and their mixtures in different mass portions were determined the Bond work index value by the standard Bond's procedure. They found that the energy required for grinding is most often lower when the components mixture grinded separately regarding to the required energy for grinding components together as a mixture.

METHOD AND MATERIAL

Specification of the Bond's mill, together with the experimental execution conditions of the standard Bond's test are given in Table 1.

Table 1 *Bond's mill specification and grinding conditions*

Mill diameter, D_m, cm	30.48
Mill length, L_m, cm	30.48
Number of mill rotations in minutes, n, min^{-1}	70
Mill balls weight, M_b, kg	21.125
Geometry of mill liner	smooth
Grinding type	dry
V_{ore}, cm^3	700

Andesite and limestone samples were prepared by crushing in a laboratory jaw crusher and roll crusher in a closed cycle with screening to size 100% -3,327mm. The samples of pure andesite and pure limestone are separated from the ground material for experiments. The composite samples of andesite and limestone are made from the rest, in the following ratios:

limestone : andesite = 25 : 75,
limestone : andesite = 50 : 50,
limestone : andesite = 75 : 25.

The Bond work index determination according to the standard Bond's test is done on all these samples with comparative sieve size of 74, 105 and 150 microns. The Bond Work Index is calculated using the formula (Bond, 1961):

$$W_i = 1{,}1 \cdot \frac{44{,}5}{P_c^{0{,}23} \cdot G^{0{,}82} \cdot \left(\frac{10}{\sqrt{P_{80}}} - \frac{10}{\sqrt{F_{80}}}\right)} \quad (1)$$

where:

W_i – Bond work index (kWh/t);
P_c – test sieve mesh size (μm);
G – weight of the test sieve fresh undersize per mill revolution (g/ob);
F_{80} – sieve mesh size passing 80% of the feed before grinding (μm);
P_{80} – opening of the sieve size passing 80% of the last cycle test sieve undersize product (μm).

After each grinding cycle, solubility in HCl was determined on comparative sieve undersize and thus defined contents of limestone and andesite in the same.

RESULTS AND DISCUSSION

In order to better understand the mechanisms that occur in the Bond ball mill during the standard Bond grindability test performance on the two-component mineral mixtures, the composition changes of the batch cycles milling products and mill circulating charges were monitored on two-component mineral mixtures

Composition changes of milling product

Figures 1, 2 and 3 show the grinding product composition changes during the Bond's grinding tests performance using the test sieves 74, 105 and 150 microns on limestone and andesite composite samples with mass ratios 25:75, 50:50, 75:25.

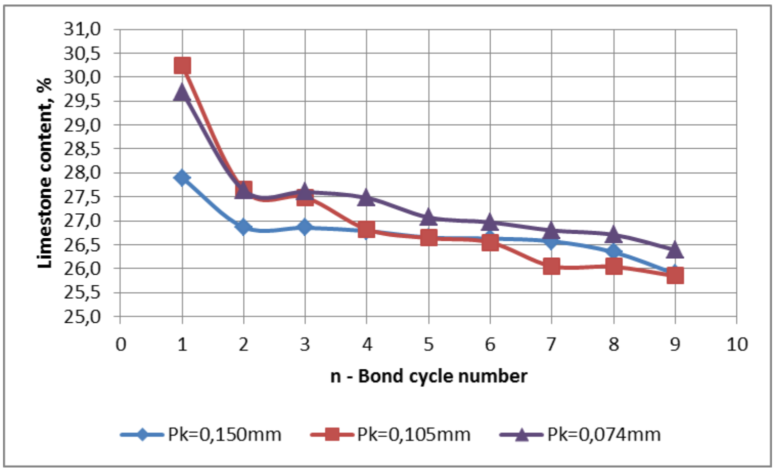

Figure 1 *The limestone content in grinding product during the standard Bond test on samples with the composition limestone : andesite = 25: 75*

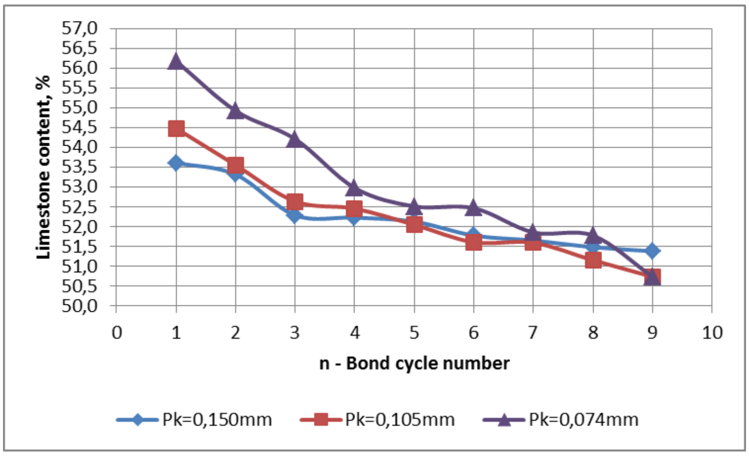

Figure 2 *The limestone content in grinding product during the standard Bond test on samples with the composition limestone : andesite = 50: 50*

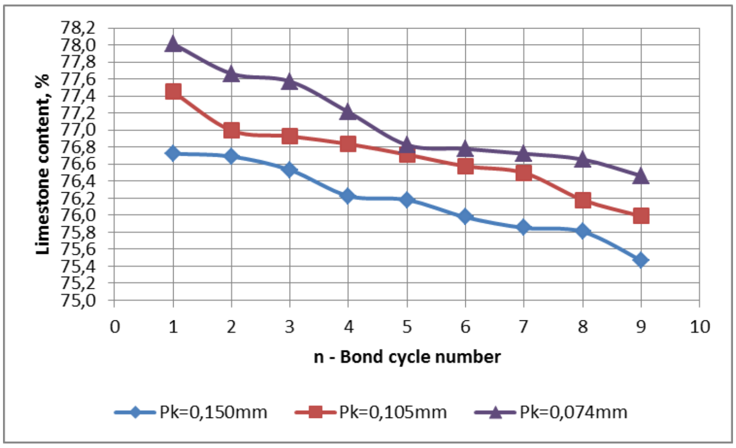

Figure 3 *The limestone content in grinding product during the standard Bond test on samples with the composition limestone : andesite = 75: 25*

It can be seen in Figures 1, 2 and 3 that during all Bond tests on samples with varying mass portion of mixtures components with different test sieves, the grinding products of initial grinding cycles have the increased content of soft component (limestone). With increase of grinding cycles, the soft component content (limestone) in the grinding product gradually decreases. At the moment of reaching the steady state (250% circulating charge), the content of soft component in the grinding product is equalized by the composition of feed to the grinding process.

Composition changes of circulating charge

Figures 4, 5 and 6 shows the circulating charge composition changes during the Bond grinding tests using the test sieves 74, 105 and 150 microns on limestone and andesite composite samples with mass ratios 25:75, 50:50, 75:25.

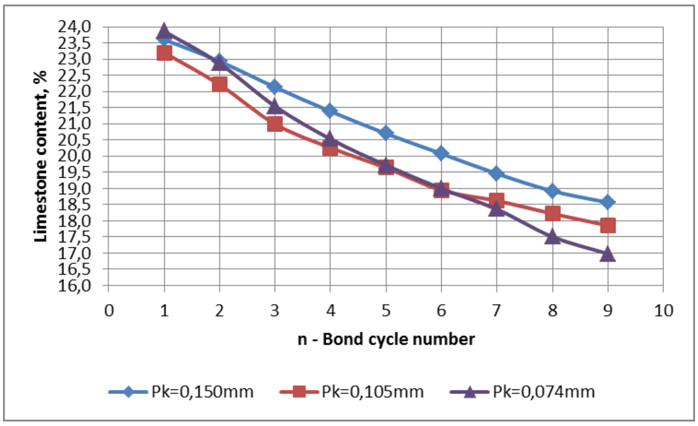

Figure 4 *The limestone content in circulating load during the standard Bond test on samples with the composition limestone : andesite = 25: 75*

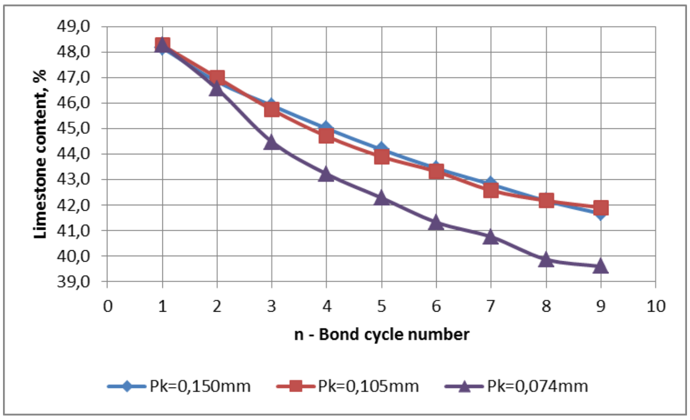

Figure 5 *The limestone content in circulating load during the standard Bond test on samples with the composition limestone : andesite = 50: 50*

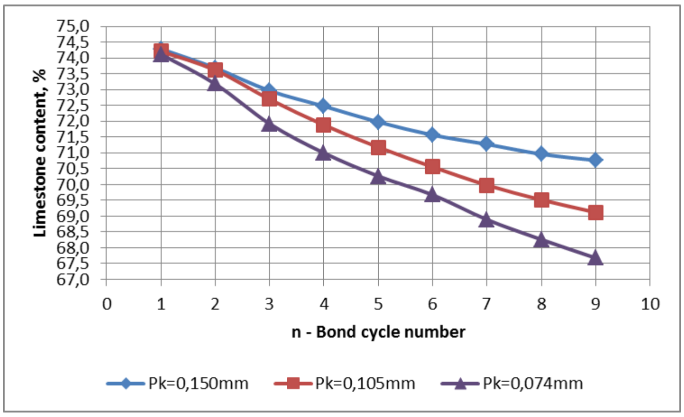

Figure 6 *The limestone content in circulating load during the standard Bond test performance on samples with the composition limestone : andesite = 75: 25*

It can be seen in Figures 4,5 and 6 that during the execution of all Bond tests on samples with varying mass portion of mixture components and with different test sieves, with an increase in grinding cycle, the mill circulating charge has softer components content (limestone) gradual increase, and harder component content (andesite) gradually decline.

In the initial grinding cycles, the softer component (limestone), which it is easier to grind, quickly reaches the desired size and passes into a grinding product in a larger mass proportion than the harder component (andesite) in relation to their starting mass portions. With the grinding cycles increase, harder component (andesite) accumulate in a mill circulating charge because it more slowly decreases a size. At the moment of reaching the steady state, it forms such a mill circulating charge in which there are the reduced softer component content with a larger mean diameter and an increased harder component content with smaller mean diameter.

The Bond work index of ore mixtures

Review of the results obtained by performing the Bond grindability tests on samples of limestone and andesite and their composite samples in various weight ratios are shown in Table 1. The Bond work index computational values were obtained using the formula:

$$W_{i\,c} = W_{i\,soft} \cdot r_{soft} + W_{i\,hard} \cdot r_{hard} \qquad (2)$$

where:

$W_{i\ soft}$ – softer component Bond work index (kWh/t);

r_{soft} – mass fraction of softer component (fractions of unit);

$W_{i\ hard}$ – harder component Bond work index (kWh/t);

r_{hard} – mass fraction of softer component (fractions of unit).

Table 1 *The Bond work index values obtained by standard the Bond procedure and values calculated according to the mass fraction of the sample components*

Sample	Test sieve, µm	W_i, kWh/t	W_i calcul., kWh/t	Difference, %
Limestone : andesite 100 : 0	74	13.90	/	/
	105	12.77	/	/
	150	12.63	/	/
Limestone : andesite 75 : 25	74	14.51	14.95	3.02
	105	13.91	13.81	-0.72
	150	13.59	13.48	-0.85
Limestone : andesite 50 : 50	74	15.50	16.00	3.19
	105	14.60	14.85	1.71
	150	14.26	14.32	0.42
Limestone : andesite 25 : 75	74	17.03	17.04	0.07
	105	16.41	15.89	-3.17
	150	15.13	15.17	0.23
Limestone : andesite 0 : 100	74	18.09	/	/
	105	16.93	/	/
	150	16.01	/	/
Mean difference				1.49

It can be seen from Table 1 that the calculated values of the Bond work index are slightly different from the experimen-tally obtained values. Maximum difference between these values is 3%. Mean diffe-rence is 1.49%, which is within the ope-rational error limits for the Bond grindability test.

According to the previous scientific research, it can be seen that the Bond Index of ore mixtures can not be predicted simply calculating the Bond work index components and their mass portions:

- Yan and Eaton (1994) performed the experiments on two different samples of gold ore, and their mixtures with a large difference in grindability Wi = 14 and Wi = 6, and they found that it is not possible to predict the computational mixtures of the Bond Index based on components Wi;
- Hosten and Avsar (1998) found that the Wi of clinker and volcanic tuff in different mass ratios mixtures is even greater than harder component Wi;
- Oner (2000) on clinker and blast furnace slag samples, and Tavares and Kallemback (2013) on limestone, basalt and copper ore samples were determined that the mixture Wi is less than the mean calculated value of components Wi according to the mass fractions.
- Ipek et al. (2005) on quartz, kaolin and feldspar samples were determined that mixture Wi is greater than the mean calculated value of components Wi according to the mass fractions.

In the case of a limestone and andesite mixture samples in different mass ratios, which were examination subject of this study, it can be said that the mean values of component mixture of the Bond work index. according to the mass fraction, corresponds to the real Bond work index values.

CONCLUSION

On the basis of the obtained data by performing the Bond grindability tests on limestone and andesite composite samples in different mass proportions, it can be concluded:

- In the initial grinding cycles, the soft component content is increased in the grinding product. With each subsequent grinding cycle, this increased soft component content in relation to the initial sample is reduced. Grinding product is equalized by the composition with the starting sample at the moment of reaching the steady state.
- In a circular mill load gradually comes to accumulation of the mixture harder component.
- The Bond work index of experimentally obtained values, and calculated values according to the mixture components mass portions, has the max difference of 3%.

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ESTIMATING HYDRAULIC PARAMETERS FOR THE COMPLEX HYDRODYNAMIC MODELS**

Abstract

Hydrodynamic models have usually been calibrated manually, by trial-and-error, with different values of hydraulic parameters and hydraulic characteristics of boundary conditions. This method of calibration and estimation of hydraulic parameters requires an extensive knowledge and experience of experts, but whether the resulting solution includes an optimal set of parameters still remains an open question. An optimization method founded upon the Gauss-Marquardt-Levenberg algorithm, along with PEST software based on that algorithm, introduces automation of model calibration with regularization, which substantially reduces the effect of expert judgment on the result. The method also introduces the so-called "pilot points", which transcend the concept of homogeneous zones with the values of hydraulic parameters of a hydrogeological system or zones with the specified boundary conditions. Mineral ore deposits are the most complex in geological and hydrogeological terms, so the lignite coal mine "Tamnava - West Field" was selected as a good area to test the approach. Applying the proposed method, the spatial distributions of the horizontal (Kx=Ky) and vertical (Kz) components of hydraulic conductivity are determined in the study area.

Keywords: *calibration, optimization, PEST, hydraulic conductivity*

INTRODUCTION

Hydrodynamic modeling is the most complex and most appealing method for simulating the aquifer regimes. It is based on numerical solving the partial differential equations that describe the groundwater flow and processes taking place in the porous medium. Hydrogeologists mainly follow this approach to assess the groundwater regime, quantify the groundwater balance, analyze the flow pattern, make the alternative prognostic calculations for a technical concept, and predict the movement of groundwater, a pollutant or heat. In the case of mineral ore deposits, the groundwater modeling is mainly used for alternative prognostic calculations made in connection with design of the groundwater control systems-lowering groundwater levels to below the elevation of mining operations [1, 2, 3]. Hydrodynamic models are also used to assess the effectiveness of groundwater control systems and select the optimal solution [4].

Calibration of the hydrodynamic model is the most delicate process in modeling, which includes fitting the groundwater flow simulation results to data recorded in nature

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(piezometric levels and components of the groundwater balance).

Until recently, manual calibration has been widespread; it involves a trial-and-error with different combinations of model parameter values, to fit the estimated model parameter values to those observed in nature. Such approach to a hydrodynamic model calibration requires a vast experience and extensive knowledge, while the ultimate solution has a distinct expert judgment component [5]. However, the automated calibration, using a special-purpose software, has been gaining ground over the past several years. This approach optimizes the values of select parameters of the hydrogeologic system: hydraulic conductivity, specific yield and specific storage. It also optimizes the values of boundary conditions, such as the rates of infiltration and evapotranspiration, discharges, piezometric levels and the like. The optimization method is based on the Gauss-Marquardt-Levenberg algorithm [6], which looks for the minimum residual sum of squares - the difference between measured data and model simulation results.

PEST (Model-Independent Parameter Estimation and Uncertainty Analysis) software is commonly used worldwide for the automated model calibration with regularization [7, 8]. This is the most advanced software for optimizing the parameters of any simulation model and analysis of uncertainty in prognostic calculations [9, 10]. PEST is widely used in geoscience [11, 12, 13].

Mineral ore deposits are the most complex case of hydrodynamic modeling of aquifer regimes. The complexity of such areas is attributable to the dynamics - continuous changes in the model's flow field corroborated by a constant expansion of deposits. In the present research, the optimization approach to the estimation of hydraulic parameters in hydrodynamic modeling was applied to the largest open-cast mine in Serbia - the lignite coal mine of Tamnava - West Field. Hydraulic conductivity (K) was estimated by this complex analysis.

STUDY AREA

The Tamnava - West Field coal mine belongs to the Kolubara Coal Basin. To the west and south the mine borders on the Radljevo open - cast mine, and to the east on the Tamnava - East Field open-cast mine. On the northern side, there is a natural boundary where the coal bed lenses out. The geologic framework in the paleo relief is comprised of the Paleozoic and Mesozoic sediments, while the coal basin itself is built up of the Neogene deposits: alluvial and terrace sediments of the Kolubara, Kladnica, Turija and Peštan rivers (Fig. 1). There are also other sediments, such as diluvial-proluvial and oxbow deposits. Quaternary sediments discordantly overlie the Pontian strata (Pl_1).

The Tamnava - West Field is the largest open-cast mine in Serbia, where lignite coal is mined. A total of 11,600,000 tons of coal was extracted in 2015, which was 15.5% more than the annual budget.

METHODOLOGY

The methods used in this research were the hydrodynamic modeling and the Gauss-Marquardt-Levenberg algorithm [6] for optimization. PEST software, based on the said algorithm, was used for estimation. The concept required the introduction of pilot points [7, 8, 9, 10], which did not necessarily signify fictitious points, although the points at which some of the parameters were known were relatively few. Each pilot point represented a parameter whose value was to be determined. The concept of pilot points is not restricted to hydraulic conductivity; it applies to all parameters determined during the course of model calibration.

There are several ways in which the pilot points can be specified in the model, such as by means of a regular grid or triangulation [7]. The use of pilot points in PEST is referred to as regularization, whereby the distribution of certain parameters and/or values of boundary conditions are regularized. The outcome of this approach in

PEST calibration is a result that includes the heterogeneity of the medium (flow field) with regard to the distribution of the determined parameters of the medium (hydraulic conductivity in the present case).

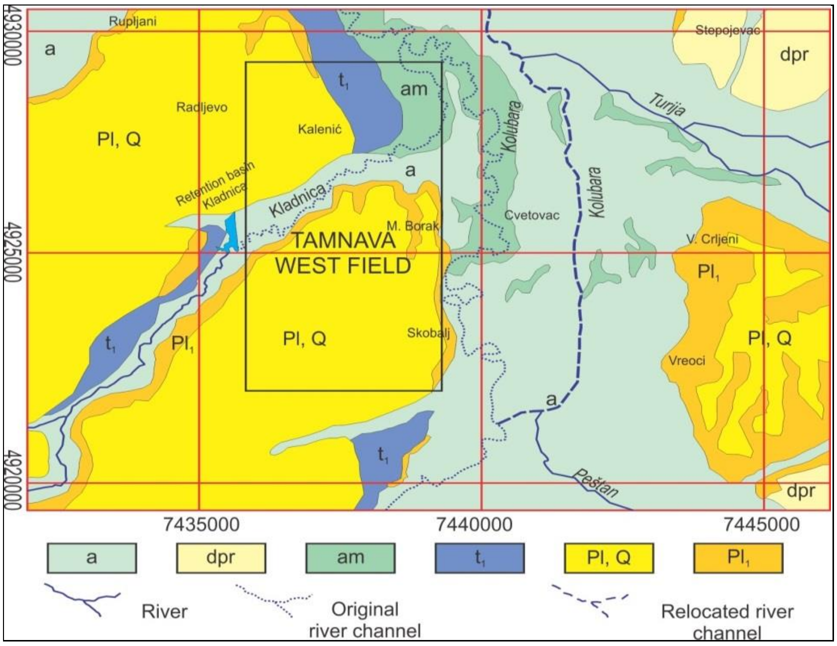


Figure 1 *Geological map of the open-cast mine Tamnava - West Field (according to the national geological map of Serbia, scale 1:100,000, Obrenovac section and [14])*
Legend: a - riverbed sediments; dpr - diluvial/proluvial sediments; am - oxbow sediments; t_1 - lower river terrace; Q, Pl - riverine-lacustrine terrace; Pl_1 - sand and clay (marly and coaly).

RESULTS

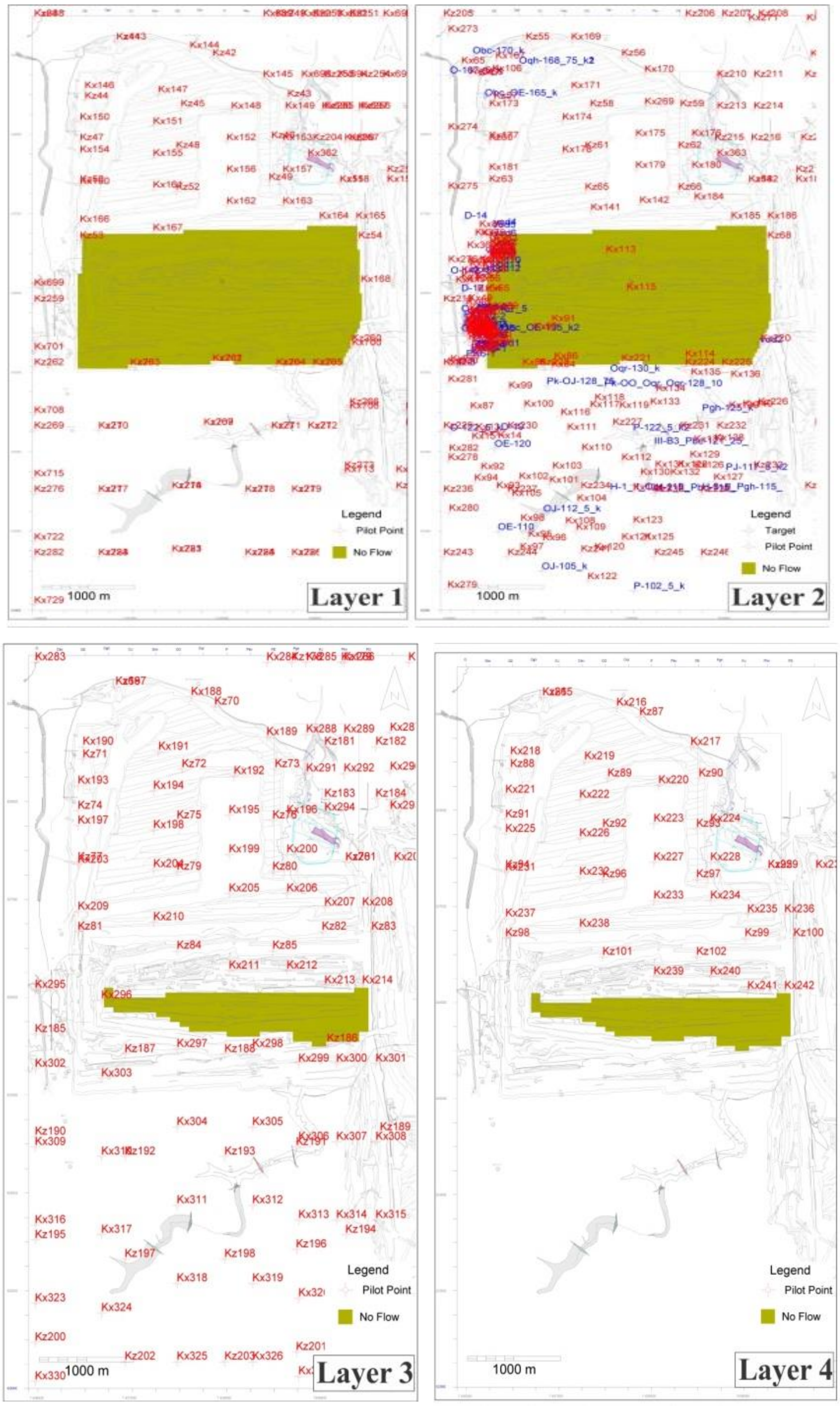
A three-dimensional hydrodynamic model of the Tamnava - West Field, based on the method of finite differences, was developed using the MODFLOW code [15] with the Groundwater Vistas Advanced graphic user interface, version 64-Bit 6.74 b.24 [16]. It was designed as a multi-layer model, with a total of eight layers (Table 1), as described in [17]. Each of these layers corresponded to a real layer, modeled on the basis of the results of analyses of *in situ* investigations. The initial values of hydraulic conductivity for all the lithologic units were entered based on the outcomes of *in situ* hydrogeological investigations and are shown in Table 1.

Both manual and automated (PEST with regularization option) calibration of the model was undertaken. Pilot points were specified for automated calibration, given that they help to obtain much more realistic heterogeneous zones with hydraulic conductivities. Figure 2 shows the model layers in which pilot points were specified. They were used to determine the spatial distribution of the horizontal (Kx=Ky) and vertical (Kz) components of hydraulic conductivity. No pilot points were specified in the 6th model layer represented solely by the second coal bed. A total of 729 pilot points were specified with the horizontal component and 286 with the vertical component of hydraulic conductivity. The way the pilot points were specified depended on the hydro-geological significance of the various sediments and the number and distribution of piezometers in the water-bearing layers (Table 1 and Fig. 2). In the case of semi-permeable sediments, a homogeneous grid of pilot points was specified for each distinct lithologic unit. On the other hand, the pilot points for water-bearing sediments with piezometers were specified by triangulation between three neighboring piezometers, with an additional pilot point in the center of each triangle. Then the density was increased in the parts where the pilot points were located. In the 8^{th} model layer, a so-called regular grid of pilot points, spaced 500 m apart, was specified. The pilot points determining a distribution of vertical component of hydraulic conductivity were moved 50 m relative to the horizontal component, to display the points more easily.

Determined representative values of hydraulic conductivity were the outcome. A total of 49,964 zones with values of hydraulic conductivity were identified in the model of Tamnava - West Field. Figure 3 shows the hydraulic conductivities of the model layers. The results are presented as the maps of hydraulic conductivity distribution, with different color fields according to a color scale. The data generated by the software can also be exported to xls and presented in tabular form.

Table 1 *Schematic view of the flow field - representation of the lithologic units in the model layers with initial values of hydraulic conductivity (K_x, K_y, K_z)*

Model layer	Lithologic units	$K_x = K_y$ (m/s)	K_z (m/s)
First confining layer (stratum)	Quaternary clay and heterogeneous mine waste in the northern part of the area	$5x10^{-6}$	$5x10^{-7}$
Second combined water-bearing -	Upper aquifer sand and gravel	$5x10^{-4}$	$5x10^{-5}$
confining layer	and heterogeneous mine waste in the northern part of the area	$1x10^{-6}$	$1x10^{-7}$
Third confining layer	Aleurites and mine waste in the northern part of the area	$5x10^{-6}$	$5x10^{-7}$
Fourth confining layer	First coal bed	$5x10^{-9}$	$5x10^{-10}$
Fifth combined water-bearing -	Intermediate aquifer sands in the western and central parts in front of the mine contour	$1x10^{-5}$	$5x10^{-6}$
Confining layer	Heterogeneous mine waste in the northern part of the area, clay sediments in the north-eastern part and coals in the eastern and southern parts of the area	$1x10^{-6}$	$1x10^{-7}$
Sixth confining layer	Second coal bed	$5x10^{-9}$	$5x10^{-10}$
Seventh water-bearing layer	Lower aquifer sands of high hydraulic conductivity	$3x10^{-5}$	$5x10^{-6}$
Eighth water-bearing layer	Lower aquifer sands of low hydraulic conductivity	$1x10^{-5}$	$5x10^{-6}$


Legend
Pilot Point
No Flow
1000 m
Layer 1
Legend
Target
Pilot Point
No Flow
1000 m
Layer 2
Legend
Pilot Point
No Flow
1000 m
Layer 3
Legend
Pilot Point
No Flow
1000 m
Layer 4

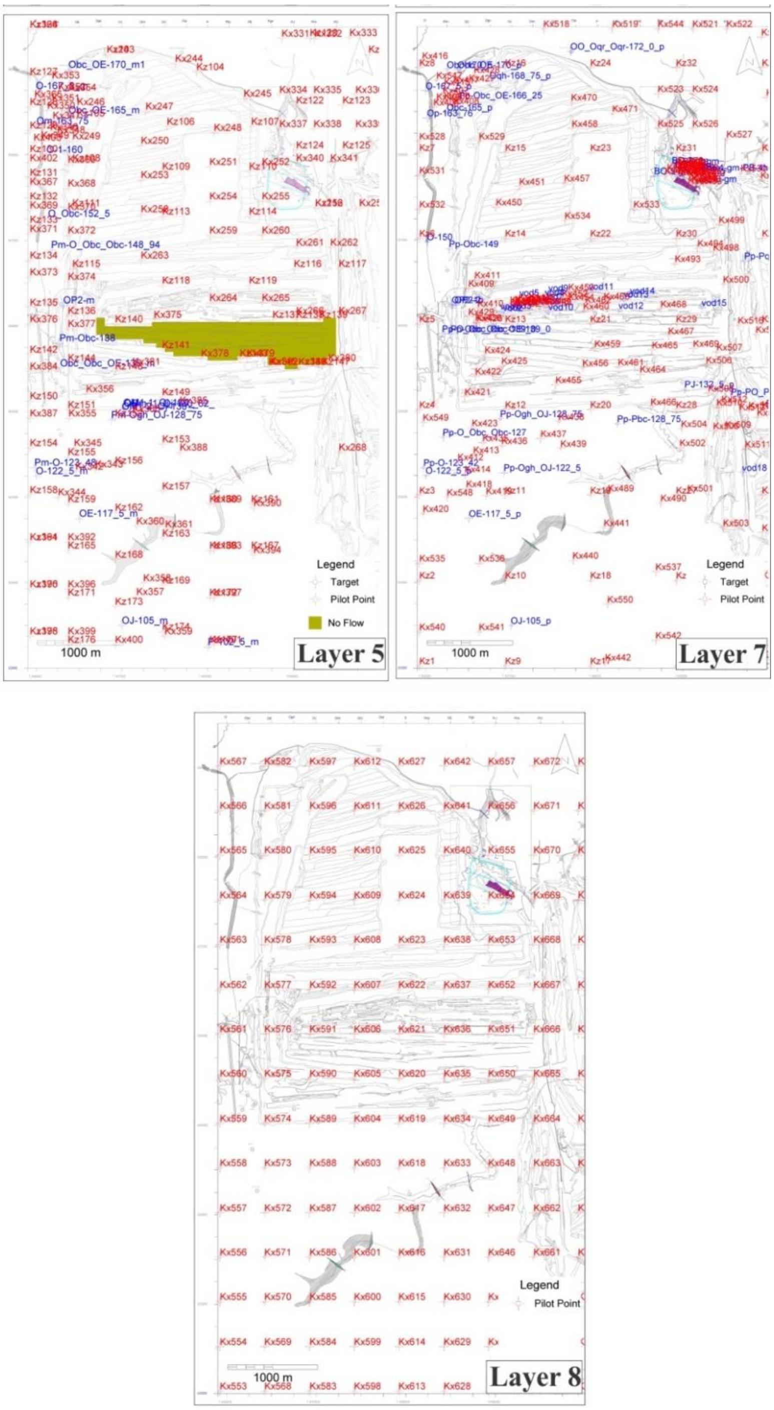
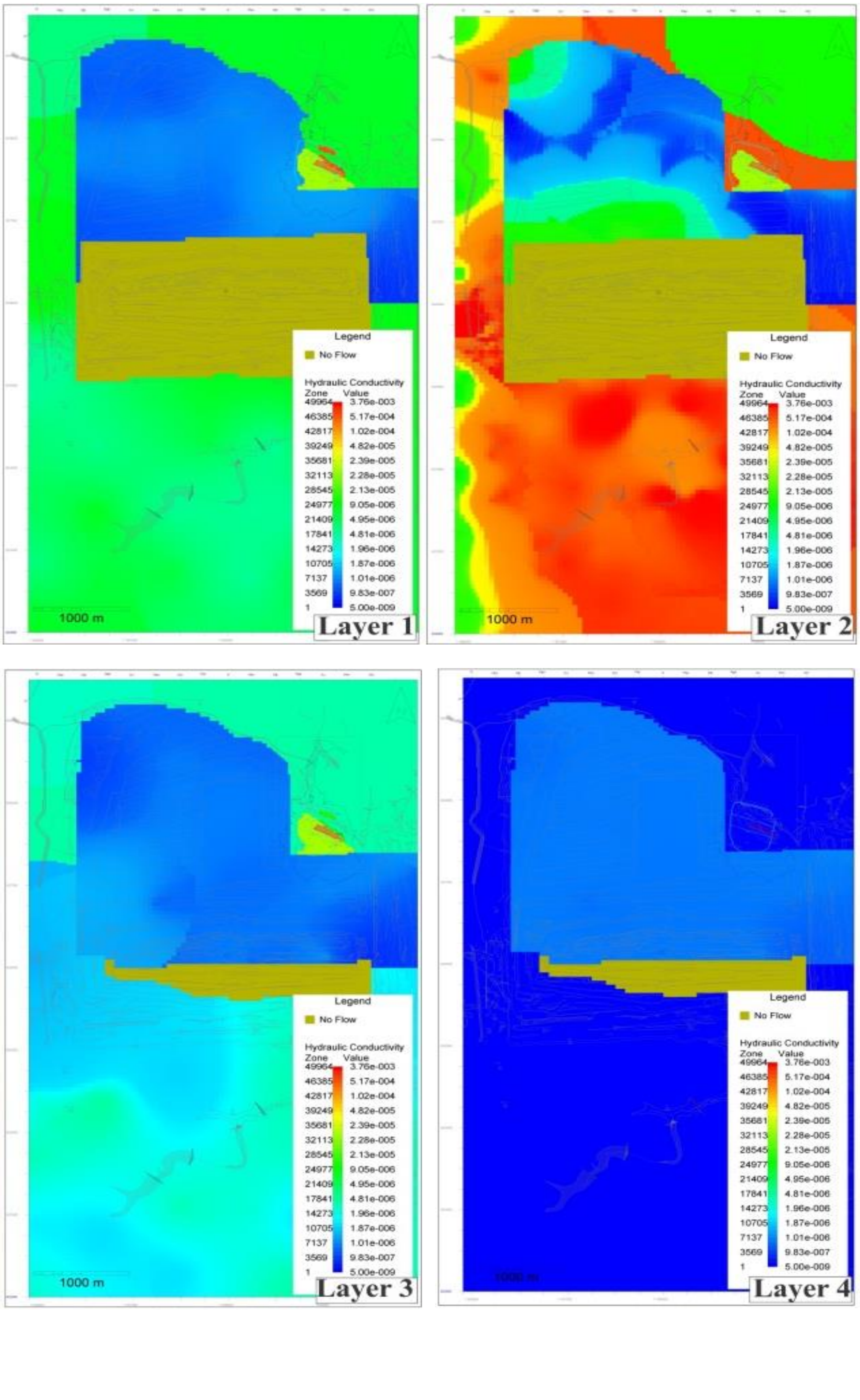


Figure 2 *Distribution of pilot points in the model layers of the Tamnava - West Field open-cast mine*


Legend
No Flow
Hydraulic Conductivity
Zone Value
49964 3.76e-003
46385 5.17e-004
42817 1.02e-004
39249 4.82e-005
35681 2.39e-005
32113 2.28e-005
28545 2.13e-005
24977 9.05e-006
21409 4.95e-006
17841 4.81e-006
14273 1.96e-006
10705 1.87e-006
7137 1.01e-006
3569 9.83e-007
1 5.00e-009
1000 m
Layer 1
Layer 2
Layer 3
Layer 4

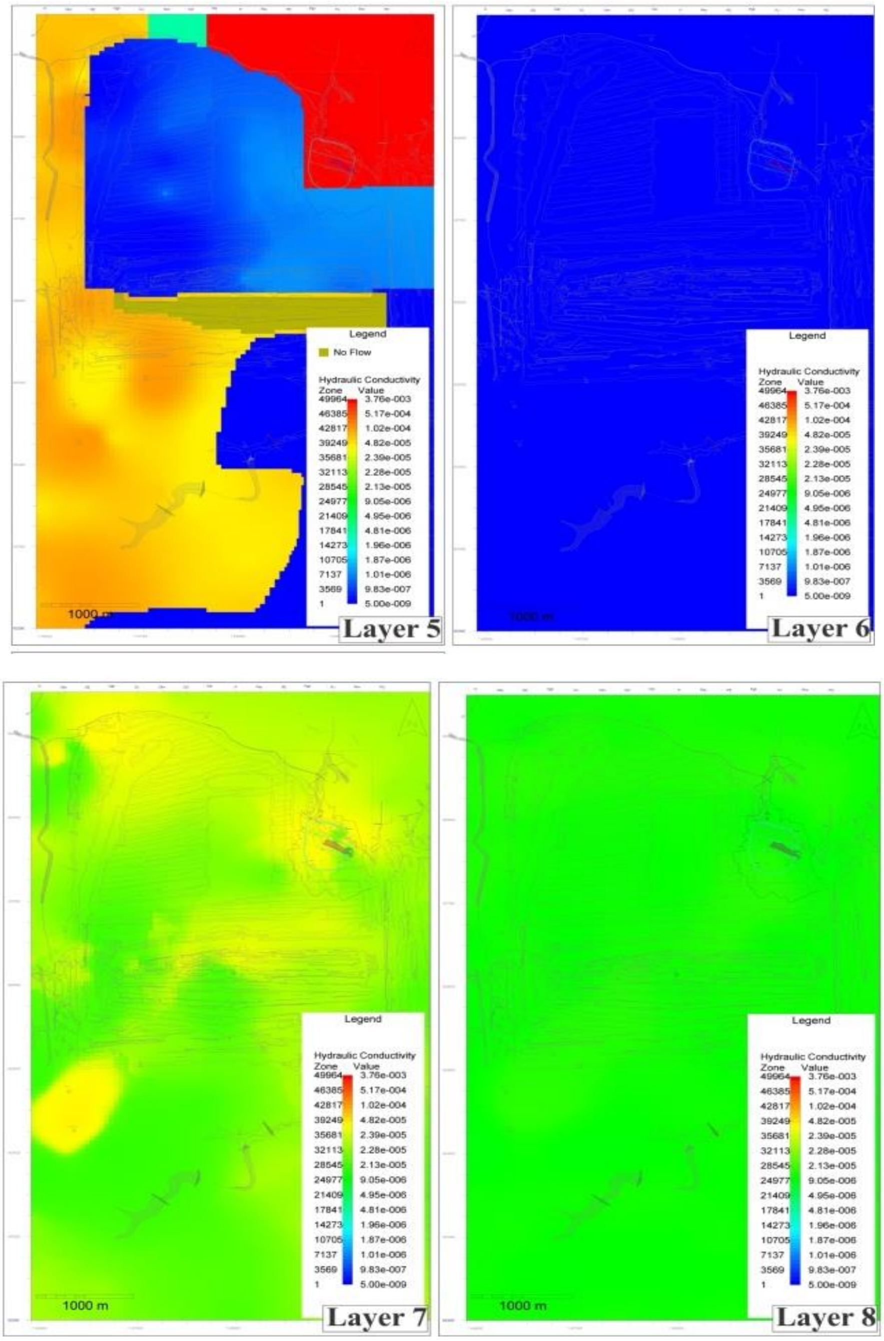


Figure 3 *Zones of hydraulic conductivity in the model layers of the Tamnava - West Field open-cast mine*

CONCLUSION

The paper described the application of an optimization method based on the Gauss-Marquardt - Levenberg algorithm in hydrodynamic modeling, undertaken to assess a hydraulic conductivity during the course of automated calibration with regularization. The method considerably reduces the influence of expert judgment on the result. PEST software was used to optimize the parameters during the automated calibration process. This software has a broad range of applications, which transcend groundwater modeling. A development of PEST introduced the concept of pilot points, which surpasses that of homogeneous zones with values of parameters of the medium or zones with specified boundary conditions. Even though the concept is a big step forward in the estimation of hydraulic parameters in hydrodynamic modeling, there are some issues. One of the biggest problems in connection with the use of pilot points in PEST is the needed computation time. Every increase in the number of pilot points in the model considerably lengthens the calibration time. Namely, PEST considers each pilot point as a parameter whose optimum value is to be determined. It should be noted that in PEST, each parameter requires one or two simulations per iteration. The described model of the Tamnava - West Field coal mine had a total of 1015 pilot points, which meant 1015 simulations (or 2030 if central differentiation was used) per iteration. A larger number of iterations per run were often needed during model calibration. If each run takes several minutes, then a long of time is needed to complete the process. The calibration time is measured in hours, and sometimes in days. However, there is certainly a solution for this problem and the use of modules that shorten the computation time (Parallel PEST, BeoPEST, Cloud Computing and Singular Value Decomposition) is expanding.

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VERTICAL ACCURACY OF DATA ON THE TOPOGRAPHIC MAPS AND THEIR APPLICATION IN MINING[*****]

Abstract

The paper describes some experiences and the methodology used for evaluation the vertical accuracy of data on the official (state) topographic maps. The vertical accuracy is an important element of quality 3D representation on the topographic maps in digital, as well as in analoguos forms. A comparative way of testing is usually applied for determining the vertical accuracy, namely the comparison of the measured values of topographic maps with "true" or "conditionally true" values (numeric data of the geodetic and height points). This method gives a direct accuracy assessment of the printed maps and 3D terrain models, especially when used in industries such as mining. To a large extent, the vertical accuracy of data and geomorphology (geographic) fidelity relief on the topographic maps is not always sufficient quality. The type of survey and how the matter affects the quality, or the geodetic control points are drawn precisely, where the accuracy of the contour lines is lower. However, the application of a new technology is changes the 3D visualization of terrain, thus increasing the vertical accuracy of data.
Keywords: *topographic map, 3D data model, vertical accuracy, application, mining*

INTRODUCTION

Using geospatial information within the decision making process in the mining, armed forces, hydrology, especially after the appearance of floods and wide application in the state administration. At the same time, the importance of knowing its quality is also increasing; if decisions are based on a digital based technology. According to the ISO 19157:2013, the quality of geographical information is described in a quantitative way with five elements: completeness, logical consistency, positional accura-

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cy, temporal accuracy and thematic accuracy. The term positional accuracy means the compliance of a point position that belongs to some topographic model belongs to its true position in space. The positional accuracy may be a horizontal and a vertical accuracy, (Perdue, 2013).

This article focuses on the official topographic maps at a scale of 1:25 000 (TM25), topographic maps at a scale of 1:50 000 (TM50) and topographic maps at a scale of 1:100 000 (TM100), in the classic (older) and digital (newer) forms. One of the main goals in this article is to determine the vertical accuracy of geodata and for that a comparative method of testing is usually applied, with the comparison of measured values of height displaying a field with the "real" or "conditional exact" values. This article also focuses on digital terrain modeling and 3D data models. These models were created with the conversion from an analog form of topographic maps to a digital, while considering various aspects of digitization the cartographic sources.

INTERNATIONAL STANDARDS FOR VERTICAL ACCURACY EVALUATION

The international standards define the basic principles and procedures for vertical accuracy assessments and evaluations. There are no particular measures of accuracy, or statistics of calculations and quality reports such as the standard deviation or mean-square error. It is a matter of the ISO standards user that defines those things as they wish according to their objectives and positional accuracy reports. The same goes for the "industrial" or "de facto" standards at the international level. Just at a national level, there are standards, which, in detail, deal with this matter, although there are only few such countries, (Iliffe, et al., 2013).

Two of America's national standards have a strong influence on the standardization in this area: the United States National Map Accuracy Standards (NMAS) from 1947., and the National Standard for Spatial Data Accuracy (NSSDA) from 1998. The first one is related to assessments of mainly analogous maps (sometimes of digital maps too) and is not quite appropriate for using in conditions nowadays, while the second one is modern and usable nowadays; it is related to all digital spatial data (in a raster as well as in a vector form). To those standards one has to attach the very detailed and overall excellent elaborated standard STANAG 2215 - Evaluation of Land Maps, Aeronautical Charts and Digital Topographic Data and maps, (Radojčić, et al., 2011).

The positional accuracy of data sets with 3D coordinates is determined by combining the results of horizontal accuracy assessments (accuracy related to the horizontal geodetic datum, i.e. 2D coordinates) and vertical accuracy assessments (accuracy related to the vertical geodetic datum, i.e. 1D coordinates), (Aguilar, et al., 2010). The NSSDA uses the root-mean-square error (RMSE) to estimate the positional accuracy. The RMSE is the square root of the average of the set of squared differences between the dataset coordinate values and the reference coordinate values for identical points. The positional accuracy values are reported in ground distances (metric units or feet). This allows users to directly compare datasets of differing scales or resolutions. The accuracy is reported with a 95% certainty level. For example, the vertical accuracy lets:

$$RMSE_h = \sqrt{\frac{1}{n}\sum_{1}^{n} dh^2} \qquad (1)$$

where *dh* are the differences between the measured and reference vertical coordinates of points (control heights).

Furthermore, the standard (ISO, 2013) defines the absolute and relative (point-to-point) accuracy. Under the absolute accuracy standard it can assume the uncertainty in the 3D position of a point with respect to the WGS84 reference system, combined with EGM96 geoid model (Radojčić, et al., 2011). The absolute vertical accuracy is uncertain in terms of the height of a point with respect to the vertical datum. It is expressed as a linear error with a 90% certainty level. The relative vertical accuracy is uncertain in terms of the height difference between two points; it is expressed as a circle of error, i.e. a linear error with a 90% certainty level.

In the vertical accuracy evaluation procedure, the first step is to calculate the height differences between the measured and reference height δH_i, the next step is to calculate the differences from the mean value of all differences $\overline{\delta H}$ and to calculate the linear standard deviation, (Radojčić, et al., 2011):

$$\sigma_L = \sqrt{\frac{\sum\left(\delta H_i - \delta\overline{H}\right)^2}{n-1}} \qquad (2)$$

Next, the tests for blunders and systematic errors are performed. Finally, one has to evaluate the linear error with a 90% certainty level, in the English language it is traditionally noted as LMAS (Linear Map Accuracy Standard). If is not significantly differing from the zero value, LMAS is calculated as:

$$LMAS = 1{,}645 \cdot \sigma_m, \qquad (3)$$

All topographic-cartographic products are divided in five classes (Table 1) by the value of the LMAS, (Radojčić, et al., 2011).

Table 1 *The topographic-cartographic products classification by vertical accuracy*

Class	**Resolution or the map scale**				
	1:25 000	**1:50 000**	**1:100 000**	**1:200 000**	**1:250 000**
0	2.5 m	5 m	10 m	20 m	25 m
1	5 m	10 m	20 m	40 m	50 m
2	10 m	20 m	40 m	80 m	100 m
3	*Poorer than class 2*				
4	*Not determined*				

For the vertical accuracy evaluation, the STANAG 2215 demands at least 167 check points per data set, just like for the horizontal accuracy evaluation. However, in this case, the samples have to be representative not only in a planar sense, but in a vertical sense too. This means that, within the data set, there have to be check points with different heights, especially points with extreme heights.

SERBIAN EXPERIENCES IN ANALYSIS FOR VERTICAL ACCURACY OF DATA

The Military Geographical Institute (MGI) created a system of topographic maps whose main content is based on photogrammetric land survey and the periodic cycles of revision and amendments after that time period. On this basis, the MGI obtained geographical maps at the different scales and contents. They were created using the system of derived maps and were represented in the conformal (*Gauss-Kruger*) map projection, with the Greenwich meridian as the default. The same or similar cartographic-editorial decisions are applied. In other words, all maps are created in a single geodetic and cartographic system, which considerably facilitates their application.

In this article, the data quality of the relief on the topographic maps includes both the vertical accuracy and the geographic fidelity (data quality). For the analysis of the quality of the data, topographic maps at the scales TM25, TM50 and TM100 have been considered. Using 3D geospatial information within the decision making process in the mining (Figure 1) and wide application in the state administration.

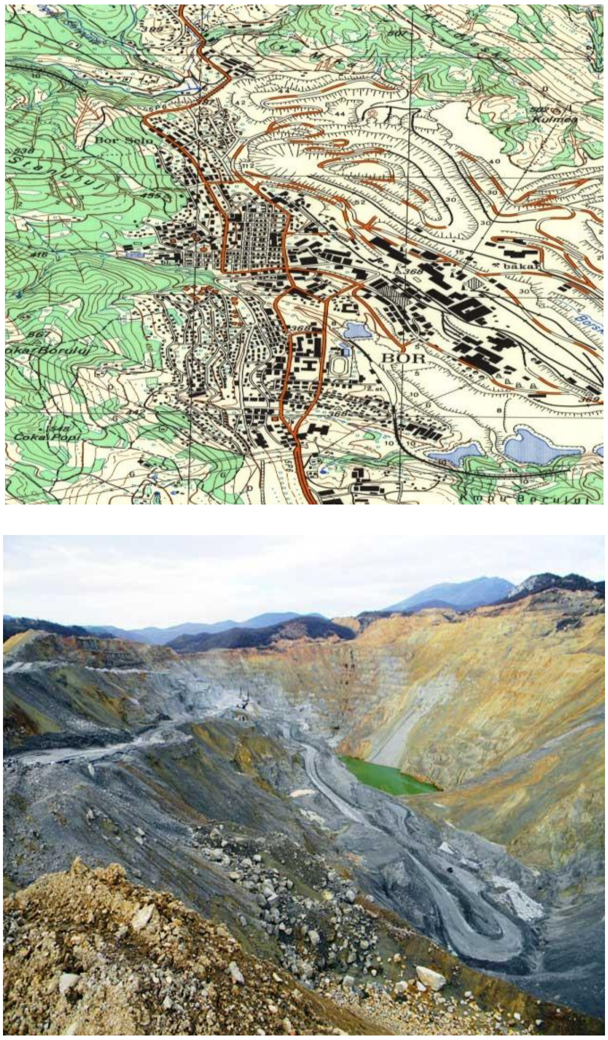

Figure 1 *Mining Basin Bor - Veliki Krivelj (URL 1)*
(http://rtb.rs/rtb-bor-doo/rudnik-bakra-bor/rudnik-bakra-veliki-krivelj/)

THE TRADITIONAL TOPOGRAPHIC MAPS

The vertical accuracy of topographic maps depends on the precision of representation the relief and scale, (Frančula, 2003), i.e. the accuracy of contour lines as the main way of the relief representation and the accuracy of numerically marked elevation points (levels). The mean square errors of positions the contour lines, which determine the vertical accuracy, are commonly used as an elevation indicator of the accuracy of topographic maps, as well as the mean square errors of the heights of points in relation to the nearest geodetic control points (Table 2).

Table 2 *The comparison of vertical accuracy of TM25, TM50 and TM100*

The vertical accuracy Criterion	**The mean square error (m)**		
	TM25	**TM50**	**TM100**
The vertical accuracy of detailed points	$\sigma_h = \pm 2.1$	$\sigma_h = \pm 2.7$	$\sigma_h = \pm 3.3$
The vertical accuracy of detailed points by Koppe	$\sigma_h = \pm (1.4 + 4.1 \text{ tg } \alpha)$	$\sigma_h = \pm (1.3 + 14 \text{ tg } \alpha)$	$\sigma_h = \pm (1.1 + 31 \text{ tg } \alpha)$

Formulas and many expressions used as indicators of the relief quality represented by contour lines do not give a precisely and easily understandable picture of deviation thecontour lines and their actual position. The accuracy of the elevation points of the contour lines is determined by many complex procedures. One of the commonly used equations is defined by Koppe:

$$\sigma_h = \pm(A + B\, tg\alpha) \qquad (4)$$

where α is the slope of terrain, and A and B are coefficients which are determined depending on the scale and type of the cartographic material (paper map or reproduction original).

The geomorphology (geographic) fidelity of maps includes the relief content and time determinations, namely data fidelity of topographic content. It is impossible to find a mathematical expression for geographic fidelity. Only the number of errors in relation to the total number of data can be de termined, such as names or signs in a single sheet of a topographic map. Obsolete, outdated, and thus, defective or incorrect content decreases the quality and usefulness of a topographic map, since they do not show exact reality as it is, but the condition as it was. The geomorphological fidelity relief on the topographic maps depends on the scale of mapping and the time covered by the data height on the map; it also depends on the overall quality of the map. From the point of visualization and data density on a topographic map, an important factor is the factor of loaded content that is directly related to the other two factors: the geographic fidelity and the accuracy of vertical display. Criteria displayed and the density of data on topographic maps is:

- Evaluating and comparing the structure of content: geodetic points, peaks, contour lines, course lines, ridge lines (Figure 2); and
- The analysis of the density and degree of generalization elements of map.

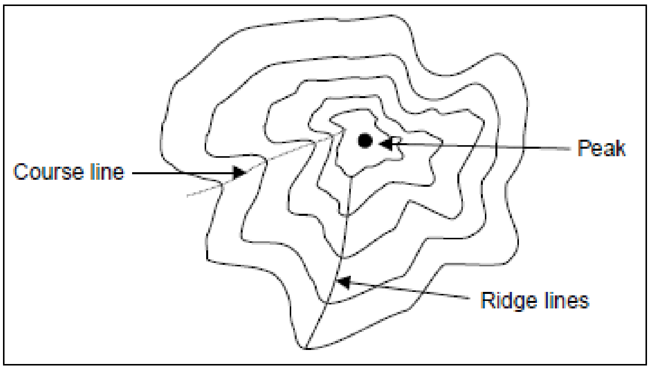

Figure 2 *Display the relief on maps by lines and check points (Li, Z., Zhu, Q., Gold, C., 2005.)*

Geodetic control points have particular relevance to the topographic maps at larger scale. That is the reason that the structure of geodetic control points selected had to be identical to TM25, TM50 and TM100.

A comparative review of the structure of the geodetic control points at these maps and the scope of mapped content of geodetic base analyzed a sample of 16 sheets TM25 covering geographical territory of Serbia (Table 3).

Table 3 *Data on geodetic points*

• Geodetic points		The map scale		
		TM25	**TM50**	**TM100**
1	Trigonometric point	●	●	●
2	Spot elevation with values in (m)	●	●	○
3	Religious building as geodetic point (church, mosque, synagogue, monastery)	●	●	●
4	Infrastructure facility such geodetic point (factory chimney, telecommunication tower, weather station)	●	●	●
5	Border post as a trigonometric point	●	●	○
6	Monument as a trigonometric point	●	●	●
7	Saddle as spot elevation	●	●	●

● *displayed on TM*
○ *not shown on TM*

Comparing the number of mapped points of geodetic base (trigonometry and elevation points) on the sheets TM25, TM50 and TM 100, produced the data shown in Table 4.

Table 4 *Comparison of the number of mapped points of geodetic basis on the TM*

The map scale	Area in %	Ratio of trigonometric points in %	Ratio of spots elevation in %
TK25	100	100	100
TK50	25	49	30
TK100	6	26	15

Here, the average values are given, but it is important to note that different approach were applied to the generalization of trigonometry and elevation points from sheet to sheet of the maps. The range values of the generalization of trigonometry is from 100% to 26%, while the range of the generalization of the elevation spots is from 100% to 15%; that means that there were a lot of subjective approaches to the cartographic generalization.

A higher degree of generalization of the elevation was caused by generalization of the others, especially line elements of map. But even so, it should be noted that the number of mapped trigonometry and elevations decreases much slower than the surface on the topographic map showing the designated area.

The main difference in the relief representation on the TM50, compared to the TM25 and TM100, is in the primary equidistance. On the TM50 it is twice higher, being it is 20m. Keeping this in mind, it can be concluded that the TM25 can display details of the relief that are higher or lower than 2.5m, while on the TM50, details can display the relief higher or lower than 5m, using the intermediate contour lines. Even so, they show characteristic landforms, which are not present in the intermediate contours at 1/4 of equidistance (curl, vale, sinkholes).

The amount of details in the relief that can be displayed on the TM50 and TM100 is increased. As the TM50 equidistance is 20 m, in the most favorable case (flat terrain) on the basis of experience, the height can be read with an accuracy of up to 1/10 of equidistance. Data on the relief and land forms of the TM25, TM50 and TM100 are given in Table 5.

Table 5 *Data of relief and relief forms on TM*

Relief		Map scale		
		TK25	TK50	TK100
1	Basic contour line - index 10, 20 and 20 (40) m	● (10)	● (20)	● (20)
2	Main contour line - index 50, 100 and 200 m	● (50)	● (100)	● (200)
3	Intermediate line at 1/2 equidistance	●	●	●
4	Intermediate line at 1/4 equidistance	●	●	●
5	In the field, visible landforms (curl, vale that can display contour lines) - contour line third category	●	●	●
6	Sinkholes in scale or as a conditional sign	●	●	●
7	Lonely rock that cannot be provided in the ratio of map	●	●	○
8	Ravines and gorges of natural distance from the river bank	●	●	●
9	Dents and terraces of banks flows in flat terrain	●	●	●
10	Gully – gullies	●	●	●
11	Karst sink- holes	●	●	○
12	Dry moat	●	●	○
13	Abyss	●	●	●
14	Heaps of stone - a mound	●	●	○
15	Cave with water or without water	●	●	●

● displayed on TM
○ not shown on TM

When it comes to show the land forms, the nature of that element of content the topographic maps should be the least changeable, (Petrović, at al., 2016). However, in the relief area there is a variety of changes due to the human activities (reclamation, mining, etc.) and there are also the influence of natural forces (landslides, erosion, etc.). In addition, substantial changes are visible in a view of relief applying the specific methods of surveying and cartography (topographic and photogrammetric surveys, base height, generalization of field types, etc.). Also, the construction of open pits and tailings, power plants, and accumulation of lakes and a network of channels cause modifications of confluences and river flows.

DIGITAL TOPOGRAPHIC MAPS

The vertical accuracy of digital topographic maps depends on the process of analogous to digital conversion (Figure 3), and the methods of data georeferencing and processing (system of technical possibilities and human factor). Nevertheless, the general quality depends on the positional and height accuracy of the topographic content, and data updating.

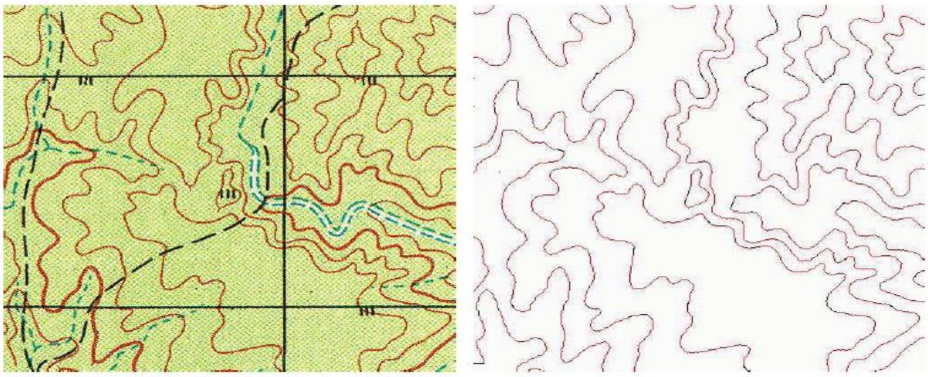

Figure 3 *The paper map is scanned and then the contour lines are extracted to some layers*

After vectorizing TM25, TM50 and TM100 (paper maps and reproduction originals) in a vector form, an additional activity was the control and modeling of data (Figure 4). That control was used to check the reference data (geodetic points) and implementation the modifications and updates, according to the available reference data sources.

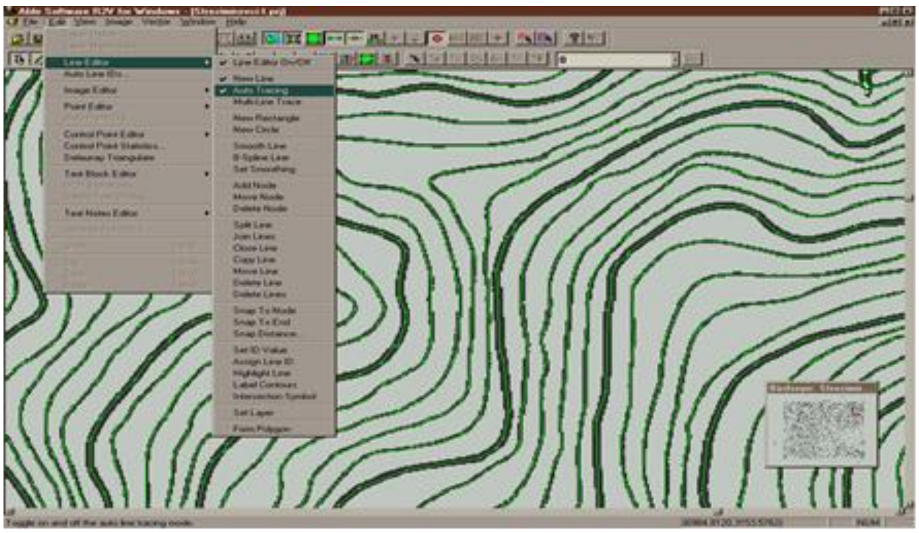

Figure 4 *The process of vectorization from raster to vector data*

The limiting factors are certainly the original data collection errors. The limits of the contour line errors are given in Table 6 with the positional mean square error in meters. The types of the terrain and slope are also given in the same Table.

Deformations can be up to 1.5 times higher in the covered field. In the mountainous regions, the number of contour lines is adjusted to the height difference between the top and foot of the mountain.

Table 6 *Limits of contour lines errors, types of terrain and the slope*

Flat terrain 0^0 - 2^0	**Hilly terrain** 2^0 - 6^0	**Mountainous terrain** > 6^0
± 3.9 m	± 5.1 m	> ± 5 m (*depends on the slope*)

When discussing the quality of data obtained by digitization the existing topographic maps, it should be kept in mind that all the data has already been processed. Specifically, this data was already reviewed, which includes the removal of irregular details on the digitalized content as a result of surface deformation and random errors.

On the other hand, the processing that has been already made using this data carries certain risks. Since this data has been already processed, it is practically impossible to remove all the errors, which were made during that modeling, from the data, because there is usually no information that could be used for reconstructing the original data. Errors, contained in the data obtained by the digitalization of the existing maps, contain both errors of the original data collection and processing (both surveying and mapping errors) and also transformation errors (scanning, georeferencing, vectorization, modeling and processing of data).

For digital models generated from the classic cartographic material, it is usually assumed that the elevation accuracy is from 1/4 to 1/5 of the equidistance of the represented contour lines (Frančula, 2003). Based on the experience and empirical values, achieved for the value of the graphical scribing, the accuracy is usually set to 0.2 mm. In Table 7, the empirical accuracies of the 3D data model created by digitization of cartographic material are presented.

Table 7 *The quality of 3D data model obtained by digitization the TM25, TM50 and TM100*

Scale	**Equidistance (m)**	**Vertical accuracy (m)**	**Graphic scribing accuracy (m)**
1: 25 000	10	2,1	5
1: 50 000	20	3,9	10
1:100 000	20	5,1	14

Despite that, the vertical system in digital cartography is usually represented in a grid form. In that case, it could be said that accuracy of the digital elevation representation depends directly on the sources and technologies used for measuring the geodata on the density of elevation points (i.e. grid size) and their geometric positions on the terrain slope (Li, et al., 2005).

DIGITAL TERRAIN MODEL

Specifically, the process of the DTM production consists of the analog - digital conversion (scanning and vectorization) of contour lines, adding heights to contour lines, transforming vector lines into clouds of points and generating the 3D data model.

From an interpretation and topological aspect, there are two basic forms which can represent the DTM - regular grid and TIN (Figure 5). The quality of the DTM is defined by the positional accuracy of indi vidual points that are directly measured. Their quantity, with respect to the quality of sample, represents the terrain surface.

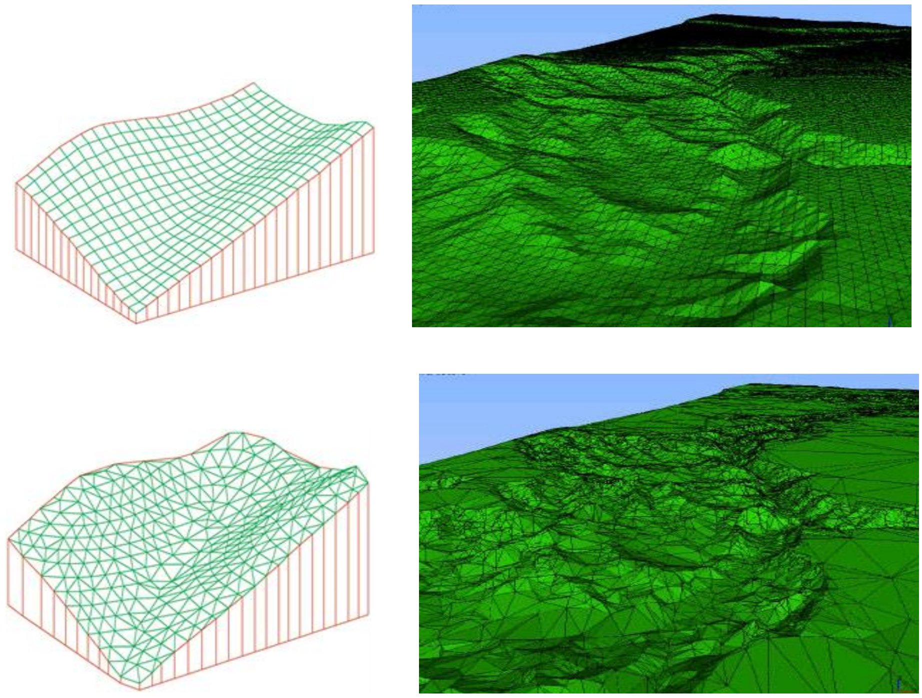

Figure 5 *Interpretation of 3D data model in Grid and TIN format*

The vertical accuracy of the digital terrain model (DTM), obtained by digiti-zation the contour lines and other features from topographic maps, includes all the sources of errors, both in the process of its conversion into a digital form, and in gene-rating the 3D data model by interpolation (Li, et al., 2005).

To control the quality of the obtained models (the previously explained method for both procedures), coordinates of the points from the catalog of state points of a trigonometric network, which are located in that area, were used. Thus, there were visual and exact methods for assessing the data quality of the 3D data model (Gorokhovich, Voustianiouk, 2006). For evaluating the accuracy, the equation for standard errors is used:

$$\sigma_H = \sqrt{\frac{\sum (z_i^* - z_i)^2}{n}} \; ; \qquad (5)$$

where:

z_i^* - checkpoint height obtained by interpolation;

z_i - provided control points height; and

n - number of control points.

The vertical accuracy of the DTM obtained is based on the digitalized contour lines from the topographic maps (reproduction originals) and is shown in Table 8. In this case, beside the grid and triangular irregular network (TIN), the grid model is created by two methods of interpolation and visualization of the elevation surface. One of them is the inverse distance weighed

(*IDW*), and the other method is a spline using software ArcGIS - 3D Analyst, (ESRI, 2010). They are also presented in different resolutions.

Table 8 *The quality of DTM obtained on a basis of digitized contour lines of originals TM*

TM25					**TM50**					**TM100**				
TIN	GRID				TIN	GRID				TIN	GRID			
	IDW		Spline			IDW		Spline			IDW		Spline	
	Resolution – step (m)					Resolution – step (m)					Resolution – step (m)			
	25	10	25	10		50	20	50	20		100	40	100	40
The mean square error (m)														
2.3	2.9	2.7	1.9	1.7	4.6	5.2	5.0	3.6	3.4	7.9	8.2	7.9	6.3	6.1

The precision of a grid model is determined by the cell dimensions. A high density grid with points of high accuracy produces an accurately approximated surface, (URL 2). But the TIN model is in the form of triangulated irregularly scattered points and depends on the degree of the surface slope and curvature. For an increased accuracy of surface approximation, the TIN model requires dense points and inclusion thecharacteristic break lines, (URL 2).

CONCLUSION

This paper presents some ways to obtain the vertical accuracy of data on the digital topographic maps and using a 3D data model obtained on the basis of digitized contour lines of originals topographic maps. Namely, height information is more and more important in the decision making process, monitoring and planning processes in state administration, engineering, mining and other areas of public life. Using digital technologies has significantly increased the geospatial information marketplace, and is still increasing it, both user and producer wise (URL 2).

The vertical accuracy of digital data is in accordance with the data derived from the classic topographic maps, having to meet requirements generally formulated by the national standards, (Gorokhovich, Voustianiouk, 2006). From the mathematical point of view, the reliable DTM must have the surface geometric continuity and possibility of differentiability and smoothness surface at any point. In practice, however, good DTM considers the model that illustrates the terrain topography confidentially and well.

The data quality on topographic maps primarily depends on the chosen scale and method of visualizing the elevation surface. Moreover, the vertical accuracy of content depends on the application methods of interpolation. The analysis of the three different scales (TM25, TM50, TM100) and interpolation methods, i.e. the method of inverse distance weighting and spline, over the same set of spatial data of the selected areas carry out important conclusions. In the interpretation of spatial data continuity and terrain topography, the best results were obtained by spline method and scale TM25. Similar representations are obtained in all scales by the spline method and method of inverse distance weight.

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AN ANALYSIS THE EFFECTS OF CHANGES IN PRICE OF METAL AND OPERATING COSTS TO THE PROFIT IN EXPLOITATION THE COPPER ORE DEPOSITS, A CASE STUDY: COPPER MINE MAJDANPEK, SERBIA***

Abstract

Mining is the process of extracting a naturally occurring material from the earth to derive a profit. Whether the company make a profit or not depends on many economic parameters, among which the most important are the metal prices on the world market and realized operating costs in the process of exploitation. This work presents the influence of copper price change and value of operating costs on the generated cash flows, i.e. profit, in the case of the open pit South Mining District, which operates within the Copper Mine Majdanpek, Serbia.

Keywords*: metal price, operating costs, profit, Copper Mine Majdanpek*

1 INTRODUCTION

The design and scheduling of the open pit mines is a significant and complex problem in mine planning. The principal aim of a mining operation is to ensure that an ore body is mined in a way such that the value realized from the mine is maximized.

Profitable exploitation of the mineral deposits requires a certain economic assessment and planning of exploitation. First, it must be determined which part of the deposit is economical for the mine (mineable reserve) and what methods of excavation can be applied under the given conditions. The next step is defining the final limit of the open pit and mining dynamics of the mineable ore reserves. Finally, a DCF analysis is performed. The aim of these efforts is to determine the most profitable excavation plan and the highest rate of return of invested funds. These activities are carried out in the field of long-term planning or strategic planning. Planning an open pit can be explained in a series of steps, each preceding the next, as shown in Figure 1.

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Figure 1 *Steps in planning an open pit*

Market scenarios are often explored, usually in terms of an upside and downside case for metal prices. Metal prices arguably have the largest impact on project valuation, and an impact on what the optimal operational plan will be.

Also, the operating costs have a significant role in achieving the maximum cash flows during the life of ore exploitation at the open pit.

2 PRICE-COST RELATIONSHIPS

The revenue to the mine every year depends upon the tons of concentrate produced and the price. The costs to the mine on the other hand depend upon the amount of material mined and processed [1].

If one assumes that *K* tons of concentrate are produced every year, then the yearly revenue depends directly on the price received for the product.

A large capital investment is required at the start of the mining. As will be discussed later this must be recovered from the yearly profits. If the yearly profits are not as expected, then the payments cannot be made. Therefore it is important that the price projections or price forecasts be made covering at least the depreciation period (that period in which the investment is being recovered). The operating cost can be reported by the different unit operations: drilling, blasting, loading, hauling and other. The "other category" could be broken down to include dozing, grading, road maintenance, dump maintenance, pumping, etc. Some mines include maintenance costs together with the operating costs. For analysis it is also necessary to define the direct and indirect costs incurred in concentrating, smelting, and refining metal.

There are certain costs which are regarded as the 'fixed', or independent of the production level. The other costs are 'variable', depending directly on production level. Still other costs are somewhere in between.

3 MARKET METAL PRICES

In order to reduce uncertainty about the correct assessment of the metal price on the market, three deterministic approaches are often applied:

- technical approach,
- fundamental approach, and
- combination of technical and fundamental approach.

From the listed deterministic approaches, in the previous practice, it has been shown that the best results are a combination of technical and fundamental approach.

Figure 2 gives a historical overview of the copper price trends for the period 1960 ÷ 2015 [2].

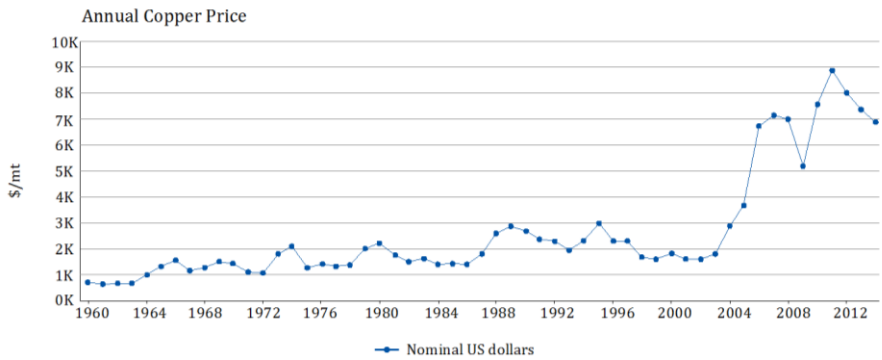

Figure 2 *Trends of copper price for the period 1960 ÷ 2015 [2]*

A long term forecast of copper price trends for the period 2013 ÷ 2025 is presented in Figure 3 [2].

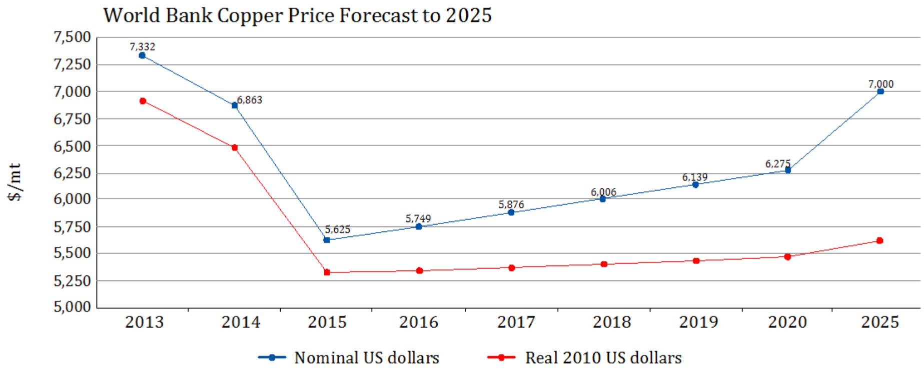

Figure 3 *A long term forecast of copper price trends for the period 2013 ÷ 2025 [2]*

4 OPERATING COST MEASURES

Reduction of the unit operating costs is one of the most important goals of the company. It leads to an increase in the net cash flow and profitability, and helps to ensure a sustainability of operations even at the low metal prices. However, there are two ways of looking at it [3].

1) The first way is to try to reduce the unit costs for input and reduce the consumption. This is the basic goal of productivity that should be implemented in the exploitation process. In the process of planning the long-term

development of the mine, there are limited ways to reduce costs such as:

- *Reduction of the unit input costs,* which is applicable while the reduction of costs is not followed by a decrease in quality and hence an increase in total costs.
- *Reduction of the consumption rate,* as long as consumption is not already reduced to an effective rate of consumption that can not be improved. Any further attempt to reduce, for example, by limited supply, can only result in reduction the related activities, which will be a counter productive.

So, there are good and bad ways to reduce costs.

2) Another way of looking at minimizing the unit costs is based on the results of the optimization strategy, what is the goal of the feasibility study. In the same way, the NPV can be found for several strategies and choose the one that brings the maximum NPV; the unit costs can be also found for different strategies and choose the ones that generate the minimum unit cost. As a result, the basic productivity and cost-change factor are the same in each case, and certain differences are taken into account in the analysis. Variations in the unit costs are then the result of interaction between the physical activities and costs incurred in different plans, and are not the result of measures to reduce the costs.

5 ULTIMATE PIT AND PUSHBACK SELECTION

Optimization of the open pit implies the obtaining of possible contour of the open pit, based on a block model of deposit that has an economic value, and which can be calculated. The concept of a possible contour of the open pit means the open pit contour with the maximum slope of the general slope, formed after drawing the transport routes and safety berm, and which meets the stability criteria.

A well-known early contribution to this field was made by Lerchs and Grossmann [4], who presented a graph-theoretic algorithm for determining the final contour of the open pit, known as the ***ultimate pit,*** such that the total profit from the mine is maximized.

Figure 4 shows the NPV - tonnage graph on the basis of which the Whittle process finds an optimal excavation limit and ***pushbacks.*** The graph shows the achieved NPV, as well as the quantities of ore and tailings for each nesting pit.

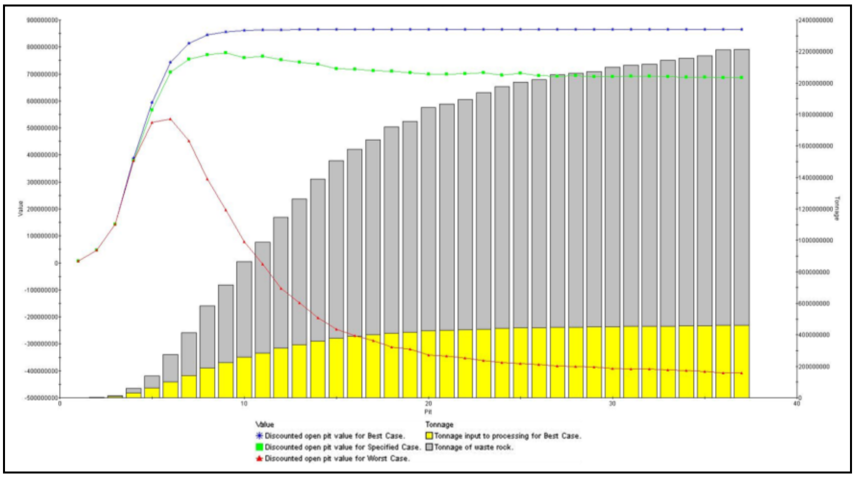

Figure 4 *A typical NPV tonnage graph by the Whittle method*

A cash flow curve relative to the tonnage tends to be at the top. Behind the point of maximum, it is not economical to excavate, but excavation of this part of the deposit can be considered in case of improving the economic conditions (increase of metal prices, or reduction of costs) or improvement of technological conditions.

The choice of one of the open pit shells as the open pit ultimate limit is made by the planning engineers and management, and the choice is made in accordance with the company goals. An inexperienced choice may be considered to be the best contour of the best case curve. The experienced engineers usually choose the best open pit on the basis of the average net value obtained on the basis of a curve of the best and worst case. Some users modify this technique and choose the open pits that by the value fall to 60 to 70 percent of difference between the curves of the best and worst case [5], [6].

6 SCHEDULE OPTIMIZATION

Scheduling is the process of determining the timing of activities. With the widespread use of a discounted cash flow as a value measure, the ability to optimize value through strategically focused scheduling is very important. Cash received earlier in the project is worth more, in present value terms, than the same amount of cash received later in the project. This encourages the mine planner to bring forward the positive cash flows and defer negative cash flows. The common methodology is to access ore as early as possible whilst mining as little waste is necessary.

The removal of material is contingent upon the removal of a cone of material situated above it, the size and shape of which is dictated by the requirement of safe wall slopes for the pit. This is modeled in the precedence constraints for the mine. An additional class of constraints are the production constraints, imposed by the availability of extraction and processing capacity in each year. Techniques applied to solve the mine production scheduling problem include heuristics [7], parametric methods [8], dynamic programming [9], [10], [11] and integer linear programming [12], [13], [14]. The major limitation with these approaches is that they encounter significant computational difficulties when trying to solve problems of realistic size.

7 CASE STUDY

The Copper Mine Majdanpek, in the production, technical and technological sense, represents a complex mining system that has activities from geological explorations of mineral resources, ore exploitation and processing to a number of supporting activities as the necessary support to the core activities.

Production and processing of ore in the Copper Mine Majdanpek is currently developed at the open pit South Mining District and is of great importance for copper production in the system of company Mining Smelter Basin Bor Group (RTB Bor Group) [15].

The economic results of the mine operations, and therefore the company itself, depend primarily on the metal price on the stock exchange and costs arising in the production process.

Based on the defined economic variables, the analysis was conducted for five scenarios:

1) Scenario 1 – an analysis of cash flow change for the forecasted copper price on the market and projected operating costs.
2) Scenario 2 - an analysis of cash flow change for the copper price increase by 5%, whereby the operating costs do not change.
3) Scenario 3 - an analysis of cash flow change for the copper price increase by 5%, whereby the copper price does not change.

4) Scenario 4 – an analysis of cash flow change for the copper price and operating costs increase by 5%.
5) Scenario 5 - an analysis of cash flow change for the copper price and operating costs reduction by 5%.

The Mineable reserve of the copper deposit South Mining District Majdanpek are calculated on the basis of a block model of deposit, formed in the software Gems [15]. View of a block model of the Cu deposit South Mining District is shown in Figure 5.

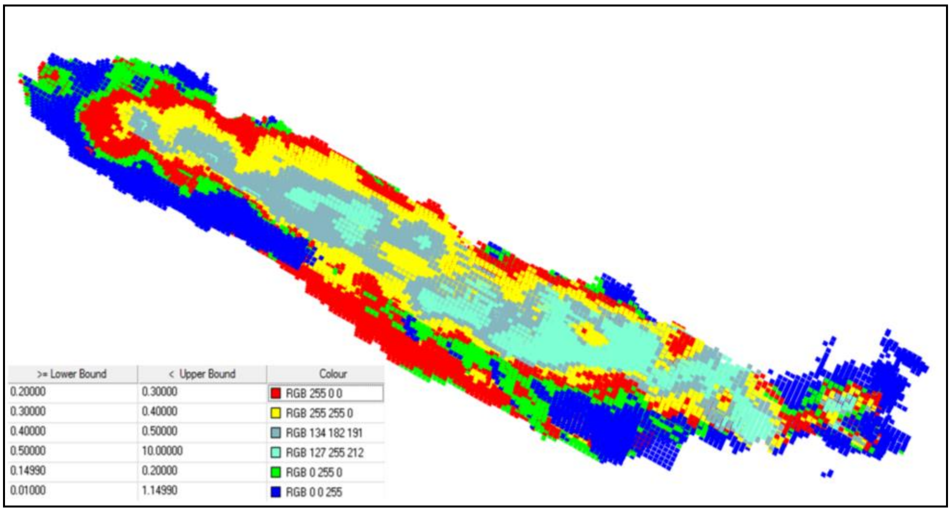

Figure 5 *View of 3D block model of the deposit South Mining District Majdanpek [15]*

The optimization process was carried out in the software Whittle using a modified Lerchs-Grossmann (LG) algorithm, based on which the ultimate pits and pushbacks were selected. The optimization of excavation dynamics and DCF analysis were carried out in the same software, based on which the cash flows for defined scenarios were generated.

The analysis does not include the capital costs and capital replacement costs.

8 RESULTS AND DISCUSSION

The obtained results of conducted analysis are shown on graphs in Figures 6 and 7.

Based on the obtained results, shown in the graphs, the following can be concluded:

1) The best economic results are achieved in the case of Scenarios 2, that is, increase of the copper market price. Compared to Scenario 1, where the analysis was carried out for the projected economic para-meters, significantly better Cash Flow is achieved, which generates an increase of NPV by 12.8%.
2) In the case of Scenario 3, the lowest profit is realized, that is, increase of the operating costs leads to a reduction of NPV by 10.7%.
3) In the case of an increase in both copper and operating costs, Scenario 4, the company operation is slightly improved, expressed through an increase of NPV by 2.1%.
4) Reduction the price of copper and operating costs, Scenario 5, leads to a fall in the company economic benefits, i.e. a decrease of NPV by 2.1%.

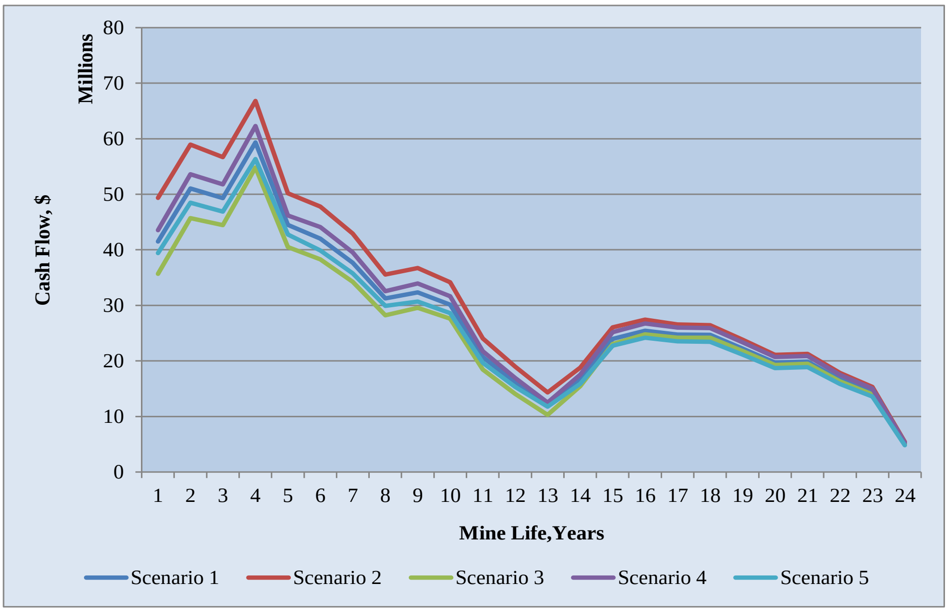

Figure 6 *Cash Flow Graph for different Scenarios*

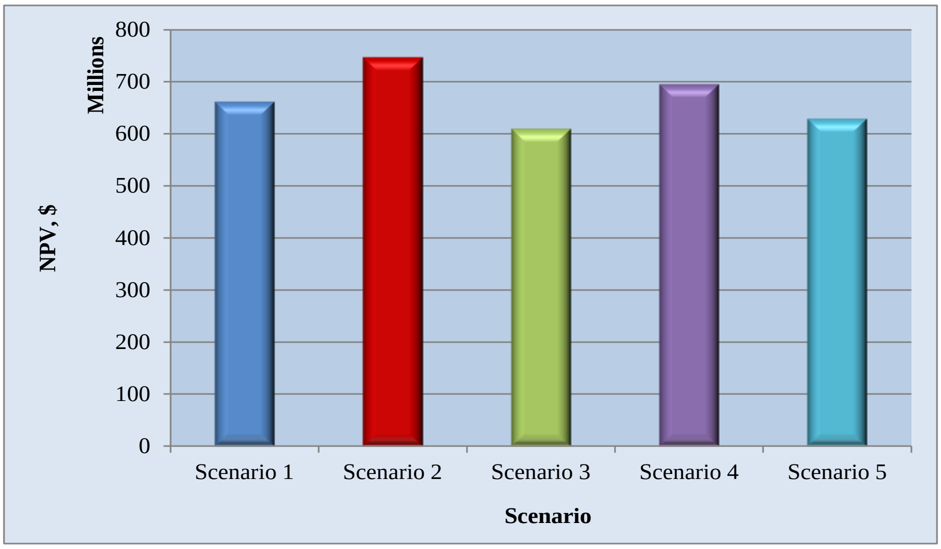

Figure 7 *NPV Graph for different Scenarios*

CONCLUSION

The conclusion is that the profit depends upon the relative changes of the price and costs.

Therefore, the mining companies apply different strategies for sustainable business in the market in terms of changing the metal prices on the stock market, thereby paying a special attention to the management of operating costs arising in the process of mining and processing of mineral raw materials.

The conducted analysis is important looking from the real aspect the impact of metal prices and operating costs, as economic variables, not only to the economics of mine, but also the entire company RTB Bor Group. On the example of the open pit South Mining District Majdanpek, the conducted analysis showed how sensitive the NPV is to a change in copper prices on the market, or projected mining operating costs.

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OPTIMAL NUMBER OF REVOLUTION THE ECCENTRIC SHAFT OF A JAW CRUSHER WITH A SIMPLE MOTION OF THE MOVING JAW

Abstract

The paper analyzes forces acting on a piece of raw material in a jaw crusher with a simple motion of the moving jaw, and based on this defines the formula to define the optimal number of revolutions the eccentric shaft. Under the optimum number of revolution the eccentric shaft, the number of revolutions is assumed to ensure that the crusher achieves the maximum crushing capacity.

***Keywords**: jaw crusher, capacity, optimum speed, shaft*

INTRODUCTION

The most important technological feature of the jaw crushers is its capacity. The capacity depends on the number of revolutions of the eccentric shaft with a simple motion of the moving jaw. The crusher achieves the maximum capacity at the optimum speed of the eccentric shaft. The optimum speed of the eccentric shaft is the number of revolutions that ensures that the time of a half-revolution of the eccentric shaft t_2 is equal to the time t_1 required during the idling of the moving jaw, the crushed pieces fall the level BB1 through the working space for height h to the level of discharge AA1(Fig.1).

In the theoretical considerations and derivation the formula for the optimal number of revolutions of the eccentric shaft, two different approaches are present in the literature. The first approach (Andreev, 1966) [1], based on the assumption that discharge of the crushed product from the workspace of the crusher, is carried out during an empty stroke and that the half-time of the eccentric shaft rotation must be equal to the free fall time of the crushed pieces from the level BB1 to the level AA1 of discharge opening (Fig.1). Starting from this assumption, the optimal number of rotations of the eccentric shaft is defined by the formula [1]:

$$n_o = 30 \cdot \sqrt{\frac{g \cdot tg\alpha}{2 \cdot e}} \text{ (Rpm)} \quad (1)$$

n_o - optimum speed of the eccentric shaft, (Rpm)

g - acceleration due to gravity, (m/s^2)

α - crusher working angle, (°)

e - movement of the moving jaw at the level of discharge opening, (m)

In carrying out the formula (1), the resistant force between the crusher jaws, when leaving the workspace of the crusher, were not taken into account. Therefore, in practice, the reduction in the number of turns, which is obtained according to the formula (1), is recommended for 5-10%.

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Another approach (Magdalinović N, 1980/81)[2] is based on the assumption that the crushed products does not fall freely from the level of BB1 to the level at the discharge opening AA1, but during the discharge, the crushed product slides along the steep level B1A1 on the mobile jaw (Fig.1). According to this assumption, the optimal number of rotations of the eccentric shaft is defined by the formula [2]:

$$n_o = 30 \cdot \sqrt{\frac{g\cdot(cos\alpha - f\cdot sin\alpha)\cdot sin\alpha}{2\cdot e}} \text{ (Rpm)} \quad (2)$$

The first assumption (Andreev, 1966) at least reflects the reality of discharge the crushed products, since the pieces of crushed raw material do not fall freely through the workspace of the crusher

The second assumption (Magdalinović N, 1980/81) is closer to the reality, but ignores the fact that when sliding the crushed products on the surface of the moving jaw, exist the friction force between the pieces and a fixed jaw T_2 (Fig.2).

The aim of this paper is to include, in addition to the force of friction along the surface of the mobile jaw, the friction force between the pieces and surface of the fixed jaw, in the analysis of discharge the crushing product from the workspace of the crusher.

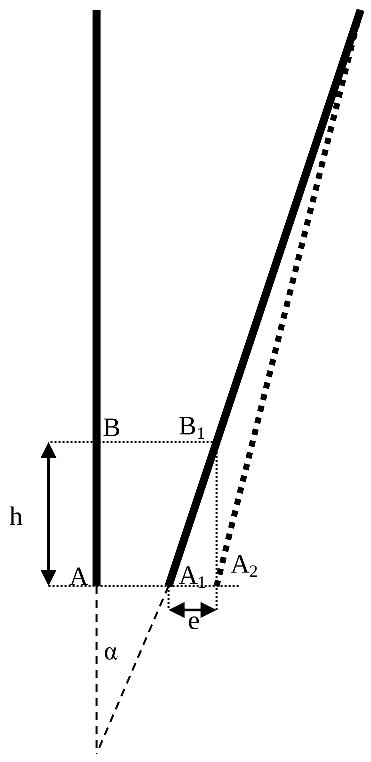

Fig. 1 *Cross section of the workspace of the jaw crusher*

Theoretical analysis

In discharging the crushing product, the catch angle α is slightly increased, and this will be ignored in the analysis.

Sliding the pieces on a surface of the moving jaw plate (Fig. 2) opposes the friction force T1:

$$T_1 = f \cdot N_1 \quad (3)$$

f - coefficient of friction the pieces on the surface of the movable and fixed jaw plate

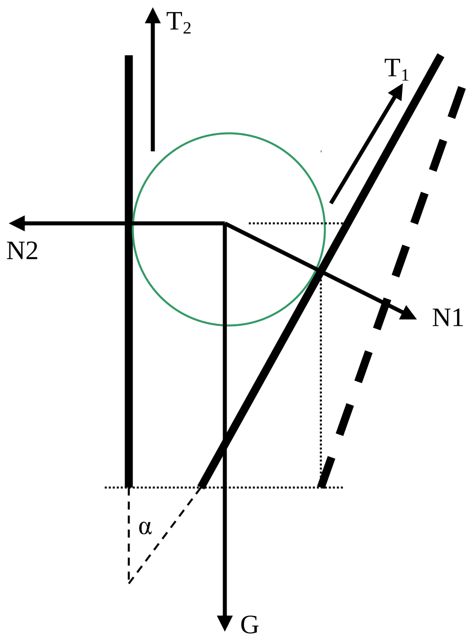

Fig. 2 *Force acting on a piece when discharge from the workspace of crusher*

When the crushing product discharge through the working area of the crusher, the friction force of the piece on the surface of the fixed jaw T2 (Fig.2) also exists:

$$T_2 = f \cdot N_2 \quad (4)$$

For discharging the pieces from the workspace of the crusher, the resultant R of all the forces acting on the piece in a vertical direction is a valid one:

$$R = m \cdot a = G - T_1 \cdot cos\alpha - T_2 \quad (5)$$

From the conditions of equilibrium, the force follows:

$$\Sigma X_i = 0 \implies -N_2 + T_1 \cdot sin\alpha + +N_1 cos\alpha = 0 \quad (6)$$

$$\Sigma Y_i = 0 \implies T_2 + T_1 \cdot cos\alpha - -N_1 \cdot sin\alpha - m \cdot g = 0 \quad (7)$$

Where, after solving the equations (6) and (7), the following values are obtained:

$$N_1 = \frac{m \cdot g}{f \cdot (cos\alpha - f \cdot sin\alpha) + f \cdot cos\alpha + sin\alpha} \quad (8)$$

$$N_2 = \frac{m \cdot g \cdot (cos\alpha - f \cdot sin\alpha)}{f \cdot (cos\alpha - f \cdot sin\alpha) + f \cdot cos\alpha + sin\alpha} \quad (9)$$

After replacing (8) and (9) in the equation (10), the expression is obtained:

$$m \cdot a = m \cdot g - f \cdot N_1 \cdot \cos\alpha - fN_2 \quad (10)$$

Where a is the acceleration of pieces when discharge through the working space of the crusher

Acceleration a can be expressed by the first derivative of the velocity v by time t, and the equation (10) takes the form:

$$\frac{dv}{dt} = g \cdot (1 - \frac{f \cdot (2 - f \cdot tg\alpha)}{f \cdot (2 - f \cdot tg\alpha) + tg\alpha}) \quad (11)$$

respectively:

$$dv = g \cdot (1 - \frac{f \cdot (2 - f \cdot tg\alpha)}{f \cdot (2 - f \cdot tg\alpha) + tg\alpha}) \cdot dt \quad (12)$$

Integrating the equation (12) gives the expression for the velocity v of falling the crushing product through the workspace of the crusher:

$$v = g \cdot (1 - \frac{f \cdot (2 - f \cdot tg\alpha)}{f \cdot (2 - f \cdot tg\alpha) + tg\alpha}) \cdot t + C \quad (13)$$

For the initial conditions t=to=0, v=vo=0, and from the equation (13), it follows that the integration constant C=0, and the final expression for the velocity rate of the crushed product through the workspace of the jaw crusher is:

$$v = g \cdot (1 - \frac{f \cdot (2 - f \cdot tg\alpha)}{f \cdot (2 - f \cdot tg\alpha) + tg\alpha}) \cdot t, \text{ (m/s)} \quad (14)$$

The velocity of the piece v can be expressed by the first derivative of the traveled path (the height h - Fig.1) by the time t, and the equation (14) gets the form:

$$\frac{dh}{dt} = g \cdot (1 - \frac{f \cdot (2 - f \cdot tg\alpha)}{f \cdot (2 - f \cdot tg\alpha) + tg\alpha}) \cdot t \quad (15)$$

respectively:

$$dh = g \cdot (1 - \frac{f \cdot (2 - f \cdot tg\alpha)}{f \cdot (2 - f \cdot tg\alpha) + tg\alpha}) \cdot t \cdot dt \quad (16)$$

Integrating the equation (16), the expression for the transmitted height h is obtained by discharging the fragmentation product from the level BB1 to the level AA1, which is read as follows:

$$h = \frac{g \cdot t^2}{2} \cdot (1 - \frac{f \cdot (2 - f \cdot tg\alpha)}{f \cdot (2 - f \cdot tg\alpha) + tg\alpha}) + C \quad (17)$$

For the initial conditions t = to = 0, h = ho = 0, and from the equation (17), it follows that the integral constant C = 0, and the final expression for the transmitted height of decay the crushing product through the workspace of the crusher is read as follows:

$$h = \frac{g \cdot t^2}{2} \cdot (1 - \frac{f \cdot (2 - f \cdot tg\alpha)}{f \cdot (2 - f \cdot tg\alpha) + tg\alpha}) \quad (18)$$

From the equation (18), the necessary discharge time t1 is followed, which ensures that the crushed product that is below the level of BB1 comes out of the workspace during the empty stroke.

$$t_1 = \sqrt{[\frac{2 \cdot h}{g \cdot (1 - \frac{f \cdot (2 - f \cdot tg\alpha)}{f \cdot (2 - f \cdot tg\alpha) + tg\alpha})}]} \quad (19)$$

From the right triangle A1A2B1 (Fig. 1), it follows that:

$$h = e / \operatorname{tg}\alpha \quad (20)$$

Changing the expression for h from the equation (20) to the equation (19), it is obtained:

$$t_1 = \sqrt{\{\frac{2 \cdot e}{[g \cdot \operatorname{tg}\alpha \cdot (1 - \frac{f \cdot (2 - f \cdot tg\alpha)}{f \cdot (2 - f \cdot tg\alpha) + tg\alpha})]}\}} \quad (21)$$

The time t_2 of the empty stroke of the crusher, that is, the discharge time of fragmentation product is equal to the half-time of revolution of the crusher eccentric shaft:

$$t_2 = 60/(2 \cdot n) \quad (22)$$

where: n is the number of revolutions, (Rpm)

Optimal speed of the eccentric shaft follows from the equality of time:

$$t_2 = t_1 \quad (23)$$

respectively:

$$\frac{30}{n_0} = \sqrt{\frac{2 \cdot e}{g \cdot tg\alpha \cdot (1 - \frac{f \cdot (2 - f \cdot tg\alpha)}{f \cdot (2 - f \cdot tg\alpha) + tg\alpha}}} \quad (24)$$

From where it follows that:

$$n_0 = 30 \cdot \sqrt{\frac{g \cdot tg\alpha}{2 \cdot e} \cdot [1 - \frac{f \cdot (2 - f \cdot tg\alpha)}{f \cdot (2 - f \cdot tg\alpha) + tg\alpha}]} \quad (25)$$

n_0- optimum speed of eccentric shaft, (Rpm)

g - acceleration due to the gravity, (m/s^2)

α - crusher working angle, (°)

e - movement of the moving jaw at the level of the discharge opening (m)

For the conventional gripping angle of the abrasive crushers, α = 22^0, and the friction coefficient, f = 0.3 (Fig. 3), a comparative graphic representation the change in the number of shaft rotations, in the function of the moving jaw at the level of the discharge opening, is given, according to the equations (1), (2), (25), and the crusher manufacturer Metso. Fig. 3 shows that the catalog values for the number of turns of the eccentric shaft, depending on the movement of the moving jaw, are found between the curves described by the equations (2) and (25).

It should be noticed that the values for throwing the moving jaw are calculated by the equation (26)[3], and based on catalog data [4], related to the number of revolutions and the size of discharge with:

$$e = 7 + 0.1 \cdot b_1 \text{ (mm)} \quad (26)$$

b_1 - minimum width of a discharge opening of the jaw, (mm)

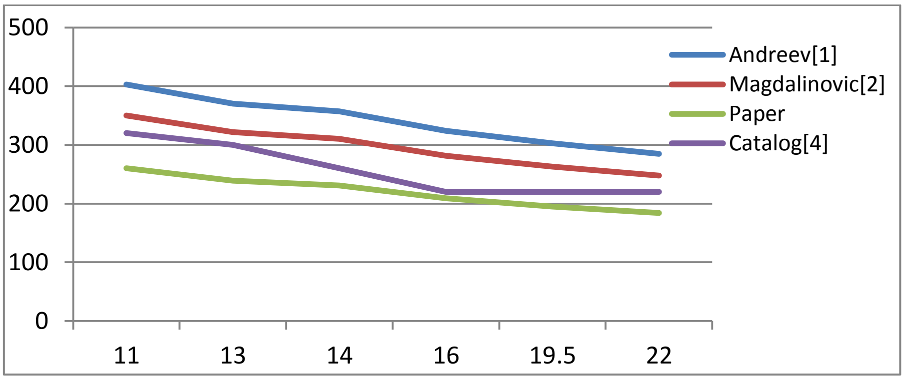

Fig. 3 *Graphic view the number of revolutions (Rpm) depending on t hrowing the moving jaw (mm)*

CONCLUSION

Having in mind the geometry of the workspace of the jaw crushers with the free movement of the moving jaw, and the obviously resistance the frictional force to the moving and fixed jaw when the crushing product is discharged, the optimum speed of the crusher eccentric shaft can be determined according to the formula (25), defined in this paper.

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Gordana Rendulić, Marija Mirić***

THE ROLE OF LEADERS IN MOTIVATION OF EMPLOYEES IN THE MINING COMPANIES

Abstract

The new millennium brings a new paradigm of business that takes place in completely different conditions and is based primarily on knowledge, creativity and post-modern leadership. Radical changes, in which today's economy and its entities exist and develop, require the new ways of leadership. Hence, the new paradigm articulates and gives a critical dimension of leadership, as an interaction between the leaders and followers, with the intention to change it, based more on the emotional and ethical assumptions than on forced active influence, having in mind the nature of the business performed by the employees in various activities, especially in the mining companies. The aim of this analysis is to determine the correctness of relationship between the leaders and followers as a social category and projections of further trend of this relationship, given that it is supposed that this relationship is A direct reflection on motivation the followers in their work and the results of work in the mining companies.

Keywords: *corporate culture, leadership, motivation, mining companies, leadership style, performance, business success*

1 INTRODUCTION

Today's business is increasingly leaving the intensive model of economic growth based on the comparative advantages of natural resources and unskilled labor. There is a new form of economic creativity which increasingly inaugurates some new intangible origin resources such as: knowledge, creativity, innovation, information, quality, standards, time, design, speed, know-how and other. The level of business success depends on the quality of human resources and their competence available to the business systems; regardless of their place in the organizational structure. A new knowledge about business and people is a source for completely new business philosophy, the initiator of the new changes and bearer of risk, the creator of innovation and resource allocation, the designer of new quality and values, the creator of business performance and others. On the social scene the civilization appeared whose base is on education and development system, which requires that every person works in a scientific manner in order to actively participate in the social and economic reality, creating a socially and personal wealth.

Modern economy functions in a completely new environment and a new geo culture that, in addition to the knowledge and standards in economic terms, respects and develops a knowledge for the new ethical norms and forms of corporate culture that significantly change and impact on the leadership, business policy, employee behavior, and most of all life and work of a modern businessman in the mining companies. The absence of leadership development

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in the contemporary business, based on a strategic approach, would cause a huge damage to all business systems and overall economic and business creation, especially in developing countries that are in the process of transition of ownership, as is the case in the Republic of Serbia. Poor leadership is a key factor in the failure of business and the main obstacle to overcome economic recession. Therefore, the role of the leadership in mining companies due to the nature of business and the risks to which the employees are exposed, becomes an essential activity of the management of each company.

2 LEADERSHIP AND ENVIRONMENTAL CHANGES

Changes and their permanent metamorphosis do not only condition the economic life of a society, but they have become a way of life of economic entities in every developed economy. Business systems are in a state of stability when the strategy, organizational structure and style of their leadership are in accordance with the internal and external environment. But the state of stability of business systems is difficult to maintain because it is permanently disturbed by the changes in the internal and external environment. Globalization as a planetary process of change has brought many demands to the companies to be successful in their further work. One of the important requirements is that the enterprises should increase their ability and readiness to learn, to develop their human resources in order to overcome successfully the complexity and increasing uncertainty in which they carry out their mission.

“Globalization of knowledge can be understood as the growth, development and knowledge exchange between different economic entities on a global basis.” [1] That is why the changes in the structure and leadership of the company are inevitable, which means that the leadership is forced to live with changes and to adapt and transform its role in line with the nature of the environment. Changes in the companies in our country are a direct response to the transitional changes in property, changes in the market (desire of customers, changes in competition), changes in state and legal regulations, changes in the economic situation, changes in the political atmosphere, changes in the international relations, and more. Changes and knowledge are the main bearer of development, and the main cause of decay, where development and change are completely natural processes, the causal consequence of survival and universal rules of existence.

This general principle of change management also applies to mining companies which activity is based on the new knowledge, technologies, new methods, as well as new ways of management and processes and employees, no matter how specific they are. And the mining production is increasingly based on the new knowledge and capabilities of human resources. ”In the knowledge economy, knowledge takes on some specifics and becomes the focus of interest in the economic science and practice. It now becomes the organizational knowledge at the level of the business system and increasingly becomes the essence and carrier of business development and growth, and the structure for the creation of new knowledge. “[2]

Changes are the way of life of today's companies and management in them and the means in hands of leaders. The leadership itself is a consequence and cause of resulting and incorporated changes in the business systems. Some of the definitions of change are: “Change within any element of an organizational system that promotes functionality, that is at a higher level of consistency for the environmental requirements,” “modification of task, structure, technology or people in an organization", "planned action that represents an attempt to systematically redesign the organization in a way that will allow it to adapt to the significant changes in the external environment and to achieve the new goals, "" abandoning the old way of doing things and accepting a new one that will contribute better results." [3]

The management of the company should recognize the environmental factors, determine the character and intensity of their effect and interact in order to create an economic horizon to the guide business, i.e. to determine the goals and strategy of the company. The idea of a management change is to enable companies to retain and improve their positions in the new circumstances. Therefore, a management change is a systematic and structured approach in creating a sustainable change in employee behavior within a company. Today's intensity and pace of change has changed the way of business management, putting leadership as an integral part of management in a very important place giving it a great role and importance in the management system.

3 LEADER'S ABILITY AND BEHAVIOR

Leadership as an unstoppable metamorphosis process continues its evolution in the modern economy. Leadership evolution starts from the connection of the leader and subordinate followers through a hierarchically - composed chain of command and one-way communication process to position the leader through the possession of the right answers and reactions, which directly qualifies him/her for leadership and as an unbiased attitude of influence between the leaders and followers. Leadership can be treated as a collective process that includes the leaders and followers and is formed in a specific social and historical context. "Therefore it is necessary to make a principle distinction between the management and leadership: while the management is focused on personal problems and problems of human resources, organizational setup and structure, preparation of certain funds and their executive recruitment, efficiency and utilitarianism, that is the internal organizational issues, management, technical objectives and control, the leadership is focused on the vision, construction of a "big picture" of change, innovation, strategic landmarks, purpose or purposes of the future."[4] Leadership in its analysis has two points of view: conventional perspective based on the concept of efficiency, since it starts from the assumption that the leadership takes place in a rational created institutions, where the fundamental function of the leadership is a mobilization of followers in a direction of organizational objectives and critical perspective involving various sociological concepts including the social structure, processes, culture and norms oriented towards the discovery of ways in which power, control, and legitimacy conflicts affect the dynamics of relations between the leaders and followers".[5]

Increasingly the question is what is a leadership? And who are the leaders? Leadership is a process of influencing and directing the activities of members of organizations towards achieving the business objectivities. It is a wise way how a leadership uses its influence and power. Leadership as the process of forming the behavior of people in the business system is focused on a human interaction "influencing the others" and on an internal integration of business system. [6] Leadership is demonstrated when the individuals mobilize institutional, political, psychological and other resources to arouse, engage and satisfy the motives of followers. [7] From the above, it can be seen that a leader is a chosen as a favorite person with a central role and the highest social status and the spirit in front of everyone in the business system. This is a man with a physical and personal qualities and characteristics (age, appearance, communication skills, knowledge, intelligence, creativity, integrity, flexibility, and an aspiration for leadership, reliability, self-confidence, extraversion, emotional stability, and the like). According to the global leadership prognosis, a leader is defined as someone who mana-ges the performance and responsibilities of other individuals in the organization. [8]

Integrity and morality (ethical and spiritual leadership) of leaders increasingly take the key positions in the profiles of leaders, so creating both the basis and guarantee for respect from followers, and all this leads to the business success. [9] Altruism or concern for others and integrity are also the important similarities. As for the differences the authentic leaders emphasize authenticity and self-awareness and tend to be more transactional than the other aspects of leaders do. Ethical leaders emphasize the moral problems while spiritual leaders emphasize vision, hope and faith, as well as work as a profession.

4 SOCIAL DIMENSION OF LEADERSHIP

Leadership is not what management is, even though it has a strong relationship with management and makes it an integral part. In most business systems there are too much of management and too little of leadership. The manager, no matter how good is a planner, organizer, coordinator and process controller, without the motivational abilities of the leader cannot lead to good business results. The leader is successful if know how to stimulate and rally the commitment of his/her followers to the business system and all his/her activities, even without managerial skills.

The manager is successful in doing business if has the leadership capabilities. A leader is the one who is able to influence the attitudes, opinions, decisions and actions of each follower.

Leadership is a specific type of relationship in management and is based on a social activity or activity between the leaders and followers. Leadership is focused on a human interaction “impact on others” and on achieving the business results. Leadership as a process in itself requires “real” and capable leader who creates a vision and responsible followers who accept the vision and follow the ideas and values of leader. Fair and humane attitude of these parties in the process has a direct impact on performance the business system which is the essence of leadership to make all followers gather around one idea and so direct the creative energy, knowledge and ability towards achieving a defined objective. Followers as bearers of working activities and supporters’ of common ideas for achieving organizational goals are also individuals with their personality, with their own personal profile and their characteristics. Leaders should always have this fact in mind when it comes to perceive the behavior of individuals at work, decision making, communication, control and others.

For modern leader and leader of the future, it is not enough to have a high level of IQ, but the so-called emotional intelligence; EQ is needed and it is ability to be more sympathetic to the others, to cooperate, to properly assess, to create a good relationship, to be attractive and ot-hers [10]. Emotional intelligence indicates the importance of ability of leaders to express their feelings to employees, to live in harmony with them and to use them to achieve the important organizational goals. Personality is, in addition to traits, abilities and personality traits as the holder of differences in behavior and work, conditioned by a number of other dimensions and complex phenomenon, which is an area of psychological research. Kno-wing the personality of the individual should be the first item when entering the world of work, because the personality of individuals creates the profile of business system. There are different people and different behaviors of these people in the business system. Some of them are consistently friendly, calm, and quiet, others are aggressive, rude, talkative, nervous, etc. While some are effective in decision-making and risk-taking, creative and open to the new ideas, have high moral standards, others may be hesitant, timid, slow, passive, without ideas, flexible in their moral attitudes, etc. It is obvious that a person makes a unique system of proper behavior, which an individual differs from others in the business system. For business system management, it is very important to understand the personality of individuals, because on the basis of that the future reactions of employee-followers can be predicted in a certain situation and it could be reacted to them adequately. Personality is a very layered, complex and developmental psychological phenomenon; it is a conditioned category by numerous factors: biological, sociological and situational. “The psychology of parents and educators is decisive in the process of growth and development the individual” [11]

To comply with the individual profile and nature of the work, the selection of psychologists should be detailed in the personality profiling of the candidates for the purpose of their efficient performance. Profile of employee with details would be available (in the form of psychological, physical, intellectual and professional files) only for responsible people in the sector of Human Resources. That file would contain information on an individual development from the childhood (family structure, growing up with or without their parents, their emotional development, strictness of parents, profession of parents, financial status, family status in the environment, etc.), schools that an individual attended, the jobs done, the qualification gained, marital status and others. All data on an individual would serve to leader to fully understand their followers, their behavior, their attitude towards work, towards colleagues and towards authority, their responsibility and others and to build attitude towards them and to consequently treat them. Harmonizing the relationship of the leaders and followers is essential for the life and development the business system to motivate the followers and good performance in work.

5 LEADERSHIP AND MOTIVATION

Leadership implements its evolution development and metamorphosis through a prism of motivation system the followers. Leadership is directly related to the inspiration of followers and management of their behavior in the performance of certain tasks. The attitude of leaders towards the followers expresses leadership style in a certain time and certain situation. The key criteria for distinguishing between the leadership styles are: the leaders attitude to the followers motivation (coercion or incentives), the way in which the leader makes decisions, source of power that is used to influence on followers, leader flexibility to adapt to different situations, characteristics of leaders (mental and physical, moral, professional, etc.), characteristics of followers and others. According to these criteria, there is a whole range of leadership styles from classic to the modern styles.

In an effort to identify the factors that most affect the business success of the company, the contemporary authors are increasingly emphasizing the employee motivation as one of the key determinants of performance. Today, motivation is in the focus of the interest of a modern leader, who has an active and important role in encouraging his/her followers for greater engagement at work and greater efficiency and effectiveness in business "Efficiency is thus focused on the choice of needs that the company will satisfy, i.e. the choice of goals and activities to provide it, and the efficiency on the production capacity and rationality of using the resources that the company has at its disposal." [12]

The quality of the accomplished performance of members of the organization is directly conditioned by a degree of their motivation, among other things, by an ability of the leader to encourage his/her followers in the right way. Motivation is a set of processes that support, direct and maintain the behavior of people, aimed at achieving a particular goal. It is considered as a complex psychological category that dictates a significant part of behavior of employees in the company, and is the basic catalyst for business actions. Directing the behavior of employees in the company, so that it is desirable and acceptable for its operation and business policy, is the responsibility of the leader.

The notion of leadership is complex, multidimensional and multidimensional, and its definitions differ depending on the aspect from which different authors view and determine it. One of the most comprehensive definition of leadership was given by Peter Northouse, who under the leadership implies a process in which an individual exercises influence on a group, in order to achieve a common goal. Therefore, it is a complex, dynamic process that is realized in the context of a group and basically implies an interactive relationship between the leaders and followers, whose interaction is more pronounced in the modern business conditions. Namely, the modern companies organize their business based on a team work, where leadership takes on a completely new dimension, reducing the formal role of leaders in such environment. Leadership is a central function of management and refers to directing the work activities of employees in the organization, as the strategic most important way to achieve the organizational goals. Managing people, among other things, means to know how to motivate them, thus ensuring that they are doing their job well and contributing to achieving the mission and achieving the goals of the business system.

An important aspect of leadership in the role of employee motivation is the ability of the leader to identify the individual goals of each employee, and accordingly offer them an adequate reward for successfully accomplished tasks, thus ensuring compliance of individual and projected goals of the organization. The ability to recognize the motive of employees and the satisfaction of their needs is what separates successful from unsucessful leaders. If motives of an employee are known, the leader is able to anticipate his/her future behavior and accordingly direct him/her to the right path to achieve a higher level of productivity and better financial results of the business system. The effects of employee motivation by the leaders are different in a different company, which is again conditioned by the activity in which the work process takes place both by the structure of the employees themselves and the conditions in which the work activities are carried out. "The current business can be organized successfully or less successfully, which will directly affect the final business result-income. Concrete producers, mining companies have different natural and technical business conditions as well as different environmental impacts in relation to the average producer of this group, a group of workers. The occurrence of these differences results in a profit deviation of a particular mining company in relation to the profit of the average producer. This impact cannot be changed during the reproduction process, and not by the organizational efforts of workers and managers. “[13]

How a leader will motivate the followers in such companies depends first of all on the style of leadership applied. At the same time, the leadership style is conditioned by a set of factors, in which the organizational structure, organizational culture, as well as the personality and characteristics of the leader are distinguished. There are numerous criteria and ways of classifying the leadership styles. Historically, the leadership style goes from a commanding, autocratic to participatory, team leadership. Thus, the leader of the autocrats as the basic means of shaping and directing the behavior of employees will use coercion, punishment and strong control, with a high degree of rigidity and directives, while the leader of the democratic participatory style will motivate his/her followers giving a greater authority and responsibility, giving them the opportunity to participate in making the important decisions. Experience and practice show that a greater degree of humanization the relationship between the leaders and followers give better employee motivation results. Each style of leadership brought a certain style of incentive-motivation of its followers. The attitude of leaders and followers evolved increasingly in favor of the followers. Leaders, thanks to their abilities and superior qualities, developed the specific relationships with followers, and thus inspired them in the most difficult moments in the business system, and thus strongly motivated them to often overcome their own possibilities and expectations. Capable leaders are very creative with many ideas and easily create the climate of change and climate of business as an important incentive factor. “Climate is an emotional value reflection of the organization culture. It is conditioned by the most common way of decision-making, the way of management, the system of distribution of salaries, human resources management policy. The climate consists of relatively permanent, emotional, social relations and interpersonal relations of the organization members, as well as the influence of these attitudes on the behavior of employees. “[14] Followers in this business atmosphere are emotionally and unconditionally tied to the mission of a capable leader and are often identified with it.

Today, it is mentioned more and more the visionary leadership, as the ability to create systems, to make the vision a reality, despite a turbulently changing environment. Visionary leadership is less concerned with the interaction between the leaders and followers, which is in the focus of numerous leadership models, and more by an interaction between the leaders and groups or leaders and systems.[15]

The idea that different people will have different motives is of vital importance to the leaders in deciding on the system of rewarding and motivating employees. Each individual represents a unique set of personal characteristics, aspirations and motives. Therefore, individualized approach of leaders to each employee is necessary, in order to identify their needs and desires and to provide opportunities for their satisfaction. In order to achieve this, the leader must have a good knowledge of his followers, and apply different methods and techniques of motivation. High cohesiveness of the group or team is necessary because it is the basis for discovering their motives. A leader who does not know his/her followers well enough cannot expect their loyalty and trust.

It is unjustified to believe that the basic motives for the work of employees are money and other material rewards. In the modern business conditions, characterized by dynamism, turbulence and stochasticity, the top-level needs, such as the needs for achievement, development and selfactualization, come to the place of material rewards as the basic motives for work. Here, the key role and significance of the leaders are seen, whose task is to convey their vision and optimism to the employees, and convince them that success is possible, all in a function of creating greater prosperity for the business system itself.

Modern leadership, and especially transformational leadership, is linked to the changes, which are the main feature of modern business. Under conditions of uncertainty, resistance to change is inevitable, and the leader is to manage it. In this sense, motivation and rewarding are the most powerful weapon in the hands of leaders, which can be used to eliminate the resistance and create an organizational climate that supports the implementation of changes in an organization.

The motivation system itself, in addition to being stimulative, can sometimes be disincentive to the followers. This case refers to rewarding the follower. Since the prize is a very sensitive category, it should be in the focus of management of the business system in order to achieve a real stimulus effect. In order for a prize (in any form) to be stimulated, it should be fair and awarded, in the same treatment, the same reward for the same results. The reward as a stimulating part for a better and more efficient performance of jobs is important every-where where the organized work is carried out, and especially the place in mining operations where the nature of the work is specific, in view of the working conditions, the difficulty in carrying out work opera-tions, the risk at which works are performed and etc.

Finally, in order to effectively and efficiently motivate employees and thus fulfill one of their most important tasks, the leader must be adequately motivated. Self-motivation is a feature inherent to the leaders, as it is question of people of the internal control locus. In addition, the leader must be an excellent connoisseur of psychology, sociology and organizational behavior, in order to be able to create a favorable organizational climate for the work of employees and to ensure healthy and human interpersonal relationships in a long period. The basis for employee motivation is the correct and clear communication between the leaders and followers that must be based on mutual respect and trust. The success of the leader is measured by his/her ability to motivate employees based on proper communication, and it is important that the leader listens to his/her environment and thus gets the valuable information about his/her team members.

The growing tendency of the importance of human resources to achieve the business, economic and overall social development in the knowledge economy points to motivation as the most effective means of achieving the goals. The role of leadership in motivating employees in the business system is of immense importance and today is one of the main determinants of business success.

CONCLUSION

Many external and internal factors are related to the success of company. The role of leaders in a strategic approach to the management is inviolable and essential. The leadership role in a turbulent environment is to project an organizational and functional entity in the mining companies. In order for success to be adequate, the leaders need to optimally harmonize their own behavior with the requirements of the environment from one and the inner environment, with the emphasis on the needs of the followers, on the other side. Due to the long transition period and the general crisis that has ruled our country for a long period of time, numerous problems have been noted in both business and leadership. Leaders in the Serbian mining companies use the democratic leadership style to the fully extent. They are dedicated to work and goals and are very motivated in their work. The special characteristics that the followers rate in the leaders are: knowledge, abilities, creativity, charisma, honesty and politeness. In the opinion of the followers, the leaders in this region do not possess a sufficient level of emotional intelligence, tolerance and flexibility. The style of leadership applied in the Serbian companies varies depending on the activity, the size of the business system, the emplo-yee structure but the demands of the followers are absolutely identical. The followers require from leader even greater responsibility, open communication, respect, respect for employee suggestions and a friendly attitude. In order to be accepted by the followers and at the same time to be their heroes, in addition to the vision, technical and conceptual knowledge, the leaders need to give more attention to the followers. Leaders should be ready to listen to suggestions, proposals and followers' ideas, to express openly their opinions, praise good ideas, argumentatively rejecting a bad idea, interpreting the current state of the environment and explaining the goals of the work. Only an open and rightful relationship with the followers, clear goals and authority, based on knowledge and integrity, can make the leaders successful.

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APPLICATION THE SOFTWARE SOLUTION FOR CALCULATION THE CAPACITY OF BUCKET WHEEL EXCAVATORS IN THE COMPLEX CONDITIONS FROM THE ASPECT OF RESISTANCE TO EXCAVATION

Abstract

This paper describes a software solution for calculation and analyzed the impact resistance to excavation on technical capacity of a bucket wheel excavator was analyzed at the open pit Gacko. The analysis was carried out for many characteristic cases with the values of resistance to excavation of 750, 1000, 1250 and 1500 N/cm' and in accordance with the set values in the working environment of the open pit Gacko - Central Field.

Keywords: *capacity, bucket wheel excavator, resistance to excavation, open pit mining*

INTRODUCTION

Excavation of overburden and inter-seam waste at the open pit Gacko - Central Field was predicted using a continuous and discontinuous equipment. Excavation and loading of overburden by a continuous equipment is carried out by bucket wheel excavators type ER 1250*17/1.5 and ER 1250*16/1.5.

In addition to these two bucket wheel excavators, which are currently involved in the exploitation process, there is another type of a bucket wheel excavator ER 1250*16/1.5 to be included in the production as an aggregate reserve within the I BTO system.

Technological parameters of the bucket wheel excavator ER 1250*16/1.5 are presented in Table 1.

Table 1 *Technological parameters of the excavator ER 1250 * 16/1.5*

Parameter	**Value**
Excavation height (m)	15
Angle of excavator rotation according to massif (^{o})	90
Angle of excavator rotation according to the excavated area (^{o})	22
Angle of inclination of lateral floor slope (^{o})	70
Angle of inclination of frontal block slope (^{o})	70

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CONTINUOUS SYSTEMS - CAPACITY THE BUCKET WHEEL EXCAVATORS

Procedure of calculation the capacity of bucket wheel excavator on overburden was carried out according to the methodology presented in the following text.

Border angle of regulation:

$$\cos \xi_{rI} = \frac{q \cdot n}{h_I \cdot s \cdot k_r \cdot V_{b\max}}$$

where:

q - volume of bucket, (0.375 m^3)

n - number of bucket discharging (76.5 min^{-1})

h_i - sublevel height (3.75 m)

s - maximum thickness of slice, (0.6 m)

V_{bmax} - maximum speed of boom rotation, (30 m/min)

The basic rotation speed of bucket wheel carrier:

$$v_{boI=} = \frac{q \cdot n}{h_i \cdot s \cdot k_r}$$

The medium rotation speed of bucket wheel carrier:

$$V_{bsI} = \frac{\xi_{uI} + \xi_{sI}}{\frac{57.3 \cdot (\sin \xi_{rI} + \sin \xi_{sI})}{V_{boI}} + \frac{\xi_{uI} - \xi_{rI}}{V_{b\max}}}$$

where:

ξui - turning angle of rotor boom in a sublevel towards the inside lateral slope (900 for the I sublevel)

ξsi - turning angle of rotor boom in a sublevel towards the outer lateral slope

ξri - angle regulation in a sublevel

The medium time of rotation of wheel carrier:

$$t_{sI} = \frac{\pi \cdot (L + e + r) \cdot (\xi_{uI} + \xi_{sI})}{180^o \cdot V_{bsI}}$$

where:

L – boom length, m

e - horizontal distance the pivot point of rotary boom from vertical axis of excavator rotation, m

r - radius of operating wheel, m

Time of cut change in a block:

$$t_r = \frac{s_{\max}}{V_t}$$

S_{max} - maximum thickness of cut, m

V_t - transport speed of excavator, m/min

Number of cuts in a sublevel is determined according to the relationship:

$$n_r = \frac{Z_{\min}}{s}$$

where:

Z_{min} is the length of block excavation for one technological cycle, which is obtained on the basis of limitations until the boom strikes on the other, the bottom sublevel:

$$Z_{\min} = r + \left(r - \frac{d + t}{\cos \alpha_g} \right) \cdot ctg\alpha_g - h_I \cdot ctg\beta_{č}$$

Changing time of zone:

$$t_e = \frac{Z - s_{\max} + \frac{h_i}{tg\beta_{č}}}{V_t}$$

Z - length of block excavation for one technological cycle, m

Time of a block changing defined by the formula:

$$t_{pb} = \frac{(H - h_i) \cdot tg\beta_{č}}{V_t},$$

Time of a block dredging:

$$T_b = \left\{ \sum \left[(t_{si} + t_u + t_r) \cdot n_r + t_{ei} \right] \right\} + t_{pb}$$

Volume of a block:

$$V = H \cdot B \cdot Z$$

Technical capacity of a bucket wheel excavator for defined technological parameters is:

$$Q_{th} = \frac{V}{T_b} \cdot k_o$$

K_o - correction coefficient that takes into account the conditions of material excavation material; $k_o = 0.97$.

The average technical capacity - Q_{thpr} is less than the technical capacity obtained on the basis of technological scheme of block mining for pure technological inability to continuously work in a regular block, i.e. due to the loss of capacity in cutting of excavator at the end of floor in a new block. Consequently the average technical capacity of the excavator is:

$$Q_{thpr} = Q_{th} \cdot k_g \ .$$

where:

k_g - mass loss in capacity due to the amount of interference excavator in the new block reduced the capacity of the excavator in the regular block.

$$k_g = \frac{(L - l) \cdot k_{kl}}{L}$$

L - floor length, m

l - length of the zone in which the interference is done in the new block, m

k_{kl} - correction coefficient of technical capacity

CALCULATION THE CAPACITY OF BUCKET WHEEL EXCAVATOR

On the basis of this methodology, a software solution was formed to calculate the capacities of the bucket wheel excavator on excavation the overburden for typical cases.

As the most important influencing factor on the capacity of bucket wheel excavator in the overburden excavation in the current period is a problem of excavation a part of overburden with increased parameters of strength, or an increased resistance to excavation. In the Gacko coal basin in the Central field, the terrain complexity is evidently demonstrated in the engineering-geological terms. The engineering-geological explorations in 2011 and 2012 should have to establish the value of engineering-geological parameters of isolated homogeneous or quasi - homogeneous zones for the investigated areas.

Zoning of a terrain and rock mass classification of the exploration area was carried out using two categories.

The first classification was made in accordance with Ćirić S. (1986). According to this categorization, the entire complex of neogene is classified into five categories (K1 to K5), each of which is an engineering geological unit with the specific physical and mechanical properties, deformation and structural properties expressed to the certain limits.

Category K1 includes the surface cover rocks as well as the lowest package of series with the values of uniaxial compressive strength less than 1,000 kPa.

Category K2 includes the rocks of the super positioning packages with the uniaxial compressive strength ranging from 1,000 to 2,500 kPa. This category within the exploration area includes clayey marls and coaly and tuffitic marls.

Category K3 is composed of two variety of rocks. The first variety is represented by gray marls of fine pelitic structure, while the other variety consists of yellow to yellow-gray marls. Varieties are altered in layers of 1.5-3.0 m thickness. Compressive strength ranges from 2,500 to 4,500 kPa.

Category K4 includes marly limestones, limestone marls, clayey and coaly marls and multicolored marls. Thickness of the unit ranges from 20 m to 25 m. Thickness of the package is quite variable, especially in the parts of basin, where the first main and floor coal seams have the super positioning ap proaching. Testing the uniaxial compressive strength of these sediments show the value of compressive strength between 4,500 and 6,000 kPa.

Category K5 includes the rocks with the uniaxial compressive strength greater than 6,000 psi.

Based on the test results of the cutting force, the propagation speed of longitudinal waves (v_p) and testing parameters of compressive strength, ***the second categorization*** of the rocks masses was done per cutting and possibilities of application the rotor excavation technology within the lithostratigraphic member 8NG member, as follows:

For the rock masses with the cutting resistance up to 500 N/cm, at speed of propagation of longitudinal elastic waves Vp = 500 - 1,000 m/s, that is, compressive strength up to 25 daN/cm^2, it is possible to use a large bucket wheel excavator, **the category K1**;

For the rock masses with the cutting resistance up to 500-1000 N/cm, at speed of propagation of longitudinal elastic waves Vp = 1000 - 2000 m/s or compressive strength of 25-50 daN/cm^2, it is possible to use a large bucket wheel excavator, **the category K2**;

Of the rock mass from the cutting resistance is 1000-1500 N/cm, at a speed of propagation of longitudinal elastic waves Vp = 2000 - 3000 m/s or compressive strength of over 50 to N/cm^2, on the border of the possible use of a large bucket wheel excavator, **the categor is K3**;

For the rock masses with the cutting resistance of over 1500 N/cm and propagation speed of longitudinal elastic waves Vp≈3000 m/s, **the categories K4** that is difficult to ripping;

Previous investigations and monitoring the resistance to cutting K_L in a function of moisturechange w indicated a possible variation of resistance when cutting " in situ " in a function of the seasons, lowering of the groundwater level and others. Increasing the resistance to cutting due to the reduced moisture content w can lead to application the bucket wheel excavator in excavation and can be the cause of accidents and reducing effect.

Categorization of rock masses within lithogenetic unit $8N_G$ was carried out according to the parameters obtained by laboratory tests on the basis of that categorization. Seams with an increased resistance to cutting are shown in the engineering geological profiles

Two media occurs in generalization by interpretation a high roofing terrain of the main coal seam.

MEDIUM I (Categories of rocks K1 and K2), which is not a problem for operation the bucket wheel excavator for overburden excavation.

The following physico-mechanical parameters of the medium I were obtained by laboratory tests:

- natural moisture immediately after opening the sample ω = 8.61 – 32.61 (%);
- bulk density γ = 16.97-22.96 (KN/m^3);
- speed of longitudinal el. waves Vp = 1193 -2017 (m/s).

MEDIUM II (Category K3)

In lithological terms, the rock masses pf Medium II correspond to marly limestone with the percentage of CaCO3> 85%. These rock masses are followed by stratification and build a larger part of the fieldcovered by explorations. It is represented by a plurality spaced seams with resistances to cutting >1000 N/cm in the conditions of the working environment.

These seams occur in the shallow parts of the field with the small thicknesses of 0.30 – 1.45 m. Their inclination towards the bottom of syncline results into increase of this system thickness, and even in the drillhole B-811gm it is 5.95 m, or in the borehole B-772 7.50 m.

Based on the existing data, calculation the amount of material categories K3 was done. Figure 1 shows the propagation of marls with increased resistance characteristics to the characteristic geological cross-sections.

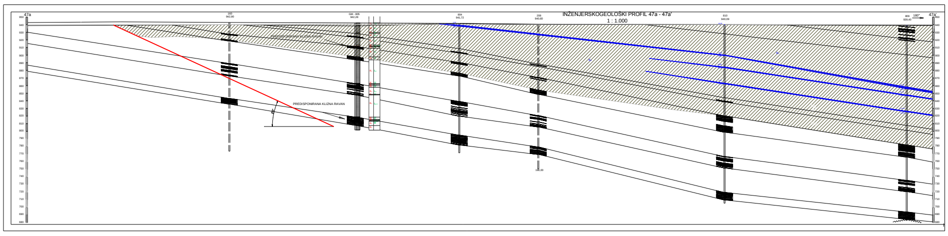

Figure 1 *Propagation of marl with increased resistance to excavation at cross sections 42-42'*

Marl (Pu), *Marl of categories K3 and K4 (Pk3)*

Conducted studies have included the western part of the Central field (Figure 2). Marl amounts with increased characteristics for resistance to exploration were tested by the method of cross sections, given in Table 2.

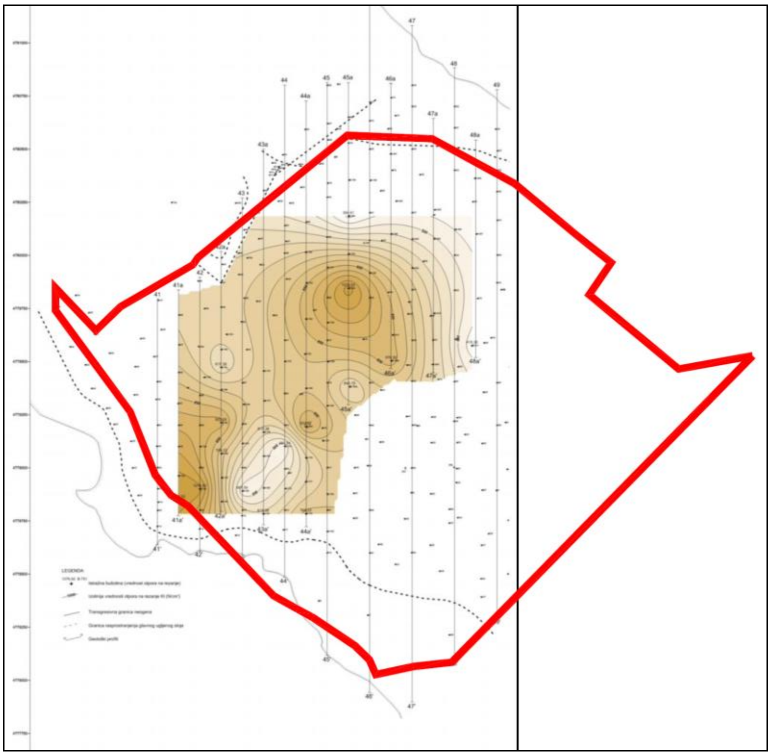

Figure 2 *The position of exploratory wells to the tested parameters and contours digging resistance in the area of box C (——the borders of the Central Fields)*

Table 2 *Calculation the amount of marl with increased resistance to excavation*

Profile	Surface area (m²)		Central area (m²)		Distance (m)	Volume (m³)	
	Pu	Pk3	Pu	Pk3		Total marl	Marl with increased resistance to excavation
41a-41a'	40,208	5,529	43,709	5,810	100	4,370,900	581,000
42-42'	47,210	6,091	57,143	6,299	100	5,714,250	629,850
42a-42a'	67,075	6,506	70,072	6,687	100	7,007,150	668,700
43-43'	73,068	6,868	77,237	7,980	100	7,723,700	798,000
43a-43a'	81,406	9,092	92,313	7,752	100	9,231,250	775,200
44-44'	103,219	6,412	107,508	7,536	100	10,750,750	753,600
44a-44a'	111,796	8,660	93,277	7,858	100	9,327,700	785,750
45a-45a'	74,758	7,055	117,627	4,153	100	11,762,700	415,250
46-46'	160,496	1,250	117,890	3,577	100	11,788,950	357,700
46a-46a'	75,283	5,904	79,963	3,618	100	7,996,250	361,800
47a-47a'	84,642	1,332	90,763	2,897	100	9,076,250	289,700
48a-48a'	96,883	4,462			**Sum**	94,749,850	6,416,550

Pu - total surface area of marl, Pk3 - surface area of K3 and K4 category

Percentage share of marl with increased resistance to excavation is about 7% of the total masses. In case of consideration the amount of marl in the whole zone in which there are marls with increased resistance to excavation, on the basis of calculation given in Table 3, the share of the entire zone in total amount of marl in the overburden is about 30%.

Table 3 *Calculation the amount of marl in the zone in which marls are present with increased resistance to excavation*

Profile	Surface area	Central area (m²)	Distance (m)	Volume (m³)
41a-41a'	22,286	22,708	100	2,270,800
42-42'	23,130	22,748	100	2,274,800
42a-42a'	22,366	27,270	100	2,726,950
43-43'	32,173	37,479	100	3,747,900
43a-43a'	42,785	39,304	100	3,930,400
44-44'	35,823	32,064	100	3,206,400
44a-44a'	28,305	28,060	100	2,805,950
45a-45a'	27,814	16,819	100	1,681,900
46-46'	5,824	16,694	100	1,669,400
46a-46a'	27,564	21,116	100	2,111,600
47a-47a'	14,668	15,161	100	1,516,100
48a-48a'	15,654		The forest	27,942,200

Bearing in mind the above presented values of resistance the overburden excavation and the presence of materials with increased resistance characteristics, calculation the capacity of bucket wheel excavator was done in overburden excavation. The calculation was made for more characteristic cases, and the results of calculations are given in the form of software solutions and tabulated. The first four typical cases are analyzed for the value of resistance to excavation of 750, 1000, 1250 and 1500 N/cm', respectively, and two characteristic cases with operation in the bewlts of material with resistance to excavation of 1000, 1250 and 1500 N/cm' (Figure 3).

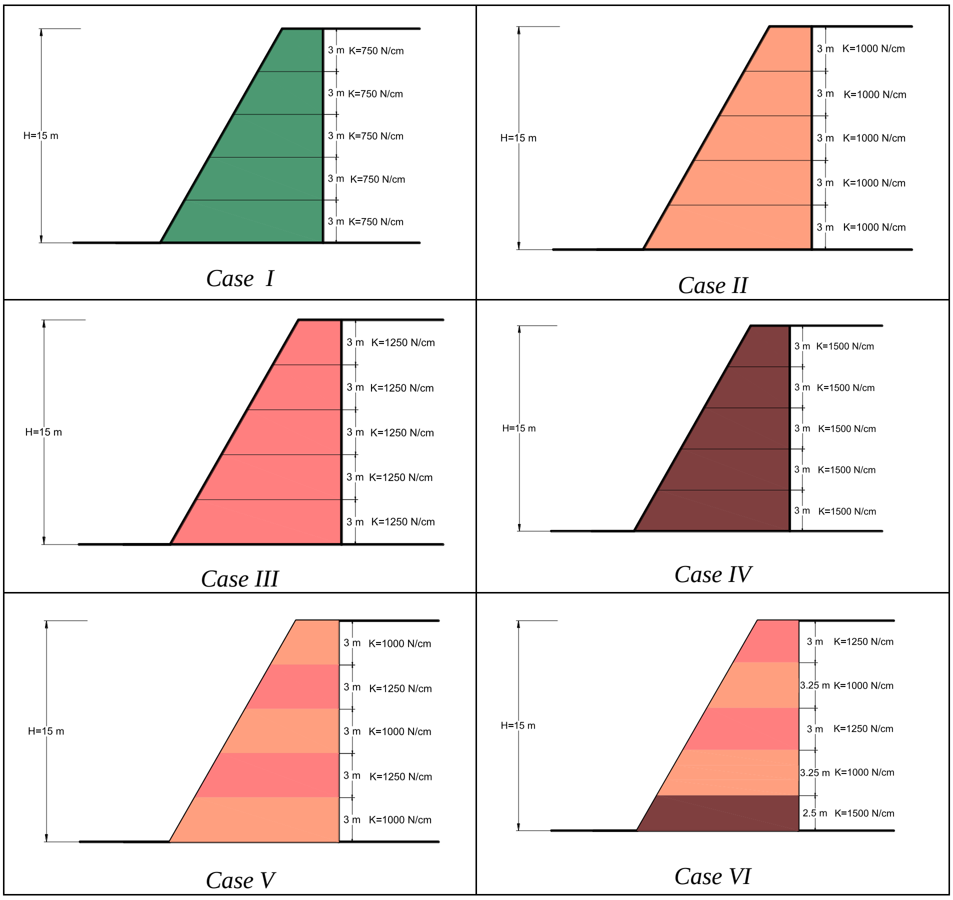

Figure 3 *Review the characteristic cases for analysis with different values of resistance to excavation*

CASE I

Calculation the capacity for resistance to excavation K_L = 750 N/cm and height of cut h = 3 m is given in this case. Figure 4 shows the technological parameters of the bucket wheel excavator for the level of 15 m. Figure 5 shows the calculation results of capacity the bucket wheel excavator for the case I; the same is also given in tabular a (Table 4).

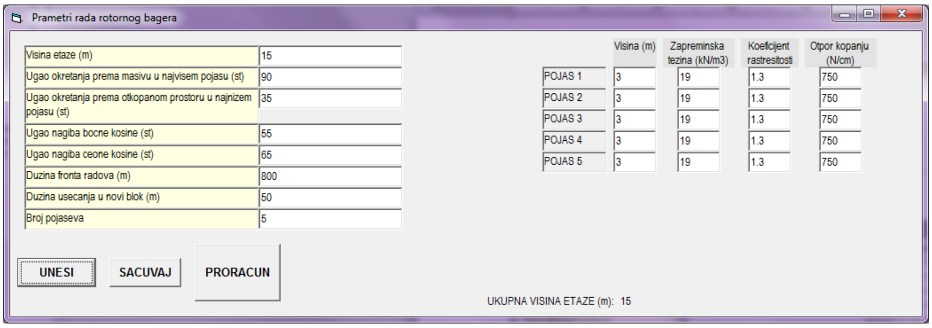

Figure 4 *Technological parameters*

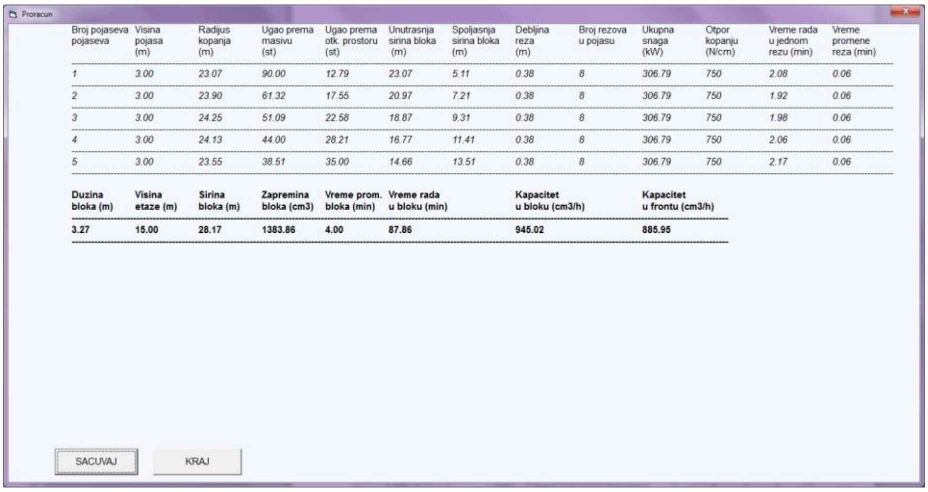

Figure 5 *Calculation results*

Table 4 *Review the results of capacity calculation for the bucket wheel excavator*

No.of belts (m)	Belt height (m)	Excav. radius (m)	Rotation angle towards massif (st)	Rotation angle to the excavated area (st)	Internal block width (m)	Outside block width (m)	Thickness of cut (m)	No. of cuts in belt	Total required power (kW)	Resistance to excavation (N/cm)	Operating time in one cut (min)	Time of cut changes (min)
1	3.00	23.07	90.00	12.79	23.07	5.11	0.38	8	306.79	750	2.08	0.06
2	3.00	23.90	61.32	17.55	20.97	7.21	0.38	8	306.79	750	1.92	0.06
3	3.00	24.25	51.09	22.58	18.87	9.31	0.38	8	306.79	750	1.98	0.06
4	3.00	24.13	44.00	28.21	16.77	11.41	0.38	8	306.79	750	2.06	0.06
5	3.00	23.55	38.51	35.00	14.66	13.51	0.38	8	306.79	750	2.17	0.06
Length of block (m)	Height of level (m)	Width of block (m)	Volume of block (cm^3)	Time of block change (min)	Excav. time in block (min)	Capacity in block (cm^3/h)	Capacity in front (cm^3/h)					
3.27	15.00	28.17	1383.86	4.00	87.86	945.02	885.95					

The same methodology was also performed for other cases, the results of calculation the capacities are given in the Summary Table (Table 5), as well as in the chart (Figure 6).

Table 5 *Calculated values the capacity of bucket wheel excavator for individual cases*

Case	Technical capacity (čm^3/h)	Resistance to excavation (N/cm')	Evaluation of participation in the total mass (%)
1	885	750	10
2	560	1000	40
3	370	1250	40
4	234	1500	10
The weighted average value for the first four cases	484	1125	100
5	427	1000-1250	
6	406	1000-1500	
The average value for the analyzed characteristic cases	439		

The annual capacity of continuous systems with 3,500 effective working hours and utilization the hour of time of 70% in the complex operating conditions with variable resistance to excavation, is per system:

$$Qex = 439 \cdot 3500 \approx 1{,}500{,}000 \text{ čm}^3/\text{year}$$

With procurement of another one continuous system with bucket wheel excavator as the basic excavation equipment, the total amount of overburden that will be excavated by continuous technology is:

$$Qexyear = 3 \cdot 1{,}500{,}000 = 4{,}500{,}000 \text{ čm}^3/\text{year}$$

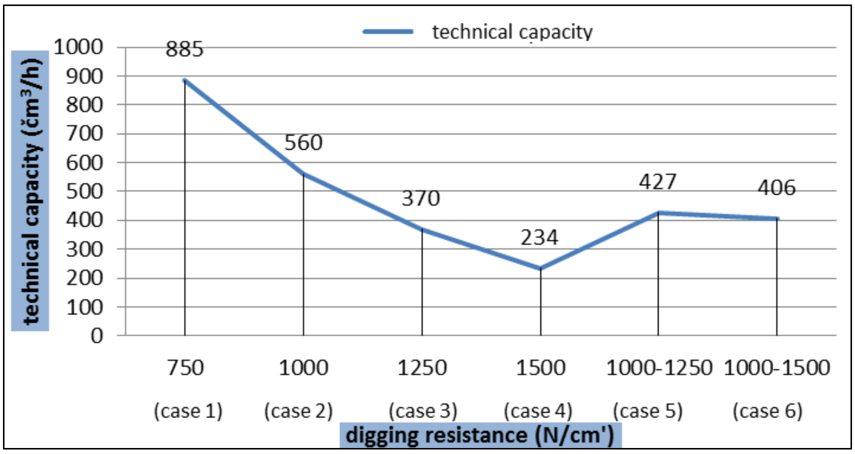

Figure 6 *Overview the calculated value of the bucket wheel excavator capacity for individual cases*

CONCLUSION

Capacity of excavation equipment at the open pits is in a function of many factors, and the problem of determining the excavated capacity has been always reduced to less than or greater generalization and negligences, sometimes very important technological parameters of the working environment. Knowing the real capacity of excavation equipment, implemented in the complex heterogeneous conditions of working environment, and the possibility of modeling and testing in terms of the variables, is the basis in the selection procedure and dimensioning the basic excavation equipment, design, planning and monitoring the mining dynamics.

Overburden at the open pit Gacko - Central Field, which is designed to excavate using the existing bucket wheel excavators is characterized by the complexity of material, and a crucial parameter that limits the capacity of the bucket wheel excavators is resistance to excavation.

Displayed procedure to analyze the spatial distribution of overburden with increased resistance characteristics, together with the software solution to calculate the capacity of bucket wheel excavator, which takes into account the relevant technical and technological parameters of the working environment in calculation the technical capacity of the bucket wheel, has enabled calculation the real capacities of overburden excavation. Also, it is possible for the given conditions of the working environment to carry out a series of analyses the capacities with variable technological parameters, and thus to realize the maximum capacities of the concrete conditions of the working environment.

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POSSIBILITIES OF INTRODUCING AN INTELLIGENT CONTROL SYSTEM IN THE FLOTATION PLANT VELIKI KRIVELJ***

Abstract

In this paper, an analysis of the possibility of implementing the fuzzy logic and artificial neural network controller in the intelligent control system in the flotation plant Veliki Krivelj was performed. Functional positioning of controllers was considered through two approaches. According to one approach, the control of flotation process would be carried out by only one controller, while in the second case two controllers would exist – one for a rough flotation and scavenging and the other for cleaning.

Keywords: *flotation, fuzzy logic controller, artificial neural network controller*

INTRODUCTION

When discussing the process control from the plant operational performances point of view, a quick, precise and adaptive reaction of the system is an essential demand. Moreover, the need for development and utilization the sophisticated control methods is even higher given the lack of information available, an existing non-linear environment, as well as rather complex nature of the system. The requirement for flexibility in production and maximizing the recovery of energy and materials further increase this need [1, 2]. Possible solution of the problem is an intelligent control.

Intelligent control is a discipline where the control methods are developed so that they mimic important characteristics of human intelligence - adaptation and learning, planning under high uncertainty, and computing the immense quantities of data [3]. In other words, intelligent control imp-lies the application of artificial intelligence methods (artificial neural networks, machine learning, fuzzy logic, evolutionary computation, etc.).

Classic control methods require understanding of work with a complete set of data, including sensor information and values within all process parameters. Unless the all necessary data is completely known, the appropriate estimations should always be taken into account. And, if the available information is at all fuzzy, qualitative, incomplete or unclear, the classic regulators and control will not provide the satisfactory results. Furthermore, the classic control techniques are largely based on the assumption that the plant operation is linear and

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time - invariable, which does not correspond to the majority of real processes [1, 2]

Unlike the conventional control, the intelligent control techniques possess capabilities that effectively deal with incomplete information concerning the plant and its environment, and any unexpected or unfamiliar conditions [2].

Accordingly, the intelligent methods find increasing application in engineering practice through different approaches – real time process control, diagnostics, modeling and process analysis, optimization, etc. Despite the diversity in applications, the analogies can be noted at several levels, such as a capability for processing imprecise, uncertain and unclear information, utilization of similar inference mechanisms, etc. [4, 5].

Taking the aforementioned into account, as well as the nature of flotation process, it can be said that the intelligent methods represent a promising technique in the control of flotation systems.

EXPERIMENTAL AND MODEL DEVELOPMENT

For the purposes of this research, the fuzzy logic and artificial neural networks, based flotation models, have been developed. Their brief systematization is shown in Table 1.

Table 1 *Basic data about models*

SC Method	Input variables					Output variables		
	Cu content in feed	**Collector dosage (roughing)**	**Frother dosage**	**Pulp pH**	**Collector dosage (scavenging)**	**Final concentrate grade**	**Copper recovery**	**Final tailings grade**
Fuzzy logic (Mamdani system)	+	+	+	+	+	+	+	+
Fuzzy logic (Takagi-Sugeno system)	+	+	+	+	+	+	+	+
Artificial neural networks	+	+	+	+	+	+		
Artificial neural networks	+	+	+	+	+		+	
Artificial neural networks	+	+	+	+	+			+

Data for models were collected from the industrial flotation plant "Veliki Krivelj", whose technological scheme is shown in Figure 1. The ore processing in the plant includes:

(1) two-stage grinding and classification,
(2) rough flotation of copper minerals,
(3) regrinding of the rougher and scavenger concentrate,
(4) three-stage cleaning of the copper concentrate,
(5) scavenging after the first cleaning.

The experimental research was performed in virtual conditions, using the MATLAB programming language. The validation of the proposed flotation models was carried out in Microsoft Excel. More details on the development and results of these models are given in the literature [6].

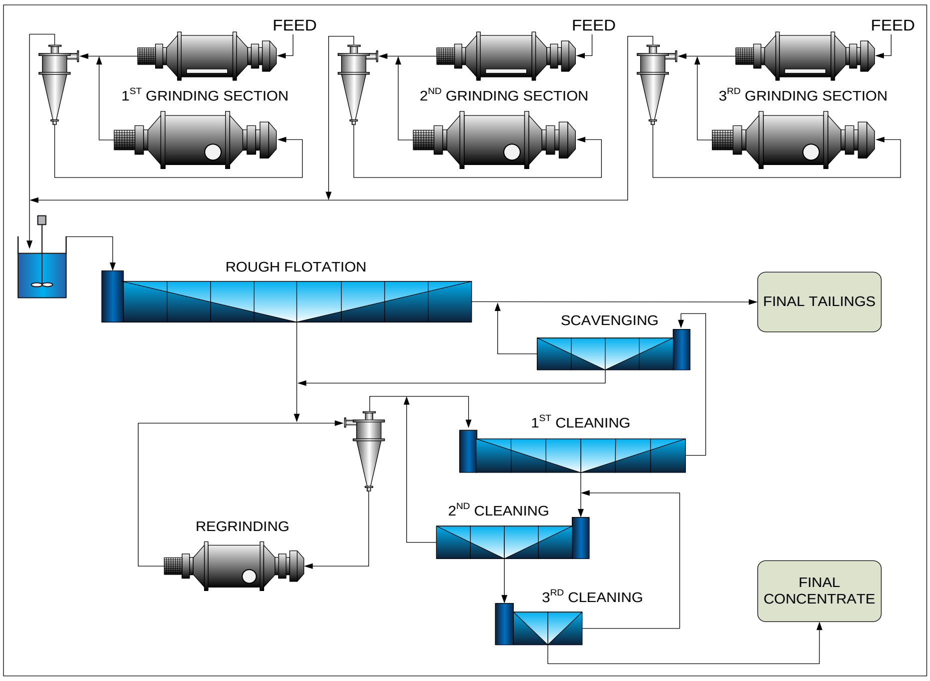

Figure 1 *Technological scheme of the flotation process in "Veliki Krivelj"*

INTELLIGENT CONTROL SYSTEM – PROPOSALS AND DISCUSSION

The purpose of a process modeling is exactly the possibility of implementing the developed model into an automatic system for that process control. Figures 2 and 3 contain suggestions for the simplified control schemes of the flotation plant "Veliki Krivelj" that would include controllers based on the soft computing methods as a form of decision support (fuzzy logic controller), or as an independent control unit (ANN controller). In this case, the classical PID controllers would be used for the lower hierarchical control levels, such as: air flow rate, pulp pH value, pulp level in flotation cells, redox potential value (Eh), etc.

Based on the developed fuzzy logic and ANN models, it is possible to consider recommendations for the positions of appropriate control modules within the automatic control system in the "Veliki Krivelj" Flotation Plant.

The results of the models development allow the functional positioning of the fuzzy logic controller in two variants of the control system architecture (Figure 2). According to one variant, the flotation process control would take place through the control actions of a single fuzzy logic controller, while in the another variant, the functionality of fuzzy logic model would be realized through the separate fuzzy logic controllers: (1) for rough flotation and scavenging on one side, and (2) cleaning on the other side.

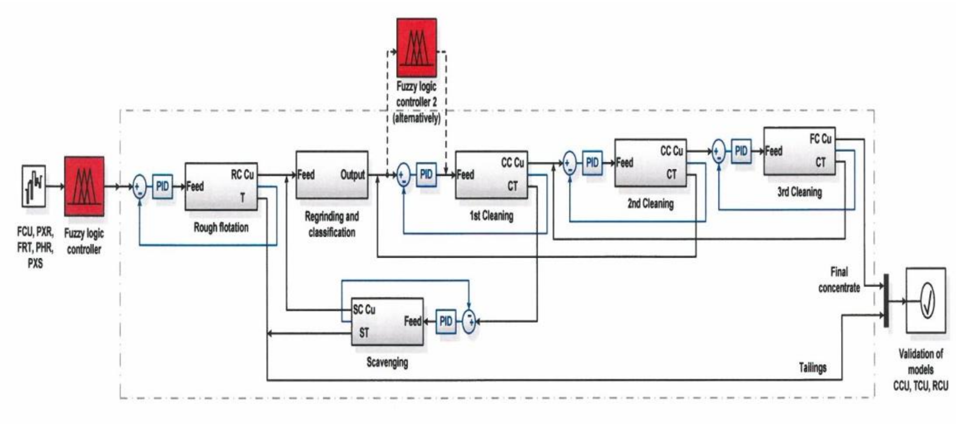

Figure 2 *Scheme of intelligent system for the flotation process control based on the fuzzy logic controller(s)*

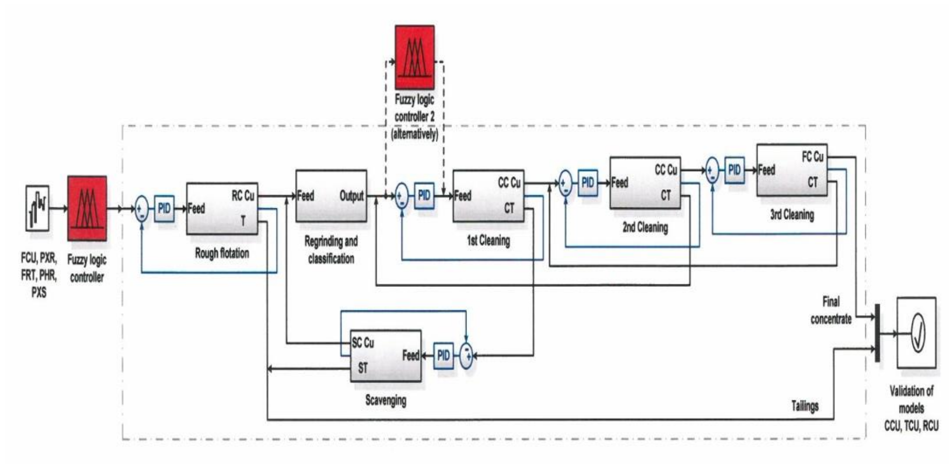

Figure 3 *Scheme of intelligent system for the flotation process control based on the artificial neural network controller(s)*

Architecture of the automatic control system allows the elaboration of both variants. By the first variant, the fuzzy models would perform the high level control of the practically entire flotation process. (Note: Although technologically closely related to the flotation, grinding and classification would be omitted from this decision support system, due to the specificity of fuzzy rules construction and qualitatively different characteristics. In that respect, it would be necessary to employ a new soft computing-based controller, or some other type of controller.)

Model performances, in spite of the large fuzzy rule base (753 rules in total), enable control of the plant operation in described manner. However, if the number of monitored parameters significantly increase, a large expansion of the fuzzy rule base would be necessary, and in a such case, the model performances would potentially decrease. In this situation, the justification of the second variant (i.e. employing of two connected, but according to the rule bases and membership functions independent fuzzy controllers) would be certain.

The rougher flotation and scavenging on one side, and cleaning on the other side are technologically enough different, therefore introducing the additional control stage would be economically justified. The flexibility of the fuzzy rule base is such that, with the adjustment of membership functions, development of the new fuzzy controller would be facilitated. Accordingly, there would be no significant differences in the way in which both controllers operate.

Similar conclusions are also justified when it comes to the artificial neural network - based controller (Figure 3), but it is necessary to examine the performances of the controller in a real dynamic system. It is usual that the ANN - based algorithms and models generally show better performances than fuzzy logic - based [6], but this is not the case in all industrial (and test) flotation systems. The decision on which control variant is optimal for the given technological process needs to be made "on the spot", taking into account the specificity of observed system.

CONCLUSION

Intelligent control methods are developed in a manner that they emulate characteristics of the human intelligence such as adaptation and learning, planning under high uncertainty and computing immense quantities of data. Therefore, these methods may be suitable for the flotation system control. In this paper, the possibility of introducing an intelligent controller into the industrial flotation plant “Veliki Krivelj” was considered. It was concluded that the fuzzy logic or ANN - based controllers can be positionned in two ways. In the first case, control of the entire process would be performed through the control actions of a single intelligent controller. In the second case, there would be two intelligent controllers: for rough flotation with scavenging, and cleaning the copper concentrate.

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METALLURGY IN THE MEDIEVAL BRANICEVO****

Abstract

During the archeological researches of the medieval Branicevo at the site Mali Grad-Todica crkva in the Kostolac village, a significant amount of iron slag was discovered. The archeological context is indicative but so far, it does not provide the precise defining the spatial function with archeological and metallurgy findings. For that purpose, the physical and chemical analyses of the archeometal samples were carried out. The results of the investigation show the primary metallurgical activity in Branicevo in the second half of the XI and XII century, while the presence of wüstite (FeO), fayalite and magnetite in most of samples indicates the iron melting. Evidences of the primary iron metallurgy show the economic significance of Braničevo in a new light and the structural analyzes of slag are important for defining the casting process and degree of the iron metallurgy development during the Byzantine government in Braničevo.

Keywords: *Branicevo, iron, smelting, metallurgy, slag*

INTRODUCTION

The medieval town of Braničevo was developed on the territory of the Roman Viminacium, on the banks of the river Mlava. The two fortified structures of the urban core of Braničevo were located on the Mali and Veliki Grad, the natural units at the end of the Sopot Greda above the village Kostolac, while the spacious suburb spread to their base [1]. *(Location Mali Grad in the first half of the XX century was re-named into the 'Todića crkva', and in the literature is reffered to as Mali Grad – Todića crkva)*

As a natural fortification system that protected and controlled the Danube passage, Mali Grad-Todića crkva was of great importance since the Eneolithic, up to the modern age (Fig. 1).

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**** *This paper represents the result of multidisciplinary research on the projects 'Archeological Research of the Medieval Town of Braničevo', supported by the National Museum Pozarevac, and backed up by the City of Pozarevac (lead by the museum advisor, archaeologist Dragana Spasić-Đurić) and the project of the Ministry of Education and Science of the Republic of Serbia. Ethnogenesis of the Serbs during the Middle Ages (until c.1250): a comparative analysis of the historic-cultural heritage, genetic material and artefacts of material culture from the aspect of analytical chemistry (Reg.No. III 47025)*

Fig. 1 *Site Mali Grad-Todića crkva, explored zone with the archeometallurgical findings*

The new archeological researches at this locality, begun in 2007, show the new aspect of political and economic significance of Braničevo during the Byzantine Government in the XI and XII century. On the systematically investigated area of about 480 m^2, primarily on the western periphery of the site, three cultural horizons were discovered: from the Hallstatt, Late La Tène period – early Roman and medieval times. The attention is focused on the earliest, medieval horizon and the period of strong economic and political bloom under the rule of the Komnenos dynasty, at the end of the XI and during the XII century [2].

ARCHEOLOGICAL CONTEXT

The results of researches from 2014 to 2017 are of a big importance. On the area of approximately 20x20 m, in the squares AC23, AC24, AD23- AD25, AE23, AE24 and AF24, a significant amount of scrum and slag (Fig.1) was discovered. Archeometal samples were found in the indicative archeological context consisting of furnaces, fireplaces and waste burial pits. Generally, all collected samples have light or dark brown color; some are metallic and heavy, while the other group has a glassy gloss, porous structure and light weight. Precise functional definition of the explored area is prevented by large devastations, since except for the two preserved furnaces and Burial pits, other objects have not been discovered *in situ*. The discovery of slag from the mold (the so-called 'casting cake') in the Burial pit XXVII is particularly significant, which was preliminarily dated using money from the last decades of the XI and the first decades of the XII century (Fig. 2).

A large concentration of archaeometallurgical findings was recorded in the squares AD24 and AE24 in the zone of two fully preserved furnaces and object-House 8, whose devastated fireplace was discovered in parts outside the original context. It is significant that the fractions of the fireplace, due to high temperatures, were merged with larger pieces of slag.

Fig. 2 *Slag from a mold, the Burial pit XXVII*

According to the dimensions and construction (air vents, so-called "blowers" and larger rectangular chimney at the top), in a functional aspect, the furnace 16 triggers quite a confusion. Its construction elements indicate that it was used to develop high temperature, which further indicates a special purpose [3, 4]. Unfortunately, the furnace was discovered completely cleaned, and after having its bottom part renovated, it was not put into operation again due to the unknown reasons. Therefore, at this stage of research, there is no archaeological evidence to indicate its metallurgical function. The specific archaeological context and certain typological similarities with some casting furnaces from the early Laten and the Late La Tène period from Bavaria do not exclude this assumption completely.

PHYSICAL AND CHEMICAL ANALYSES

For the purpose of determining and defining the function of space with higher concentration of slag, as well as the character of the activities that took place at this site during the XI and XII century, the physical and chemical analyses were carried out of individual samples from the Braničevo research in 2015 and 2016, and the results of these analyses represent the focus of this paper

The selected archeometal samples were subjected to the chemical and scanning electron microscopy at the Faculty of Mechanical Engineering in Belgrade (Tables 1, 2, Figures 3 (a-f), 4 (a-g), as well as the X-ray diffraction analysis in the Mining and Metallurgy Institute in Bor (Figures5-10, Tables 3-8).

TEST RESULTS

Chemical analysis

The results of samples subjected to the chemical analysis are shown in Tables 1 and 2.

Table 1 *Results of the chemical analysis of the archeometal samples from the site Mali Grad-Todića crkva*

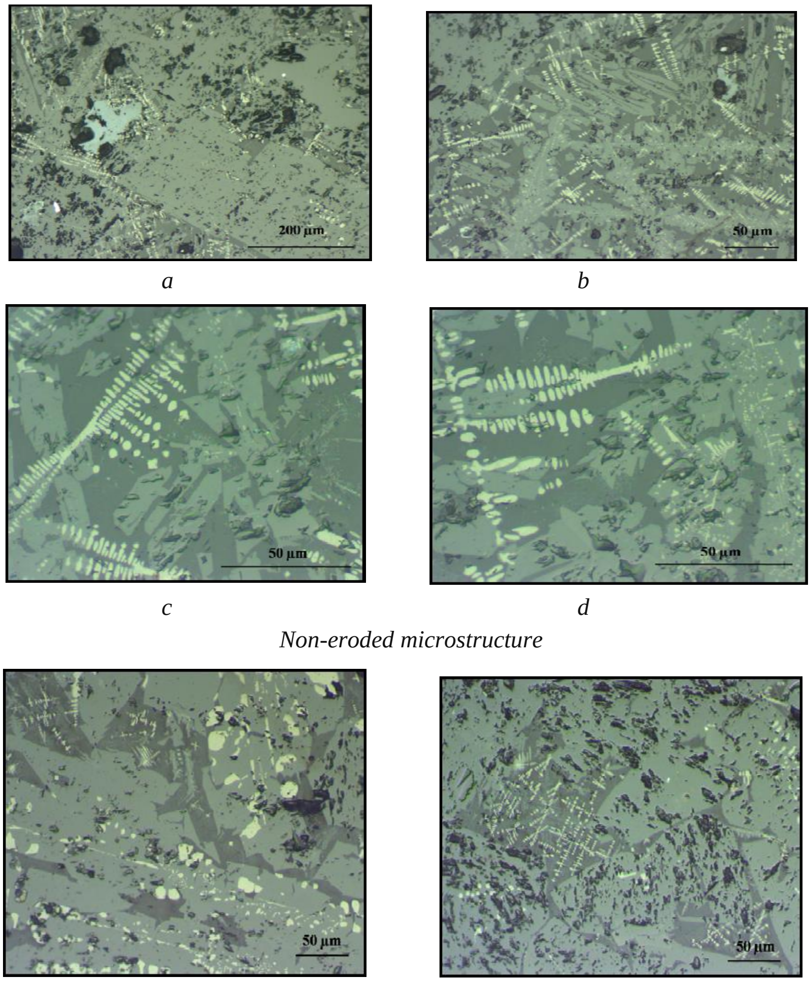
Name **TCI**	***Class*** **Alloy LE FP**		***Date*** **30/11/2016**		***Time*** **11:54:44**		***Duration*** **10.5 s**	
Sample 1	*Fe (%)*	*Si (%)*	*P (%)*	*Al (%)*	*Zr (%)*	*As (%)*	*Ti (%)*	*Pd (%)*
	54.90	31.29	7.62	5.95	0.19	0.05	/	/
Deviation (+/-)	0.723	0.803	0.307	1.238	0.028	0.013	/	/
Rating								
Name **TCI**	***Class*** **Alloy LE FP**		***Date*** **30/11/2016**		***Time*** **11:53:14**		***Duration*** **10.5 s**	
Sample 2	*Fe (%)*	*Si (%)*	*P (%)*	*Al (%)*	*Zr (%)*	*As (%)*	*Ti (%)*	*Pd (%)*
	56.84	28.43	5.96	7.37	0.28	/	0.84	0.28
Deviation (+/-)	0.735	1.005	0.448	1.265	0.028		0.209	0.086
Rating								
Name **TCI**	***Class*** **Alloy LE FP**		***Date*** **30/11/2016**		***Time*** **11:53:51**		***Duration*** **10.5 s**	
Sample 3	*Fe (%)*	*Si (%)*	*P (%)*	*Al (%)*	*Zr (%)*	*As (%)*	*Ti (%)*	*Pd (%)*
	54.60	30.13	7.33	7.71	0.23	/	/	/
Deviation (+/-)	0.739	0.822	0.317	1.303	0.029	/	/	/
Rating								

Table 2 *Results of the chemical analysis of the archeometal samples from the site Mali Grad-Todića crkva*

Name **TCI**		***Class*** **Alloy LE FP**		***Date*** **30/11/2016**		***Time*** **11:54:09**		***Duration*** **2.5 s**	
Sample-4	*element*	*Fe (%)*	*Mn (%)*	*Sb (%)*	*Sn (%)*	/	/	/	/
	value	96.27	2.43	0.81	0.49	/	/	/	/
	deviation (+/-)	1.301	0.238	0.140	0.147	/	/	/	/
Rating		1.0257 (0.00)	1.2842 (0.53)	/	/	/	/	/	/
Name **TCI**		***Class*** **Alloy LE FP**		***Date*** **30/11/2016**		***Time*** **11:54:45**		***Duration*** **10.5 s**	
Sample-5	*element*	*Fe (%)*	*Si (%)*	*Mn (%)*	*Sb (%)*	*Pb (%)*	/	/	/
	value	92.07	6.34	0.95	0.50	0.14	/	/	/
	deviation (+/-)	0.886	0.527	0.137	0.137	0.036	/	/	/
Rating		1.2542 (3.05)	1.0473 (3.45)	/	/	/	/	/	/
Name **TCI**		***Class*** **Alloy LE FP**		***Date*** **30/11/2016**		***Time*** **11:55:39**		***Duration*** **10.5 s**	
Sample-6	*element*	*Fe (%)*	*Si (%)*	*Mn (%)*	*P (%)*	*S (%)*	*Zn (%)*	*Zr (%)*	
	value	79.60	16.65	2.11	1.18	0.30	0.10	0.07	
	deviation (+/-)	0.777	0.644	0.169	0.201	0.084	0.029	0.022	
Rating		1.2542 (3.90)							

Scanning electron microscopy

Scanning electron microscopy was done on two samples that were, after preparation, photographed by the optical microscope in their non-eroded and eroded state. A part of the sample, broken into fragments, was turned into dust for the purpose of X-ray analysis in order to identify the phases (Figures 3, 4).



a *b*

c *d*

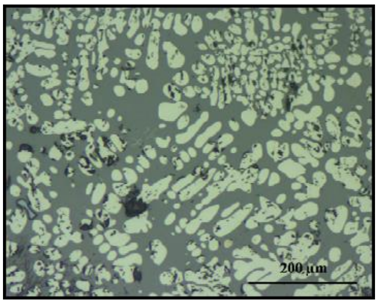
Non-eroded microstructure

e *f*

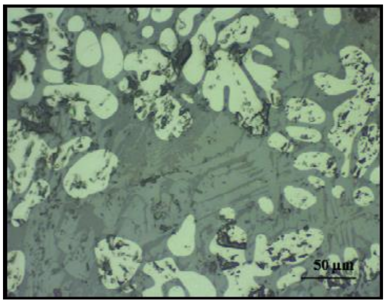
Eroded microstructure (nital)

Fig. 3 (a-f) *Structure of the sample No.5 from the site Mali Grad – Todića crkva*

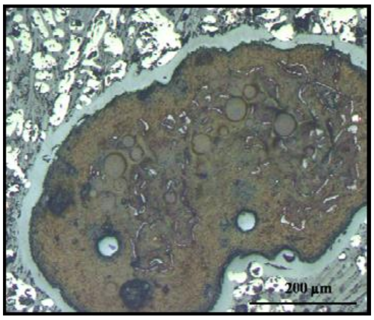
The sample has a very heterogeneous and highly porous microstructure consisting of a large amount of slag in which the metal dendrites (*wüstite*) are separated. The slag is consolidated with an iron metal base that occurs mainly in a dendritic form. The high-content of SiO_2 was identified by the X-ray analysis.



a

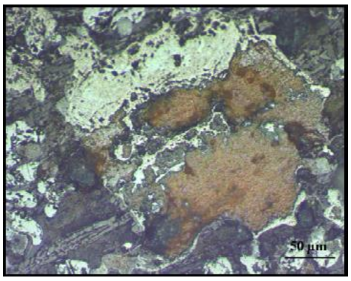


b



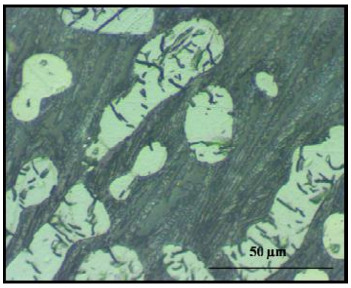
c

Non-eroded microstructure

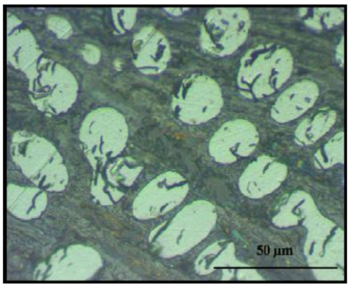


d

e



f



g

Eroded microstructure (nital)

Fig. 4 (a-g) *Structure of the sample No.6 from the site Mali Grad – Todića crkva*

The sample has a very heterogeneous and highly porous microstructure. A high concentration of FeO was identified by the X-ray analysis. The structure of samples indicates that it is a slag created in the process of obtaining iron from the ore iron.

X-ray diffraction tests

The results of X-ray diffraction tests of archaeometallurgical samples from the site Mali Grad – Todića crkva are shown in the X-ray diffractograms in Figures 5-10, and identification of the mineral (phase) composition of the tested samples is shown below the diffractograms in Tables 3 to 8.

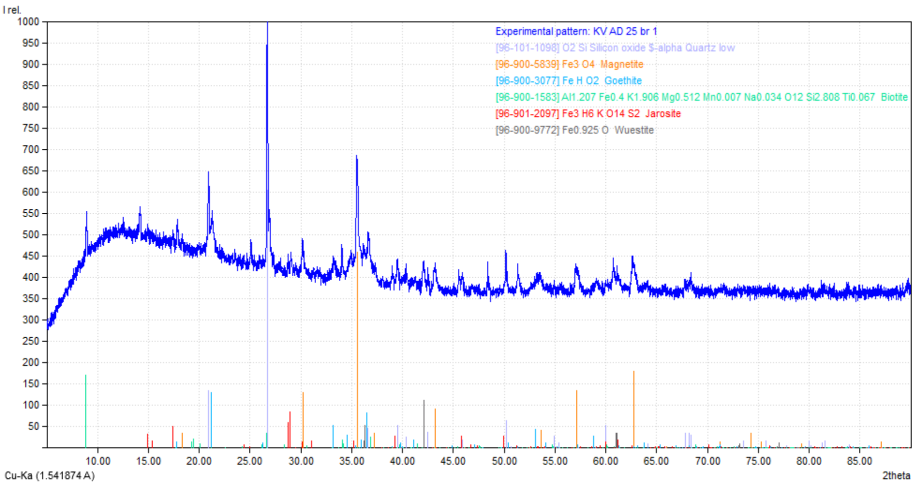


Fig. 5 *Diffractogram of the sample No.1 from the slag AD25*

Table 3 *Results of the X-ray diffraction sof the sample No.1 from the slag AD25*

Identified minerals	Chemical formula
Quartz	SiO_2
Magnetite	Fe_3O_4
Getite	FeO(OH)
Biotite	$K(Mg,Fe)_3AlSiO_{10}(F,OH)_2$
Jarosite	$KFe(OH)_6(SO_4)_2$
Wüstite	FeO

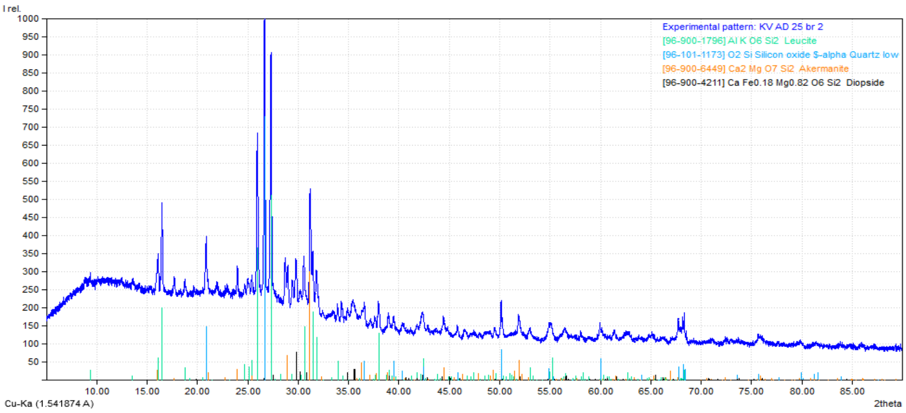


Fig. 6 *Diffractogram of the sample No.2 from the slag AD25*

Table 4 *Results of the X-ray diffraction analysis of the sample No. 2 from the slag AD 25*

Identified minerals	Chemical formula
Leucite	$K(AlSi_2O_6)$
Quartz	SiO_2
Accermanite	$Ca_2MgSi_2O_7$
Diopside	$MgCaSi_2O_6$

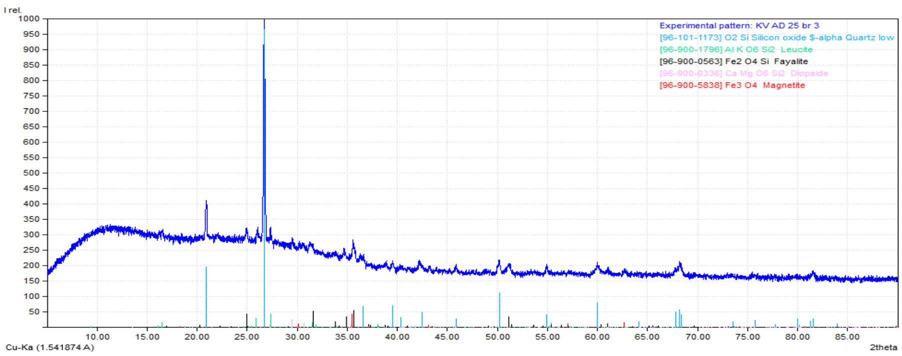


Fig. 7 *Diffractogram of the sample No.3 from the slag AD25*

Table 5 *Results of the X-ray diffraction analysis of the sample No. 3 from the slag AD25*

Identified minerals	Chemical formula
Quartz	SiO_2
Leucite	$K(AlSi_2O_6)$
Fayalite	Fe_2SiO_4
Diopside	$MgCaSi_2O_6$
Magnetite	Fe_3O_4

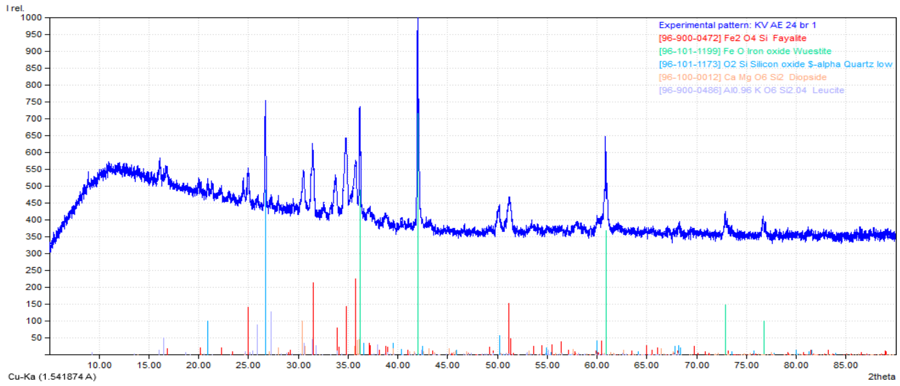


Fig. 8 *Diffractogram of the sample No.1 from the slag AE24*

Table 6 *Results of the X-ray diffraction analyzis of the sample No.1 from the slag AE24*

Identified minerals	Chemical formula
Fayalite	Fe_2SiO_4
Wüstite	FeO
Quartz	SiO_2
Diopside	$MgCaSi_2O_6$
Leucite	$K(AlSi_2O_6)$

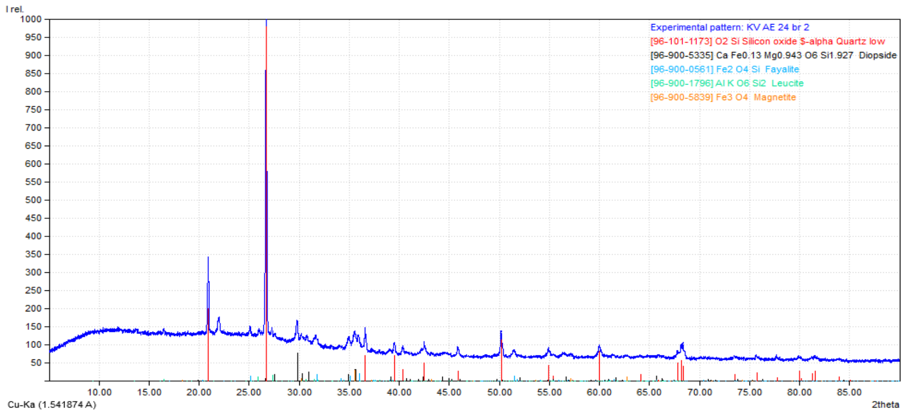


Fig. 9 *Diffractogram of the sample No.2 from the slag AE24*

Table 7 *Results of the X-ray diffraction analysis of the sample No. 2 from the slag AE24*

Identified minerals	Chemical formula
Quartz	SiO_2
Diopside	$MgCaSi_2O_6$
Fayalite	Fe_2SiO_4
Leucite	$K(AlSi_2O_6)$
Magnetite	Fe_3O_4

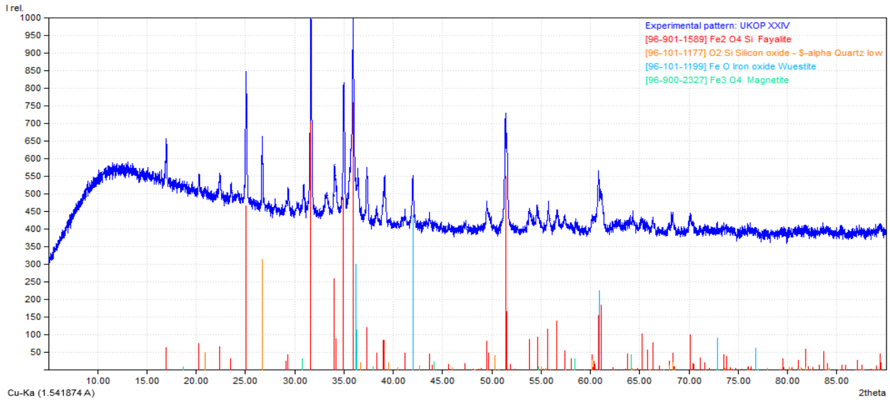


Fig. 10 *Diffractogram of the sample from the Burial pit XXIV*

Table 8 *Results of the X-ray diffraction analysis of the sample from the Burial pit XXIV*

Identified minerals	Chemical formula
Fayalite	Fe_2SiO_4
Quartz	SiO_2
Wüstite	FeO
Magnetite	Fe_3O_4

DISCUSSION OF THE RESULTS

The testing results of archaeometallurgical samples from the site Mali Grad-Todića crkva by the chemical analysis, X-ray diffraction testing and scanning electron microscopy, indicate the presence of wüstite, fayalite, magnetite and biotite in most of the samples. Analyzed samples are characterrized by a greater presence of iron slag, which means the production of iron with limited capacities, probably in so-called ovens (so-called "Grne"). Based on the X-ray diffraction analysis of the sample from Table 3 (Fig. 5), it can be concluded that the sediment of magnetite ore was used as the starting material for iron production, which in itself, due to the influence of time and conditions in the environment, contained the iron transformations such as: goethite, biotite, jarosite and wüstite.

The other samples relate to the slag, and the presence of fayalite Fe_2SiO_4, wüstite, FeO and magnetite, Fe_3O_4 and they indicate that the melting process, which incorporated these components into slag, did not allow complete reduction of ore (Fe_3O_4) into metal (Fe). In other words, the iron obtained from the ore (i.e. the degree of metal utilization), in qualitative terms, was not at a high level. The reason for this was probably the lower reduction temperature, whereby all iron oxides (Fe_3O_4, FeO) could not be reduced to the metal (Fe).

The presence of diphaside $MgCaSi_2O_6$ indicates that, as a solvent for lowering the SiO_2 melting point, a smaller amount of solvent in the form of dolomite $CaCO_3$ x $MgCO_3$ was most probably used.

2CaO x SiO_2, whose production requires a relatively higher temperature of iron reduction, is missed in a slag that according to the obtained results, was the demerit of a smelting process in Branicevo.

In the primary phase, iron was poured into the molds. After cooling, the content (metal and slag) was removed from the mold. The metal was further used, and a hardened slag, which was above metal, would retain the shape of the mold and was left aside. This is indicated by discovery of the slag in the shape of a mold from the Burial pit XXVII (Fig. 2).

Structures of archaeometallurgical samples from the site Mali Grad-Todića crkva, unambiguously indicate the primary iron metallurgy.

According to the qualitative characteristics of the analyzed samples, the casting process of obtaining iron from the ore in Branicevo was not at a high technological level, which is a general feature of the casting technologies at the other medieval sites. The main problem for the smelters in those times during the reduction process was the inability to achieve high temperatures [3,6,7].

From the perspective of today's technological processing, in the primary metallurgical processing, the iron needs to be heated to over 1535°C, in order to convert into a liquid state of honey density, which as such lies at the bottom of the casting furnace, which would then collapse, in order to reach the arched iron at the bottom. Archaeological discoveries of casting furnaces and other metallurgical installations from the ancient and medieval period indicate that in the process of iron dissociation, it was not possible to achieve such a high temperature [5,6].

The obtained iron, depending on the reduction process, was, to a greater or lesser extent, contaminated with slag (fuel residues, solvent), which was impossible to completely separate during the primary melting. The iron thus obtained (the so-called porous iron) was then subjected to the secondary metallurgical processing. The secondary reduction involves re-heating and forging, whereby the process of removing impurities, i.e. separating the iron from the slag, proceeded mechanically [3,7,8].

CONCLUSION

The results of physical and chemical analyses of archeometallurgical findings of research at the site Mali Grad-Todića crkva, obtained by the chemical analysis methods, scanning electron microscopy and X-ray diffraction tests, indicate that during the XI and XII century there was a smelting activity related to the iron metallurgy in Branicevo. This is evident from the structures of the samples with the presence of wüstite, fayalite and magnetite. The sediment of magnetite ore was identified as the starting material for obtaining iron.

The analytical methods confirmed the archeological assumptions based on a specific archaeological context with some archaeometallurgical elements and installa-tions due to devastation, were not enough to make precise conclusions about the function of the explored space.

Findings of slag are frequent occurrences in archaeological sites. They are usually the result of a secondary reduction, i.e. refining process, or successive heating and coating of crude iron. As mentioned, this is preceded by the phase of casting by the primary metallurgy process, where the casting pro-cess of the ore took place outside the residential territory [5,9].

Whether the smelting process of limited capacities in the medieval Branicevo was carried out within the fortification, i.e. area marked in Fig. 1 or in its immediate vicinity, perhaps below the during the XI and XII century, on the bank of the Dunavac, remains a dilemma that can be resolved only by the archaeological research and discovery of a melting furnace *in situ*.

On the other hand, the results show the significance of analysis of slag for defining the medieval smelting technologies and the level of knowledge of the smelters in those times, since the structural analysis of slag elements provide the important data on the final stage of smelting process [6,7,8].

The results received from a limited number of samples indicate the 'underdeveloped' technology and inability to achieve the required temperature in the process of thermal dissociation and iron extraction. However, the final conclusions about the character of the primary metallurgical process in Branicevo during the XI and XII century will be formed after analyzing a larger number of samples.

At the present level of research the site Mali Grad-Todića crkva, the presented results present the unambiguous proof of the primary iron metallurgy in Braničevo during the Byzantine Government and they represent a significant contribution to the knowledge of medieval mining in Serbia during the XI and XII century.

Also, the analysis of archaeometallurical samples from the site Mali grad-Todića crkva affirms the necessity of interdisciplinary research in order to solve numerous issues of ore origin, methods of supply, melting site location, metallurgical processes and defining the degree of iron metallurgy development in the medieval period.

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AN APPROACH TO THE EVALUATION OF FROTH FLOTATION REAGENTS BASED ON THE USE OF THE SWARA AND WS-PLP METHODS[***]

Abstract

The selection of the most suitable flotation reagents is very important in the froth flotation process because the recovery of valuable minerals largely depends on the reagent regime. On the other hand, the particular characteristics of the ore excavated from different mine sites have their own specificity that should be taken into account in choosing the most appropriate reagents. Therefore, a proposal for forming a framework for selecting the most suitable flotation reagents is discussed in this paper. The usability and efficiency of the proposed approach are considered on the conducted empirical example.

Keywords*: reagents; froth flotation; MCDM; SWARA; WS-PLP*

1 INTRODUCTION

Froth flotation is an industrial process widely used in the mineral processing for selective separation the finely liberated hydrophobic minerals.

The froth flotation separation process is based on attaching the very fine particles of valuable minerals to the surface of air bubbles. The efficiency of separation and utilization the valuable minerals largely depends on the hydrophobic character of mineral surfaces. Therefore, the flotation reagents have a substantial impact on utilization the valuable minerals, as well as the efficiency of flotation process.

There are a number of characteristics of the floated ore particles that could signifii cantly affect the separation of useful minerals. Therefore, the selection of appropriate reagents is not easy to do.

There are many, mutually conflicting, criteria that could have an impact on the selection of the most adequate flotation reagent, which is indicative of the fact that selection of the most adequate floatation reagent could be considered as a multiple criteria decision - making (MCDM) problem.

Therefore, this paper is organized as follows: In Section 2, the criteria relevant for selection the most appropriate flotation reagents are considered. After that, in Sections 3 and 4, the two characteristic MCDM methods intended for determining the weights of

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evaluation criteria and selecting the most appropriate alternative, respectively, are presented. Based on the previous considerations, a multiple criteria group decision-making approach is proposed in Section 5, whereas the usability and efficiency of the same are checked in Section 6. Finally, the Conclusions are given at the end of the manuscript.

2 CRITERIA RELEVANT FOR SELECTION THE MOST RELEVANT FROTH FLOTATION REAGENTS

There are a number of technological parameters depending on the flotation pulp conditions that indicate the successfulness of the flotation process (Magdalinovic, 2017; Langa *et al*., 2014; Lotter and Bradshaw, 2010; Bulatovic, 2007). In the cases of copper sulfide ore flotation, the following parameters could be stated as some of the most significant:

- recovery of Cu in concentrate,
- concentrate grade,
- tailings grade, and
- economic efficiency.

From the MCDM perspective, these criteria could not be easily characterized as the beneficial (revenue) and non-beneficial (cost) criteria. The main reason for this is the fact that the above-mentioned evaluation criteria are not mutually independent, which can especially be observed in a relationship between recovery and economic efficiency, i.e. changes in the recovery of valuable minerals, and throughput of flotation cells can significantly affect changes in the economic effects of flotation through a very complex relationship.

However, this problem can successfully be overcome using the WS-PLP method, which will be explained in the remaining part of this manuscript.

3 THE SWARA METHOD

The SWARA method was proposed by Kersuliene *et al*. (2010). The SWARA method could be used to determine the weights of criteria and also to solve the complex multiple criteria decision-making problems. In addition to this, compared to the well-known AHP method, the SWARA method requires a significantly lower number of pairwise comparisons.

Based on Kersuliene *et al*. (2010) and Stanujkic *et al.* (2015), the computational procedure of the ordinary SWARA method can be precisely presented applying the following steps:

***Step* 1**: Determination of a set of relevant evaluation criteria and sort them in descending order, based on their expected significances.

***Step* 2**: Starting from the second criterion, determination the relative importance s_j of the criterion j in relation to the previous (j-1) criterion, and do so for each particular criterion.

***Step* 3**: Determination the coefficient k_j as follows:

$$k_j = \begin{cases} 1 & j=1 \\ s_j+1 & j>1 \end{cases}. \tag{1}$$

***Step* 4**: Determination the recalculated weight q_j as follows:

$$q_j = \begin{cases} 1 & j=1 \\ \dfrac{q_{j-1}}{k_j} & j>1 \end{cases}. \tag{2}$$

***Step* 5**: Determination the relative weights of evaluation criteria as follows:

$$w_j = \frac{q_j}{\sum_{k=1}^{n} q_k}, \tag{3}$$

where w_j denotes the relative weight of the criterion j.

4 THE WS-PLP METHOD

The WS-PLP method was proposed by Stanujkic and Zavadskas (2015) as an extension of the well-known Weighted-Sum Method. Based on Vujic *et al.* (2016), the computational procedure of the WS PLP method for an MCDM problem containing *m* alternatives and *n* criteria could be precisely expressed as follows:

***Step* 1**: Evaluatation the alternatives in relation to the selected set of criteria.

***Step* 2**: Defining the preferred performance ratings for each criterion. At this step, the decision - maker sets the preferred performance ratings for the evaluation criteria, thus forming the virtual alternative $A_0 = \{x_{01}, x_{02}, \ldots, x_{0n}\}$. If the decision - maker does not have preferences for any criterion, it should be determined as follows:

$$x_{0j} = \begin{cases} \max\limits_i x_{ij} \mid j \in \Omega_{\max} \\ \min\limits_i x_{ij} \mid j \in \Omega_{\min} \end{cases}, \tag{4}$$

where x_{0j} denotes the preferred performance rating of the criterion *j*.

***Step* 3**: Construction a normalized decision matrix. The normalized performance ratings should be calculated as follows:

$$r_{ij} = \frac{x_{ij} - x_{0j}}{x_j^+ - x_j^-}, \tag{5}$$

where:

$$x_j^+ = \begin{cases} \max\limits_i x_{ij} \mid j \in \Omega_{\max} \\ \min\limits_i x_{ij} \mid j \in \Omega_{\min} \end{cases}, \text{ and} \tag{6}$$

$$x_j^- = \begin{cases} \min\limits_i x_{ij} \mid j \in \Omega_{\max} \\ \max\limits_i x_{ij} \mid j \in \Omega_{\min} \end{cases}. \tag{7}$$

***Step* 4**: Calculation the overall performance rating for each alternative, as follows:

$$S_i = \sum_{j=1}^{n} w_j \, r_{ij}, \tag{8}$$

where S_i denotes the overall performance rating of the alternative *i*.

***Step* 5**: Calculation the compensation coefficient for the all alternatives with $S_i > 0$, as follows:

$$c_i = \lambda \, d_i^{\max} + (1-\lambda) \, \bar{S}_i^*, \tag{9}$$

with:

$$d_i^{+\max} = \max_i r_{ij} w_j; \quad r_{ij} > 0, \tag{10}$$

$$\bar{S}_i^+ = \frac{S_i^+}{n_i^+}, \text{ and} \tag{11}$$

$$\bar{S}_i^* = \frac{S_i^+}{n_i^*}, \tag{12}$$

where: $d_i^{\max}$ denotes the maximum weighted normalized distance of the alternative *i* to the preferred performance ratings of the all criteria, so that $r_{ij} > 0$; $\bar{S}_i^*$ denotes the average performance ratings achieved on the basis of the criteria, so that $r_{ij} \geq 0$; n_i^+ denotes the number of criteria of the alternative *i*, so that $r_{ij} \geq 0$; λ is coefficient, $\lambda = [0.1]$ and is usually set at 0.5.

***Step* 6**: Calculation the adjusted performance rating for the all alternatives S' with $S_i > 0$, as follows:

$$S_i' = S_i - \gamma \, c_i, \tag{13}$$

where the decision-maker can reduce, or even eliminate, the impact of compensation coefficient varying the values of the coefficient γ.

***Step* 7**: Ranking the alternatives and select the most efficient one. The considered alternatives are ranked by ascending S_i'.

The usage of the compensation coefficient is not mandatory in the WS PLP method and can be omitted setting the value of coefficient γ to zero.

5 A FRAMEWORK BASED ON THE USE OF THE SWARA AND THE WS-PLP METHODS

The framework based on the SWARA and the WS-PLP methods can accurately be expressed through the following phases and the corresponding steps:

Phase I: ***Formation a team of experts who will carry out the evaluation, determine the set of available alternatives and form the set of the evaluation criteria***.

Phase II: ***Determining the relevance and weights of evaluation criteria***. In the proposed approach, the SWARA method is proposed for determining the weights of evaluation criteria.

Phase III: ***Evaluation the alternatives***. The evaluation of alternatives is based on the use of the WS-PLP approach. The performances of alternatives in relation to the chosen evaluation criteria should be between 1 and 5, where any real number, located at the specified interval, could be used in order to make an evaluation more precisely.

Phase IV: ***Selection the most appropriate alternative***. As a result of conducting the previous phase, the K ranking orders of alternatives are obtained.

Based on the theory of ordinal dominance, the alternative appearing in the first position for the largest number of times is potentially the most appropriate one. However, in some cases, when the dominant alternative is not so easy to determine, the evaluation process should be sent back and the experts should reconsider its rating.

6 AN EMPIRICAL ILLUSTRATION

In this section, an example of selection the most adequate froth flotation reagents is considered so as to briefly demonstrate the efficiency and usability of the above-considered approach. The selection of the most adequate froth flotation reagents is considered on the ore excavated from the Veliki Krivelj Open Pit.

A team of experts was formed with the aim of proposing the most appropriate reagent from the following:

- A_1 - Potassium ethyl xanthate (PEX),
- A_2 - TC 1000,
- A_3 - Aero MX 5126, and
- A_4 - S 10887.

For the purpose of making an evaluation of the above-mentioned alternatives, the team of experts has chosen the following criteria:

- C_1 - recovery of Cu in rougher concentrate, %
- C_2 - content of Cu in rougher concentrate, %
- C_3 - economic efficiency
- C_4 - specific surface area of rougher concentrate, cm^2/g

It should be noted that the criteria were considered under the following conditions: (1) grinding fineness 60% -75μm and (2) pulp pH 10.

After that, the team of three experts has determined the weights of evaluation criteria applying the proposed approach, i.e. using Eqs (1)-(3). The values of relative importance s_j for the selected criteria are shown in Table 1.

In this evaluation, the values of s_j were determined on the basis of consensus of three experts.

In the next phase, the experts made an evaluation of the preselected flotation reagents in relation to the set of evaluation criteria. The obtained ratings, as well as the weights and preferred ratings obtained from three experts are given in Tables 2, 3 and 4.

Table 1 *The relative importance and weights of criteria*

Criteria	s_j	k_j	q_j	w_j
C_1		1	1	0.49
C_2	0.90	1.90	0.53	0.26
C_3	0.70	1.70	0.31	0.15
C_4	0.50	1.50	0.21	0.10
			2.04	1.00

Table 2 *The ratings, weighting and preferred ratings obtained from the first of three experts*

Criteria	C_1	C_2	C_3	C_4
w_j	0.49	0.26	0.15	0.10
A*	4.70	4.00	4.50	5.00
A_1	3.10	4.00	3.00	2.00
A_2	3.90	3.00	3.20	5.00
A_3	4.70	2.50	4.50	3.00
A_4	4.20	3.50	3.30	4.00

Table 3 *The ratings, weighting and preferred ratings obtained from the second of three experts*

Criteria	C_1	C_2	C_3	C_4
w_j	0.49	0.26	0.15	0.10
A*	5.00	3.50	4.50	4.80
A_1	2.90	3.50	2.50	2.60
A_2	3.70	2.50	3.50	4.80
A_3	5.00	2.00	4.50	3.40
A_4	4.30	3.30	4.00	4.30

Table 4 *The ratings, weighting and preferred ratings obtained from the third of three experts*

Criteria	C_1	C_2	C_3	C_4
w_j	0.49	0.26	0.15	0.10
A*	4.80	3.70	4.50	4.80
A_1	3.00	3.70	2.70	2.50
A_2	3.90	2.70	3.10	4.80
A_3	4.80	2.50	4.50	3.10
A_4	4.20	3.50	3.30	4.20

The normalized decision matrix and weighted normalized decision matrix formed on the basis of responses obtained from the first of three experts are accountted in Tables 5 and 6.

Table 5 *The normalized decision matrix based on responses obtained from the first of three experts*

Criteria	C_1	C_2	C_3	C_4
A_1	-0.20	-1.05	-1.27	0.00
A_2	-0.40	-0.53	-0.91	-0.50
A_3	-0.76	-1.53	-0.36	-1.00
A_4	-1.20	-0.53	-1.36	-0.50
A_5	-0.20	-1.05	-1.27	0.00

Table 6 *The weighted normalized decision matrix based on responses obtained from the first of three experts*

Criteria	C_1	C_2	C_3	C_4
A_1	-0.10	-0.28	-0.20	0.00
A_2	-0.19	-0.14	-0.14	-0.04
A_3	-0.37	-0.41	-0.06	-0.08
A_4	-0.58	-0.14	-0.22	-0.04
A_5	-0.10	-0.28	-0.20	0.00

In the same manner, the normalized decision matrix and weighted normalized decision matrix for the second and third experts were calculated. The performance ratings and ranking orders obtained on the basis of the responses obtained from the three experts are shown in Tables 7, 8, 9 and 10.

Table 7 *The ratings and ranking orders obtained on the basis of responses of the first of three experts*

	S_i	Rank
A_1	-0.74	4
A_2	-0.55	3
A_3	-0.33	1
A_4	-0.39	2

Table 8 *The ratings and ranking orders obtained on the basis of responses of the second of three experts*

	S_i	Rank
A_1	-0.74	4
A_2	-0.55	3
A_3	-0.32	2
A_4	-0.26	1

Table 9 *The ratings and ranking orders obtained on the basis of responses of the third of three experts*

	S_i	Rank
A_1	-0.74	4
A_2	-0.58	3
A_3	-0.33	1
A_4	-0.34	2

Table 10 *The ranks obtained from three experts*

	Expert 1	Expert 2	Expert 3
A_1	4	4	4
A_2	3	3	3
A_3	1	2	1
A_4	2	1	2

As can be seen from Table 10, the alternative labeled as A_3 ranks the first twice and, based on the theory of dominance, it is evident that the alternative A_3 is the most appropriate alternative.

In other words, the Aero MX 5126 reagent was chosen as the most suitable for the ore excavated from the Veliki Krivelj Open Pit.

CONCLUSIONS

In this article, a framework for selecting the most adequate froth flotation reagent is proposed.

The usability and efficiency of the proposed framework are considered in the real case and its usability is confirmed by the obtained results.

The proposed criteria can be replaced by the other criteria, which is indicative of the fact that the proposed framework is flexible and convenient for solving similar problems. Finally, the proposed framework is based on the use of two efficient and easy-to-use MCDM methods that should enable the easier acceptance and use of the framework for selecting the most acceptable reagents.

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WITH THE KNOWLEDGE TO THE WORLD OF ECOLOGICAL DEVELOPMENT - CASE OF THE “TREPCA” COMPANY, KOSOVSKA MITROVICA

Abstract

The modern era, in which humanity has encountered, is characterized by the numerous events, global economy, new world market, global ecological crisis, and permanent changes in all segments of business: in science, technique, technology, organization, management, etc., where the central place belongs to a key resource, that is the to human resources from which everything starts and everything depends. Today, it is necessary to have the high quality human resources that can ensure the effective realization of business and environmental policy objectives and are adequately related to the rapid technological changes that are increasingly turbulent and the changes in ownership transformation in which the Serbian society is still. Through the economic activity, the globalization of the world society more and more finds its foothold in all other spheres of life and work of modern man. As one planetary process it brings numerous criteria, standards and rules in all spheres of which the great emphasis is on the protection of the working and living environment as an inalienable property of humans, related to the life, health biological and spiritual integrity, survival and development. Today, there are many efforts in the world in order to make ecological problems crucial in the international and national legislation of every single country, and become the social responsibility of every enterprise, educational system and moral code of every individual. The Serbian society has encountered the ecological disaster caused by the war events in this area, as well as the other ecological problems caused by numerous industries. The region of Kosovo and Metohija with accent on the Kosovska Mitrovica area is concerned with numerous industrial waste materials resulted from various processes in the "Trepca" company. These materials, by their structure and method of disposal in the landfills, cause a great ecological problems and threats to the life and health of people, which will also be discussed in this paper.

***Keywords**: human resources, ecology, social responsibility, globalization, economics, quality*

1 INTRODUCTION

Enterprises as the economic systems have the task of using available social resources to meet the needs of society. Enterprises, through their business, growth and development, carry out economic activity that makes a national or world economy. In addition to the significant and numerous economic functions, the contemporary companies also have the significant non-economic functions and activities in development of society and civilization, and are important factor of sustainable development and ecological balance as one of the more important social dimensions.

The enterprises are the bearers of economic activities, as well as the survival and

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progress of the entire socio-economic reality. In the national economy of each country, the companies have a common role in the rational use of social resources and creation of a system of social needs. The achievement of wider social needs depends on the role taken in performing the certain tasks in the process of social reproduction. If the enterprise is more effective and efficient, the level of its economy condition, thanks to the quality human resources, is higher, which at the same time means that the goals of its business and development will be achieved at a higher level [1].

Natural systems comprise primarily the external and internal environment of the company. All enterprises either directly or indirectly through other enterprises are devastating the nature as a result of spending the available resources for the production of social goods. In addition, through the technological processes and products thrown away after the use, companies pollute the natural environment, disrupting in that way an ecological balance. By an excessive exploittation of non-renewable natural resources and contamination of the natural environment, companies can negatively affect the natural system of a particular country. Human must approach the exploitation of natural resources rationally and take care of the ecological treatment of natural systems in order to survive in the conditions of the activities of many enterprises directed to meet the wide and complex needs. Hence, one of the goals that individuals and society are increasingly interested in is an ecological goal, as a sum of activities related to the protection of nature, land, water and air, with the aim of protecting the life and health of people. That is why society comes out with requirements and laws for protection, primarily natural resources, as well as the laws that must be incorporated into the strategic goals of the company, in order to have no negative business effect, which would affect the ecological system as one of the pillars of sustainable development. The goals of modern economy oriented towards socially responsible business are becoming increasingly important and the concept of socially responsible business is becoming more and more accepted.

2 HUMAN RESOURCES IN CONTEMPORARY BUSINESS

Human is the key to success and the most important resource of any company. Human resource management is a key lever for achieving competitive advantage. A modern knowledge-based economy sets new demands for today's business systems and all other forms of business as well as for all employees when sustainable development is concerned. It supports the abandonment of narrowly skilled profiles of employees, emphasizing their competence and a greater role of general education. With the change of technologies, production procedures, organizational structures, environments, management, it requires permanent vocational education and employee development both for productive work and for protection of working and living environment.

The combination of work and education, as well as their compatibility, has become the inevitable need of a modern and future businessman. The demand for developed and skilled human resources is changing faster than the human resources it self, so there is a necessity to build a new human resource development strategy everywhere where needed. Human Resource Development Strategy is based on "work and education", i.e. on education in the organization, which is a process of improvement, which leads to development and better quality of human resources.

Only high-skilled knowledge workers are the backbone for acquiring and maintaining competitive advantage, and only high-quality human resources can follow today's business characterized by the rapid, dynamic, complex and unpredictable changes that have a strong impact on both business and overall management of business systems.

By content and structure, the employee training programs should be of such quality to ensure an adequate offer of well-trained human resources, to ensure the achieved work standards, as well as to develop the capabilities, skills and attitudes of employees in order to better respond to the demands of the present and future work. Training programs should increase the flexibility of work, as well as to successfully overcome rapid changes in any segment of the business system, as well as to meet the legally prescribed requirements when protecting the living and working environment.

The development and education of human resources influenced on changing of behavior in the world of work, changing the working atmosphere, improving the motivation for work, improving the organizational culture, as well as changing the awareness and attitudes towards the obligations in a business system based on ethical principles.

About development and quality of employees, the American economist Tom Peters states the following: [2]

- Human capital should be invested as much as equipment,
- We train people from the first day and provide them with the additional training whenever necessary,
- Comprehensive training includes technical problem solving, so that people can contribute to quality improvement,
- We organize training for people who move on to the manager tasks and continue to train them whenever they are transferred to a higher office,
- Training is used as an incentive and strategic impulse,
- We insist that a complete training is directed to the people from the base, all programs should be designed based on information from people from the base.

Training is progressing from the internal to dynamic; from a routine to a creative environment; from the "industry" of hierarchy, control and limiting compulsion to the "industry" of knowledge, cooperation, and intelligent choice of options. Such an approach to the professional and professionnal education and development of employyees not only provides the high-quality human resources, but also brings one message that every employee is extremely important for organization.

Continuous adjustment and focus on the external environment and a permanent approach to development the human resources quality imply a new and higher-quality philosophy of work and results in business systems. The new philosophy of development and business inevitably imposes an increasingly new attitude that is necessary to understand how the future does not belong to the superior technologies, but to the superior human resources.

3 INTERNATIONAL LAW IN SOLVING ECOLOGICAL PROBLEMS

Solving problems of the working and living environment in the modern era requires a systematic approach, cooperation and very intensive exchange of information of all interested at the level of the whole community. Environmental problems are taking an increasing part in the global problems of contemporary humanity. The level of vulnerability of the environment and natural resources has reached a very high level. All this points to the necessity of aradical change in the attitude of man to the environment.

Today, almost every human activity has such a strong effect on the environment that the ability of the planet's ecosystem to sustain the future generations, i.e. to ensure the sustainable development, is questionable. The trend of atmospheric pollution, due to the increasing needs of people as well as technological progress, has caused the global warming as the ending point of the negative domain to the lives of people on the planet earth.

The environmental protection milestone was given by the Stockholm UN Environment Conference, after which intensive activities in this area began worldwide.

Solving ecological environmental problems was particularly intensified at the end of the last century by the emergence of the major environmental disasters (the Bopala case) that cannot be solved solely applying the concept of ecology, but a new awareness is formed about the inevitability of developping a new, efficient approach to the environment and environmental sustainability.

Solving ecological issues has been intensified at all levels, which has resulted in legal regulation from global to local plan. The methodology has been developed for solving the ecological problems in local communities through the drafting and implementation of the Local Environmental Plans (LEAP). The task of this plan is to propose solutions that would contribute to the protection of the natural environment, resources and quality of life and prevent their endangering in the process of economic development of a local community.

Environmental protection is a global, planetary problem and the common interest of all countries and nations in the world. Today's ecological problems have become part of international relations, in which frameworks, legal norms and principles jointly solve these difficult challenges of the modern world. Such activity enters the fund of development and improvement of contemporary international law, whose rules and regulations are based on the protection and improvement of the environment. The Stockholm Declaration has adopted a number of principles for the organization of international actions in the field of environmental protection, starting from the following:

A human is at the same time a product and creator of the environment that gives him means of living, allowing him/her intellectual, moral, social and spiritual advancement. In a long period of development of human resources and hence of human work, the level has reached the level of which, due to accelerated technological development, a human has gained the power to change his/her environment in numerous ways and in unprecedented proportions. The human's working and natural environment is equally important for the well-being and use of the basic human rights, including the most elemental human right, and that is the right to life.

The protection and improvement of the human environment is an actual and important international issue on which people's well - being and economic develop-ment depend worldwide. This is a serious requirement of the international community, the obligation and duty of all its organs and organizations.

The existential interdependence of nations and countries in the field of ecology is greater than in any other field of human activity and must be taken into account by both the UN Organization and the relevant national authorities [2]

Thus the real frames of all countries in the world are created. The countries are obliged to take care that their actions do not cause damage to their own, but also that their actions do not harm or endanger and does not violate the right of other sovereign states. It was crucial to create the basis for international law in the field of environmental protection.

The international protection of working and living environment is directly related to the human rights, human existence, because if human is threatened as the only rational being, it will be threatened the most important and most precious resource on which everything begins and where all social wealth is based.

The international environmental protection calls for the appropriate behaviours of all entities in international relations, which is determined by the rules of international law that is increasingly developing and transfer responsibilities to all countries. The countries are obliged, in accordance with the adopted declaration, to adopt their own laws, rules and measures for the protection of the living and working environment, which does not exempt them from international cooperation in this plan. Countries are inclined to international cooperation on this issue because it is a complex and multi-dimensional complex of rights and obligations of all countries to conserve and protect the environment as the common interests of people all over the world.

4 NATIONAL RIGHTS OF ECOLOGICAL PROTECTION

The environmental problems have preoccupied Serbia and its legislation since the seventies of the 20th century. Until then, the natural resources were considered to be the non-limiting and can be used infinitely because they are inexhaustible. Strong development of the industry and the uncontrolled import of "dirty" technologies and dispersion of pollution from the near and further environment have resulted in development of ecological awareness and increasing impact on the country's environmental policy. Ecological movements like the "Green Party" have been created. There are more and more scientific works on the topic of health protection and environmental protection. Relevant legal regulations have been adopted. Human resource education has begun and development of higher education institutions for studying this issue that became a threat to the survival of humanity. The Constitution of the Republic of Serbia proclaims the right of a human to a healthy environment, where everyone is legally obliged and obliged to protect and improve the environment. The Serbian Constitutional concept starts from the principle that the right to a healthy environment is the basic human and existential right of individual, part of the culture, customs, morality, tradition, which is guaranteed by the state. Thus, an ecological policy is defined that will direct the social action for improvement and protection of the environment. This policy is an integral part of the economic policy of the society and cannot be separated or interpreted by anybody.

Based on the constitutional provisions, a whole system of positive environmental legislation has been developed: laws, regulations, decisions, etc. Particular attention is drawn to the ecological criminal legislation that defines the criminal offenses and penalties against the environmental damage.

Legislation in the field of environmental protection should suppress the following:

- Illegal construction and work of facilities and installations that pollute the environment.
- Damage of facilities and devices for the environmental protection.
- Importing of hazardous materials in the Republic of Serbia and unauthorized processing, disposal and storage of dangerous materials.
- Unauthorized construction of nuclear plants.
- Violation of the right to information on the environment condition.
- Transmission of infectious diseases in animals and plants.
- Pollution of food and water for feeding the animals.
- Forest devastation, etc.

5 SOCIAL RESPONSIBLE BUSINESS

Social responsibility of the business is a concept by which the business systems should take care of human rights, environ mental protection, and equality of opportunity for all, in the same way, with the same attention and with the same results as of economic efficiency. [3]

Socially responsible business represents awareness of the new position and importance of business systems in the modern global environment and the responsibilities that arise from them. Businesses subjects direct this concept and primary goal of acquiring and distributing profits consciously and voluntarily, and have a positive impact on their working, social and natural environment.

Social responsibility and target profit are not competitive but complementary parts. The goal of social responsibility can be seen by focusing the business system on profitable activities that do not endanger the social interest. A socially responsible business system can count on the growth of profitability and profitability over a longer period of time.

In a wider sense, social responsibility includes the economic, natural, ethical and philanthropic (discretionary) responsibility. Different thinking in approaching social responsibility alleviates the approach that the business systems must fulfil the economic and legal responsibility, and then moral and discretionary. If the business systems fail to meet the ethical and discretionary responsibility, society can respond by passing laws, and then it becomes the legal responsibility.

There are great differences between branches for potential harm to society and the environment. The pressure that business systems have in some branches of different groups, organizations and institutions is different. It is not enough just to adopt a sustainable development strategy, but also the programs and implementation plans that must be followed by an appropriate system structure. The globalization of the world economy will affect the acceleration of the process of standardizing the viewing of social responsibility. [5]

Business systems seeking affirmation as the socially responsible members of society act proactively. Problems are anticipated and prevented and socially responsible actions are suggested. These are business systems that believe that they need to take their own positions on social issues and through public relations to make them available to the mass media of mass communication. It is not just enough to announce the commitment but it is necessary to demonstrate and show the results. Research on its impact on society demonstrates commitment to the principles of openness and transparency.

The goal of social responsibility is to create a business system that has the support and affection of society. Socially responsible business means creating the sustainable goals for human life. It is a great responsibility on the management structure of business systems, that is, of conscious and competent human resources in them.

6 RESEARCH METHODOLOGY

Today's economic development is understood and defined differently, whether it is a progressive process of the economy or it is a complex process including the universality of changes experienced by the business system or economy during its existence or it is a process that goes from the current state of less efficiency to a new state of higher efficiency. The process of improving the economy, an indicator of upgrading the human standards, the process of democratization of society, the evaluation of humanization in interpersonal relations, is often defined as a process of exploitation the natural resources. Whatever the growth is defined, it has the essential meaning of progressive advancement. This progress is for the benefit of mankind. Current achievements in science, technology, organization and governance should be increasingly beneficial to the society and humanity as a whole, as this is its primary purpose. All this is in the role of progress only if there is always a limit that is called sustainable development, which is reflected in time, component, humanistic and ecological approach.

Ecological approach refers to the protection of the environment and its natural resources that comprise: soil, water, air. The quality of the environment is qualified by the following indicators: physical, chemical, biological, aesthetic and other, which are unfortunately changed by numerous business projects, such as: exploitation of natural assets, industrial production, waste disposal, transport of products,

In this paper, the research refers to the environmental protection from the tailing dumps as waste from the ore flotation in the "Trepca" company in the region of Kosovska Mitrovica.

The aim of this paper is to identify the extent to which human resources are characterized by their quality and professionalism in the “Trepca” company, where there is the environmental protection from pollution, such as the waste materials from various chemical-metallurgical processes and ore flotation and their deposit.

In this research, there are following assumptions (hypotheses):

The hypothesis that human health in this region is highly endangered by numerous pollution by the Trepca industrial park, and that the protection itself is at a low level.

That there is no adequate representation of quality experts in the field of environmental protection in the plant itself and beyond.

The latest environmental studies in the region of Kosovska Mitrovica are discouraging for the following reasons: the unresolved problem of dumps within the vicinity of the company itself and in its immediate vicinity and other sites, unprotected from wind and precipitation, the presence of lead and other heavy metals dust in the atmosphere. Landfill deposits occupy a large area of fertile soil that is permanently degraded (which is a direct damage), due to the precipitation of heavy metals and toxic substances from the landfill are directly discharged into the Ibar River, which contaminates the plant and animal world in the river itself, and wider use of water for irrigation of agricultural cultures.

Landfills as collecting points of waste industrial material obtained from the industrial process are called sanitary fields. Industrial waste is obtained differently and is of different composition, depending on the raw materials used in a particular industry, so it is differently disposed of. The most common materials to be deposited are ash, slag and dust. Common to all industrial landfills is the seizure and permanent degradation of large areas of land (as we have already emphasized). Water is polluted by both direct washing of harmful substances from landfills and a system of underwater waters. The largest water pollutants are ore flotation plants, where acids, bases and other dangerous chemical substances are used in this process.

The landfills of the Trepca Company for the previous 60 years are: the Old Flotation and Metallurgical Refinery Gornje Polje (tailing dump of granulated slag of shaft furnaces from the smelter and refinery, the deposited material about 12,000,000 m^3), the flotation tailing dump Žarkov potok about 8,200,000 m^3 of tailings, EMKO deposits of zinc metallurgy about 500,000 m^3 of tailings, chemical industry catchment area of phosphorus/gypsum about 400,000 m^3 of tailings with a surface of 17 hectares, the flotation tailing dump Žitkovac has been deposited with 8,500,000 m^3 of tailings with an area of 26 hectares.

Qualitative and quantitative measurements of industrial waste at the landfills in Kosovska Mitrovica.

Qualitative measurement and analysis of industrial waste.

Table 1 *Composition of granulated slag*

Component	Chemical composition (%)	Component	Rational composition (%)
Fe	25.74	FeO	33.11
Ca	13.80	CaO	19.90
Si	9.97	SiO_2	21.32
Zn	9.90	ZnO	12.30
Mg	3.21	McO	5.32
Al	3.40	Al_2O_3	6.51
Pb	1.40	Pb	1.40
Cu	0.18	Cu_2S	0.23
Ag	0.001	Ag	0.001
S	0.10	-	-
O	31.5	-	-

There is lead in this slag that is a toxic metal in the form of fine metal particles, as well as many other metals that indirecty harm the health of people in their surroundings.

6.1 Quantitative Measurements of Industrial Waste at the Landfills

Table 2 *The structure and quantity of materials at the landfills*

No.	Type of material at landfill	Landfill area, ha	Mass of landfills Before 1995	Mass 2005
1.	Granulated slag from coal pit furnace	6.0	2,500,000	2,450,000
2.	Intermediates from the lead refinery in Zvecan next to the Ibar	1.0	40,000	5,000
3.	Refinery intermediates in Znjrovnica	1.2	5,000	2,000
4.	EMCO sludge	14.0	500,000	450,000
5.	Jarosite sludge	3.0	120,000	110,000
6.	AB-Ag sludge + Cu slime +Ni-Co slime	1.2	70,000	10,000
7.	Pyrite roasting	14.0	600,000	400,000
8.	Phosphorus-gypsum	17.0	400,000	110,000
9.	slag+ ash in Rudare	10.0	100,000	3,837,000
	Total	67.4	4,335,000	7,374,000

Table 3 *Samples from the "Gater" landfill*

		Sample 2	Sample 2a	Sample 2б	MDK
Humidity %		9.15	12.40	10.33	
pH		10.39	11.29	11.35	
Red. Potenc.mV		206.8	207.1	206.7	
CI mg/l		4900	86	70	
Alkalinity	pn	408	600	352	
	ma	664	1088	860	
Pb (g/t)		15.3	52.3	22.0	<5.0
Zn (g/t)		0.2	7.7	1.4	<20%
Cd (g/t)		<0.2	<0.2	<0.2	
Cu (g/t)		0.6	0,7	0.3	<20.0%
Fe (g/t)		<0.8	<0.8	<0.8	
Ni (g/t)		<0.7	<0.7	<0.7	<10.0
Mn (g/t)		<3.3	<3.3	<3.3	<25%
Hg (g/t)		<2.2	<2.2	<2.2	<30.0
As (g/t)		/	/	/	<30.0

Table 4 *Samples from the G.Krnjin-Leposavic landfill*

Landfills: Gornji Krnjin and Bostaniste METALS	SAMPLE MARKING	
	Landfill: Gornji Krnjin	Landfill: Bostaniste
Pb %	0.37	0.20
Zn %	0.19	0.20
Cu %	0.007	0.007
Cd %	0.001	0.002
Fe %	14.50	14.46
Ca %	2.13	3.82
Mg %	0.20	1.25
Co %	0.014	0.016
Ni %	0.044	0.028
Sb %	0.02	0.02
Mn %	0.79	0.88
Bi %	0.003	0.002
Hg g/t	80.64	<40.32
Ag g/t	22.07	17.65

6.2 Chemical industry landfills

Table 5 *Chemical composition of Pyrite roasting*

Component	Chemical composition %	Component	Chemical composition%
Fe_2O_3	65-75	Cu_2S	0.2-2.0
SiO_2	5-10	Pb	0.1-1.0
S	1-3	As	0.02-0.03
ZnO	0.6-3.0	Sb	0.01-0.02
Ag	0.002	CaO	1-3

Official report on the concentration of lead in the atmosphere in urban environments from the "STAMPEKS" sintered pump for the period I = KSII 2015. It is presented in the following Figure.

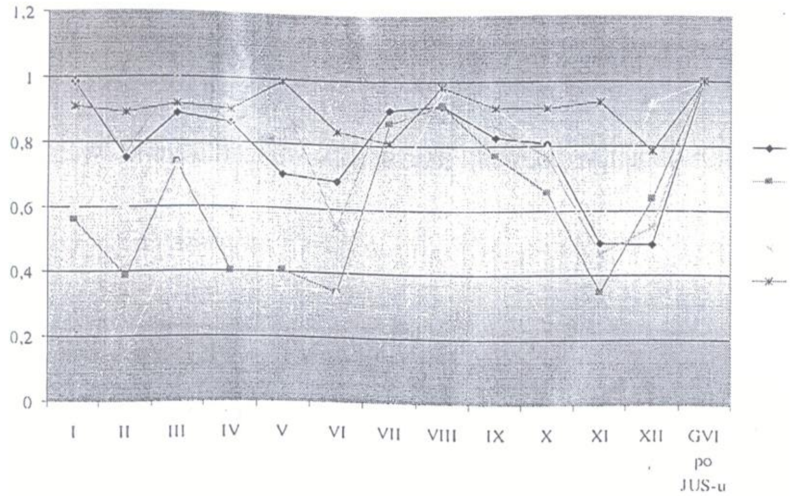

Figure 1 *Concentration of lead in the atmosphere in urban areas*

7 PROBLEM CONSIDERATION

7.1 Measures of Economic Protection

So far, a number of activities have been undertaken, but still insufficient, to eliminate these pollutions. One of the first attempts is to recycle the landfills, which, in addition to ecological, would have an economic benefit. When this procedure is in question, the dumps are divided into two groups: the dumps whose materials cannot be processed due to the small content of metals and which will remain and wait for a solution, and those whose materials are rich in metals to be processed. Those are in the metallurgy of lead and zinc, various dust, slag, foam, sludge and various deposits, obtained by the metallurgical processes. Those materials can be utilized by re-rotation in the initial process by recirculation. The waste from chemical industry in the form of pyrite dust and phosphorus-gypsum is placed in a special landfill and their use is limited, which guarantees a long-lasting durability. Until now, those materials were used very little in the re-technological process and waited for the profession at work.

7.2 Health Protection Measures

Protection measures are divided into two groups: protection measures of the employees and managerial staff in the company it self, and protection measures of the wider environment and health of the population in it.

When it comes to the protection measures of employees in the company, they can be divided into: primary, secondary and tertiary. Primary prevention measures include the prevention of general and professional illnesses as well as injuries on work. Changes and advances in technology require the educated employees in order to be protected from possible injuries. The education can be through lectures, educational materials, television, posters, schemes, flyers and various other printed and written materials, as well as the implementation of immunezation and vaccination of workers. The best protection of the health of workers is achieved using the adequate nutrition in relation to the workplace, respecting daily, weekly and annual holidays. The workers should be examined daily by the professional services of health care, and these services are legally obliged to provide the periodic systematic examinations of employees, as well as the control checks of those workers who perform their work activity in the most polluted environments. Secondary prevention includes measures and procedures undertaken in the stationary hospitals. In this mode of medical treatment, the medical and professional rehabilitation of the patient is carried out, which implies temporary or permanent change of work place.

Tertiary protection refers to the health protection of citizens and environmental protection in the immediate and in far surroundings of the company. This form of protection is the common interest of all citizens living and working in it, enterprises, institutions, universities, local governments and social community. The basis of the environmental protection is the preservation and improvement of natural resources, land, water and air. Environmental protection is only possible in the environments where there is a developed consciousness of people on environmental protection.

It is necessary to pay much attention to the industrial park as it is in the Trepca company, to work on its remediation and to make a strategy of what and how to do with so much industrial waste, not only in the region of Kosovska Mitrovica, but much wider. This problem is one of the largest ecological hotspots in Europe. In order to achieve this, it is necessary to reform and restructure the mining sector in line with the European approach, in order to enable the fast and sustainable development, environmental protection in accordance with the best practices of sustainable development, institutional development and professional development of employed in the mining and wider sector in order to face the challenge of sustainable social and economic development, placement and development of the mining sector in accordance with the European standards, the Code of Regulations in this area and their harmonization with the directives of the European Union. Permanent education is needed at all levels so that people can find out what are the potential possibilities for pollution of the working and living environment, and how to fight them. It is necessary to develop a social and ethical culture when it comes to ecological development. At the Faculty of

Technical Sciences in Kosovska Mitrovica, Department for Occupational Safety and Environmental Protection was opened in order to educate young people and solve these problems scientifically.

CONSLUSION

The right to a healthy environment is the natural, personal and inalienable right of every human being. The environment is the basis of the survival of humanity and the responsibility for its preservation is on every individual, no matter how practically is able to contribute to the reduction of pollution and its preservation. When it comes to the environmental protection, in addition to every individual, the responsibility is on the state apparatus and on every business subject-enterprise. The case of the Trepca company, due to the industrial waste being deposited for 60 years, has turned out to be alarming and almost devastating for the population of Kosovo in Kosovska Mitrovica and wider and dangerous for the whole eco-system. For this one of the European largest environmental hot spots, it is necessary to bring the science and brains as soon as possible to help and to find the best expert and comprehensive solutions for this burning problem. The deposits of industrial material are located next to the flows of two rivers, as well as in the near core of the residential area, unprotected and left to the atmospheric conditions that spread toxic substances in water and air. It is necessary to invest as soon as possible in modernizing the technological processes and reduction the emissions to both rivers and the rest of the environment and to use the experience of other regions in the state.

The landfill of such a toxic material that blows the wind and spills the rain into the river basins should be repaired as soon as possible. Adequate management of industrial waste is needed. A land remediation or bioremediation should be done in order to reduce the concentration of toxic substances to a level that does not pose a threat to human health and the environment. It is necessary to cover the landfills and other hot spots with soil, and land should be covered with vegetation of plant species that can stand a high concentration of pollutants mentioned. It is very important to ask for financial assistance and professional support not only from the Republic of Serbia, but also from larger associations such as the European Union. Not all investments in ecological development are interpreted as cost and loss, but rather as a long-term investment in healthier future.

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LASER BEAM DRILLING AND CUTTING OF PMMA

Abstract

Due to its excellent mechanical, chemical and optical properties, also on fatigue, polymethil-metacrylate (PMMA) is widely used for many purposes. PMMA has a reputation as a material that cannot be machined well, but, its elasticity and toughness enable its shaping by the deformation processes. Laser drilling and cutting are also available techniques for PMMA sheets shaping, used when both mechanical and optical PMMA properties must be preserved.

In this work, the influence of CO_2 laser cutting/drilling on transparent and coloured PMMA surfaces is investigated, as well as by the other laser systems. The cut surfaces were investigated by a light microscopy and, on those surfaces, the average surface roughness R_a was measured. The material zone affected by the laser beam during the cutting process was monitored by a thermal imaging, and theoretical simulations of temperature distribution in this area were performed using the various versions of COMSOL packages.

Keywords: *PMMA, laser cutting/drilling, surface roughness, thermal imaging, temperature distribution calculations*

1 INTRODUCTION

Thanks to its excellent corrosion resistance, relatively good mechanical properties and low friction PMMA is used as a construction material in many applications, like for vehicle (automobile) and airplane windows, as a component of holographic and similar optical materials, matrix for contemporary magnetic materials, in furniture, toys and commercial boards.

Concerning the broad area of its applications, the vast of reference data can be found about the laser methods for PMMA shaping [1-14]. The optimization of laser systems working regimes, including the investigated of large variety of laser pulses going down to femtosecond duration were also performed, both theoretically and experimentally.

The plasma state was produced in PMMA using the UV laser, and interesting chemical processes were observed. It is also worth to underline simulation of different processes when various types of laser systems were used simultaneously, including some unconventional measuring methods [6-17].

Thermal imaging. Thermal imaging is a suitable method for in-situ monitoring of the laser - material interaction, which in addition enables a comparison of different simulation models. Thermal imaging cameras enable a full image observation of a desired area, inspection of a system under load, identification and location the problems accompanying the heat production (hot points) and prevention the related da-

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mages, temperature measurements and data storage, allowing a considerable economization of time and resources [15-16] during the laser-material interaction.

In this paper, the thermal imaging is applied for visualization and quantitative data acquisition during the laser drilling/ cutting of PMMA.

Roughness. Roughness is one of the universal surface characteristics and a good indicator of material mechanical performance. No matter the method of processing (turning, milling, grinding, sand blasting, cutting, ...) the surface irregularities of machined components may initiate the nucleation sites for cracks, corrosion and other damages, even after polishing, so one of the goals of the laser processing is to minimize the surface roughness. Strictly speaking, dust particles and other conta-mination are not considered as the surface roughness, because they can be relatively easy removed from the surface.

Mechanical and optical (including laser) profilers are in use for measuring the roughness profiles. The surface roughness was measured by a roughness comparator with a diamond stylus in our experiments. The surface roughness is usually characterized by two main attributes: roughness ampli-tude, as a measure of height, or depth, and roughness sampling length, as a measure of frequency of roughness pattern appearing.

Optical properties, including the well-known numbers (Re, Nu, Pr) from fluids dynamics have an important role for characterization the laser processing of PMMA [17-23]. Some other advanced surface treatments, like high frequency (HF) induction, and electron-beam irradiation are in competitions with laser processing of PMMA, especially for its applications as chamber or windows material.

2 EXPERIMENTAL

Laser parameters, used during the CO_2 (λ = 10.6 μm) processing of PMMA, were: laser power ≈80W, pulse duration 0.7 ms. The PMMA absorption coefficient was assumed to be 4%. Numerical simulations using these parameters were performed using the Comsol Multiphysics 3.5, 4.4 and 5.2. program packages [13,14].

2.1 Samples

The samples, used for the presented investigations, were taken from large PMMA plates, and their images are presen-ted in Fig. 1 (a-d). White samples C1÷C4 have dimensions 48.1x96.6x3 mm, while black samples are 21.4x64.8x9.3 mm.

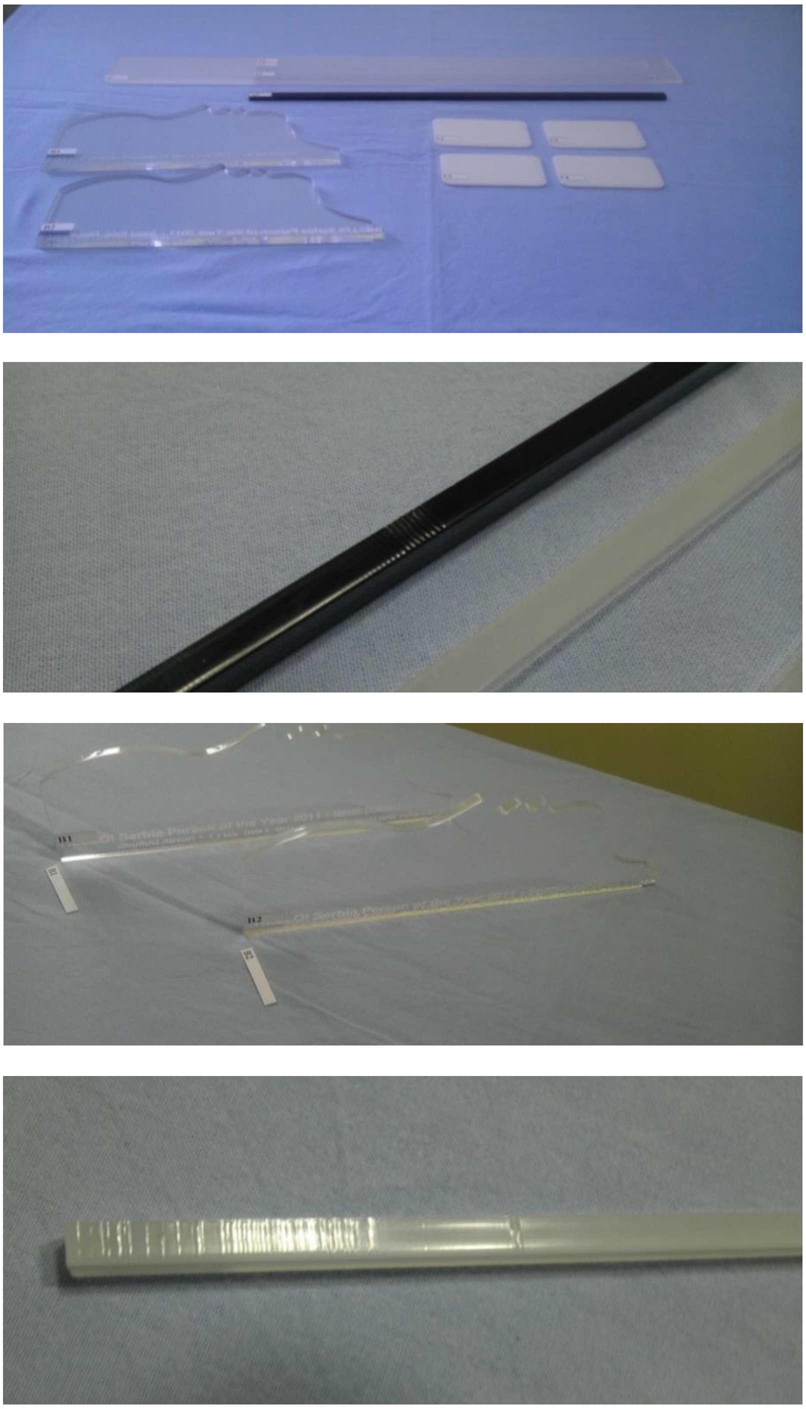
2.2 Cutting

Cutting of the PMMA samples was performed by a CO_2 laser with characteristics stated above, under a cutting speed of ≈40 cm/min. During these experiments, the oscillations in power supply were registered with a slight influence on the cut surface roughness.

3 RESULTS AND DISCUSSIONS

3.1 Roughness Measurements

Surface roughness can be numerically characterized by maximal height (depth) R_{max} of the roughness pattern, and its arithmetic average value R_a. In the presented investigations, R_a measurements were performed by a mechanical method using a diamond stylus. Sketch of black specimens and its roughness values are shown in Fig. 2.



a) b) c) d)

Fig. 1 *PMMA samples obtained by CO_2 laser cutting*

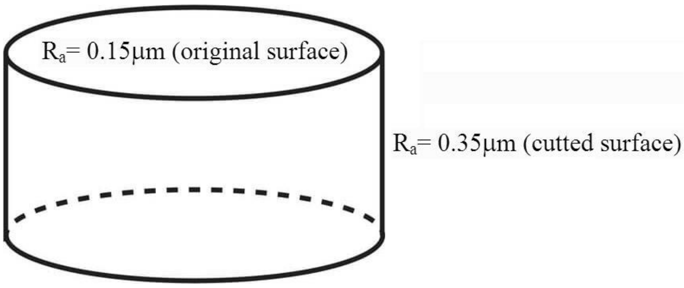


Fig. 2 *Sketch of black PMMA specimen with R_a values of appropriate surfaces*

Some measured roughness values of samples presented in Fig.1 are given in Table 1.

Table 1 *Roughness R_a of specimens cut by a CO_2 laser under the speed of 40 cm/min*

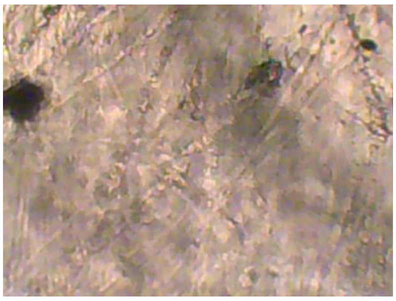
N°	**Samples**		**R_a µm**
1.	White samples	C1	0.48
2		C2	0.3
3		C3	0.52
4		C4	0.43
5		A1	0.062
6	Cutting modification	cutting I	0.098(0.02)
7		cutting II	0.12
8	Black specimen		0,35(0.015)

3.2 Microscopic Evaluations of Laser-Cut Surfaces

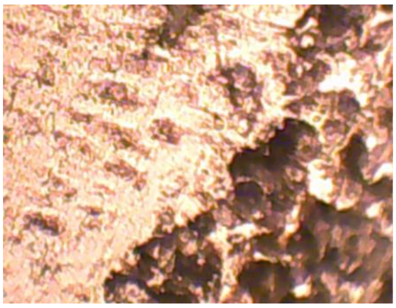
Damages and other surface changes induced in PMMA by the laser cutting/drilling are analyzed using a light microscopy, and results are presented in Fig. 3. Two characteristic areas with laser induced damages can be noticed in the presented micrographs: a) basic material far away from the laser-affected zone (LAZ) area, Fig. 3a) and laser-cut edges, Fig. 3b-g) and b).

3.3 Thermal Imaging

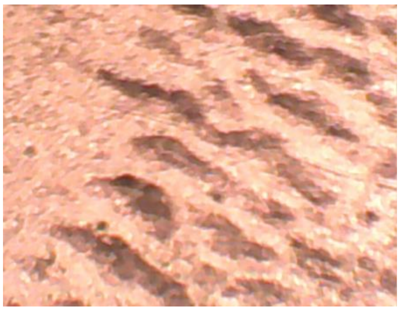
The thermal images of black and semi-transparent specimens (different fillers provides different material colors) obtained during the CO_2 laser (80 W, λ=10.6 µm, cutting speed 40 cm/min) cutting of PMMA by an IR camera (IK 21 from Vohler, Germany with professional version of the IR Snap View software package from Infrared Solutions Inc.), and in that way obtained temperature distribution are shown in Figs. 4 and 5, respectively. Before measurements were provided, the emissivity in an IR part of electromagnetic spectra firstly is determined: ε = 0.95 for black and ε = 0.93 for transparent PMMA specimens. The maximum temperature registered on a black PMMA specimen surface during the laser cutting was 318.4°C.



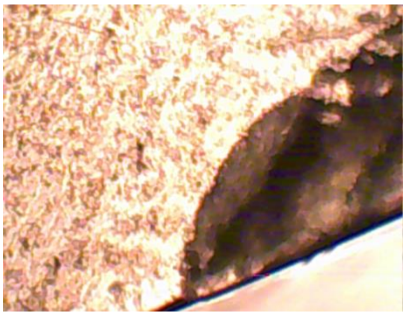
a) Micrograph of sample by a light microscope Sample surface - basic material, x20 (Microscope Litz MZ6)



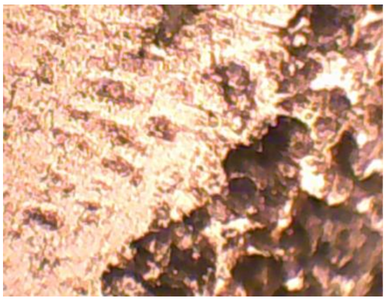
b) X100



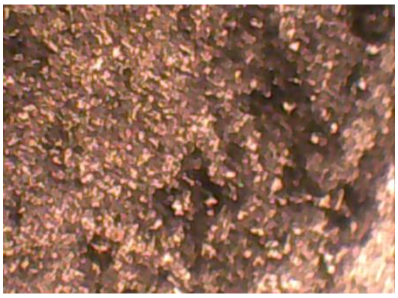
c) x100



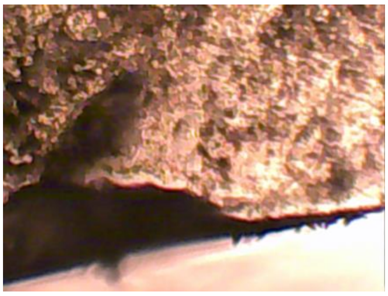
d) x100



e) x100



f) x100



g) x100

Fig 3 (*a-h*) *Light microscope micrographs of PMMA microstructures at: a) intristic material and b-g) laser cutting zone*

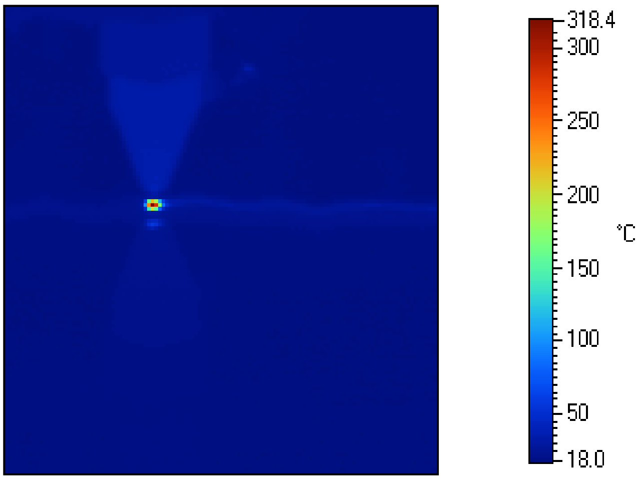


Fig. 4 *Thermal image of CO_2 laser cutting obtained on a cut black PMMA sample, together with temperature distribution scale*

The maximum temperature reached on the surface of a semitransparent PMMA sample during the CO_2 laser cutting was 243.5°C, Fig.5.

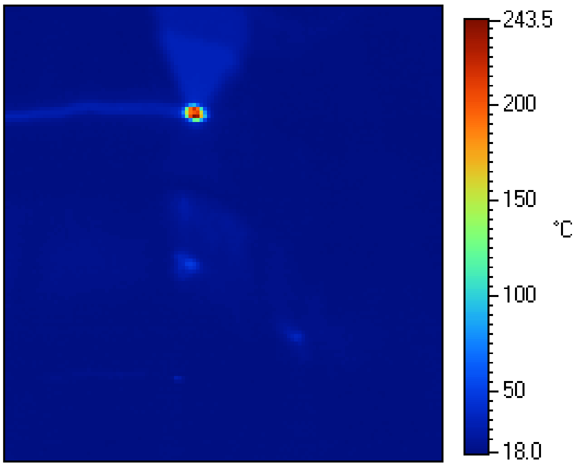


Fig. 5 *Thermal image a CO_2 laser cutting obtained during the cutting of a semitransparent PMMA sample, together with a temperature distribution scale*

4 SIMULATION OF TEMPERATURE DISTRIBUTION DURING LASER CUTTING OF PMMA

Modeling the interaction of laser beam with material is performed using the COMSOL Multiphysics packages (versions 3.5, 4.4 and 5.2). Therefore, the temperature distribution, as a consequence of absorbed energy from laser beam into material and other heat processes generated into the material are analyzed. In this case, only the solid state is considered, in applying the corresponding mode for heat conduction.

4.1 Thermodynamics Simulations of Heat Distribution

The heat conduction is modeled by the equation:

$$\delta_{ts}\rho C_p \frac{\partial T}{\partial t} - \nabla(k\nabla T) = Q \qquad (1)$$

where:

δ_{ts} - time scalar coefficient,

ρ - specific density,

C_p - heat capacity at constant pressure,

k - (in general) tensor of heat conductivity, and

Q - total heat source or sink.

If it is needed, the model can include the transverse heat convection, and surface (2D) radiation, by incorporation of the two new terms in eq. (1):

$$\delta_{ts}\rho C_p \frac{\partial T}{\partial t} - \nabla(k\nabla T) = Q + \frac{h_{trans}}{dA}(T_{ext} - T) + \frac{C_{trans}}{dA}(T^4_{ambtrans} - T^4) \qquad (2)$$

Those new terms describe the heat energy delivered from the affected area to the environment by transverse connective, and out-of plane radiation cooling.

Described model is applicable if there is no phase transition, and other substantial surface changes, i.e. for temperatures profiles below the melting point. Such a simulation is useful for understanding the processes further from the laser interaction area, and (or) during the later stages of material cooling. Such approach is applicable in cases when blowing appears during laser processing.

4.2 Simulations using COMSOL Multiphysics Program Packages

Simulations of thermal distribution in PMMA during CO_2 and Nd^{3+}:YAG laser cutting/drilling/ engraving/thermal surface treating were done using three program packages COMSOL Multiphysics, versions 3.5, 4.4 and 5.2. For Nd^{3+}:YAG is performed simulation for one case using Comsol 3.5. absorbed until to 1mm in depth in material. For such data, the calculated maximum temperature was 430 K (159°C), slightly below the melting point (433K), softening point 110+273=383 K, melting range (82÷95)+273= 355÷368 K [21-24].

Using the program package COMSOL Multiphysics 4.4, the temperature distribution in PMMA sample after CO_2 laser beam action during cutting is simulated. The temperature distribution in 2D space at momentum of 1s after starting the operation is given in Fig. 6. Absorption coefficient is assumed to be 100%. CW laser beam of 80 W mean power, and diameter of spot of 2 cm were parameters for simulation. Next data about PMMA were incorporated in this calculation: thermal conductivity λ = 18 W/mK, density ρ=1190 kg/m^3 and specific heat C_p=1450 J/kgK. The cw CO_2 laser beam with previously stated parameters and spot diameter of 2cm were considered in simulation under the assumption that the energy of laser beam is completely absorbed along the first 1mm from the material surface. The 2D temperature distribution at 1s after the start of the laser interaction is presented in Fig. 6. For such data the calculated maximum temperature was 430 K (159°C), slightly below melting point (433K).

Diameter of 2cm is pretty large for cutting in the applied working conditions, but it could be of interest for the local thermal treatments of particular surfaces using an adequate beam expander. The value of absorption coefficient deserves a special discussion.

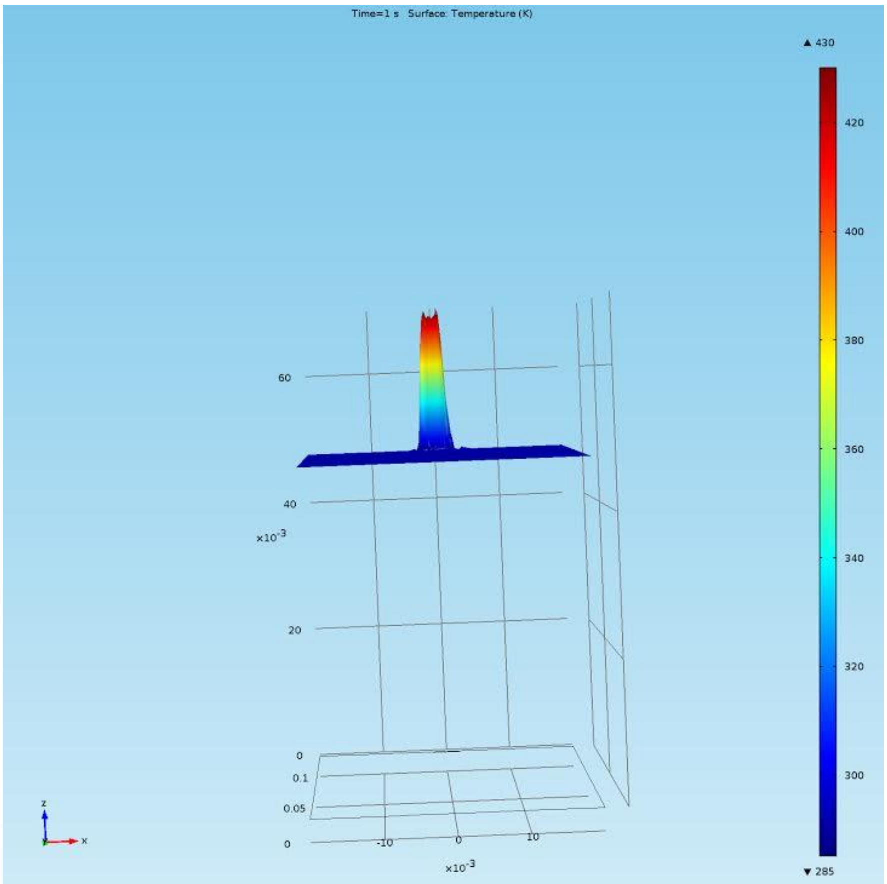


Fig. 6 *2D temperature profile obtained by simulation with COMSOL Multiphysics 4.4 program package and parameters started in the text 1s after start of the cw CO_2 laser beam – PMMA*

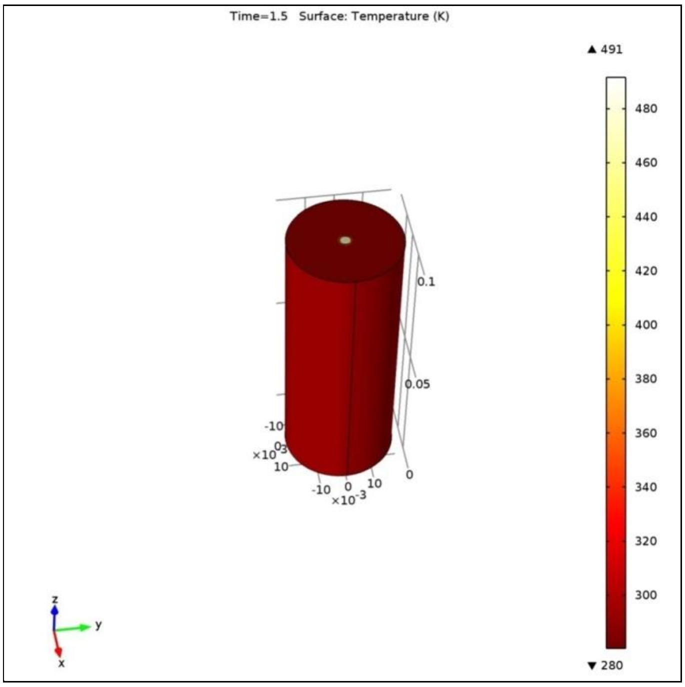
This simulation might be in relation on engraving process for specimens thicker than 1 mm, when greater spot surface is available, so this approach could be applied for engraving by the wider lines.

4.2.1 Temperature Simulations by COMSOL Multiphysics Package 4.4 Version. More Realistic Conditions for Simulations of Cutting Processes

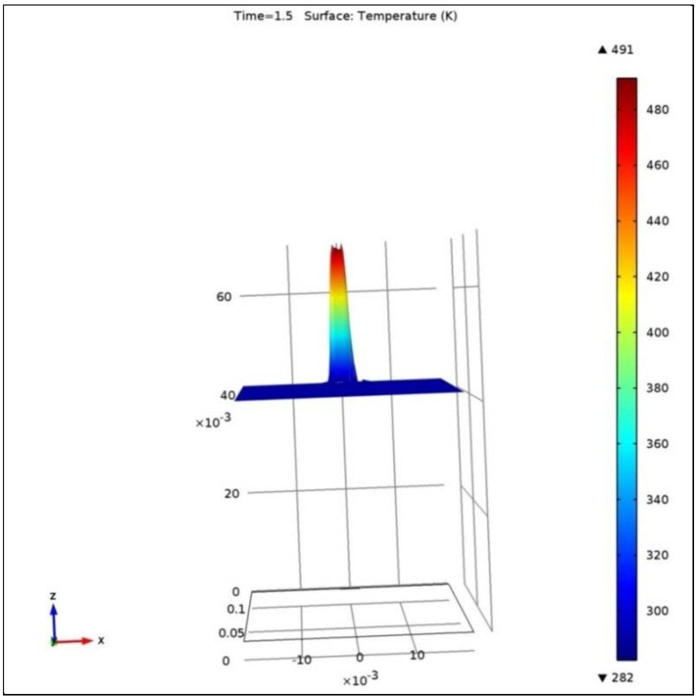
The simulation under same thermodynamic conditions further is provided after 1.5 s from the starting of operation, Fig. 7. The 3D profile of temperature distribution after 1.5 s is shown in Fig. 7a), while the 2D profile in Fig. 7b). The time is considered to be from the beginning of interaction, under the same other working parameters.

Cutting speed, data about material properties, material thickness, etc., are however data which are necessary to know, but for fast simulation as here the phase transitions were not included. Appearance of phase transitions in plastic materials need more detailed approach, knowing for example the Verdet constant, laser number etc. [17,18].

Described model is applied in the case without phase transition and without change of surface. In other words, it can be used for temperatures profiles below the melting point.



a)



b)

Fig. 7 *Temperature distribution 1.5s after the start of the cw CO_2 laser beam - PMMA interaction obtained by simulation using the COMSOL Multiphysics 4.4 Program Package: a) 3D distribution, and b) 2D distribution. Simulation parameters are the same as in Fig. 6*

4.2.2 Temperature Simulations of CO_2 and Nd3+: YAG Laser-PMMA Interaction by COMSOL Multiphysics 3.5 Program Package

Simulation of the temperature distribution during the laser cutting of PMMA is performed by COMSOL Multiphysics 3.5 Program Package and extended to two laser beams, cw-CO_2 and pulse Nd^{3+}: YAG.

The cw - CO_2 laser - PMMA interaction.

The penetration depth of the laser beam of 0.2 mm was used during the simulation, with all other working parameters being the same as in Fig.6. Under those conditions the maximum temperature of 775.1 K (502°C), was obtained, Fig. 8.

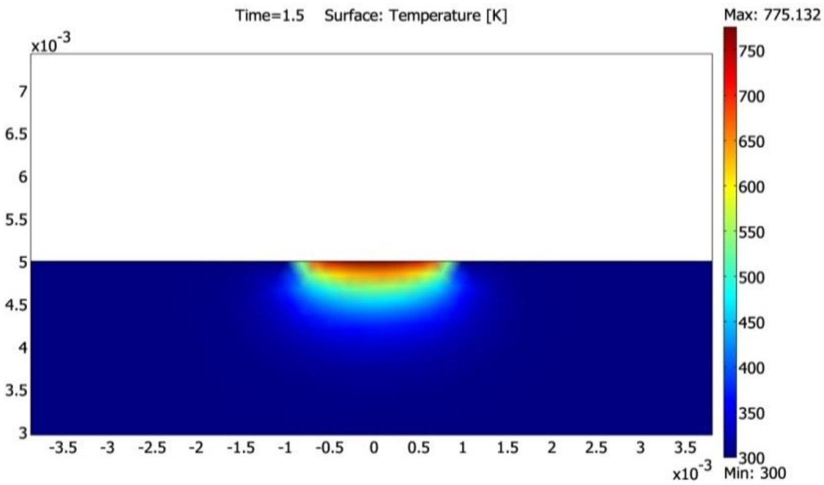


Fig. 8 *Temperature distribution during the cw-CO_2 laser-PMMA interaction 1.5 s after its start for laser beam penetration depth of 0.2mm, simulated by COMSOL Multiphysics 3.5 Program Package*

The Nd^{3+}:YAG laser - PMMA interaction.

The temperature distribution during t Nd^{3+}:YAG (λ=1.06 µm, mean power 5 kW) laser - MMA interaction has been simulated, as well. In this case the PMMA absorption coefficient of 4%, and a uniform energy distribution over the laser beam cross section were assumed. Under these conditions, the maximum obtained temperature is 879.7 K, as it could be seen in Fig. 9, indicating that a model, which includes the phase transition and the latent heat must be used. However, the presented model can give some answers about the conditions around the interaction threshold.

4.2.3 Temperature Distribution Simulations of the CO_2 laser - PMMA Interaction by COMSOL Multiphysics 5.2 Program Package

The temperature distribution during the CO_2 laser - PMMA interaction is analyzed in more details using the simulations performed by the COMSOL Multiphysics 5.2 Program Package.

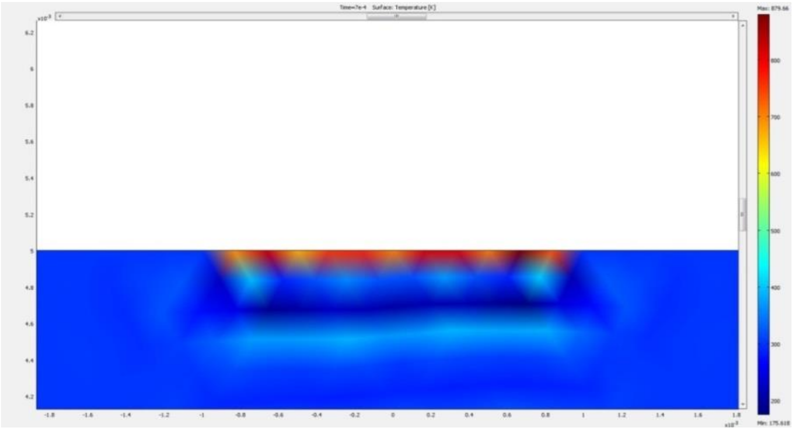


Fig. 9 *Temperature distribution in PMMA after 0.7 ms of the Nd^{3+}:YAG laser pulse duration, obtained by the COMSOL Multiphysics 3.5 Program Package simulations*

The simulation parameters were the same as previously stated, with a cutting speed of 40 cm/min (6.67 mm/s), and sample size of 1x1x1 cm. The laser beam profile was treated as the Gaussian with the standard deviation of 2 mm. The laser beam entering point was set at O = (0.005, 0.005, 0.02), and beam orientation is defined with vector e = (0, 0, -1).

The Gaussian distribution is given by a function of:

$$f = \frac{1}{2\pi\sigma^2} exp\left(-\frac{d^2}{2\sigma^2}\right) \qquad (3)$$

where d is:

$$d = \frac{\|e\times(x-O)\|}{\|e\|} \qquad (4)$$

The temperature distribution 0.3 s after the start of interaction is presented in Fig. 10 a), and b). The simulations provided that under these conditions the maximum temperature reaches 3850 K.

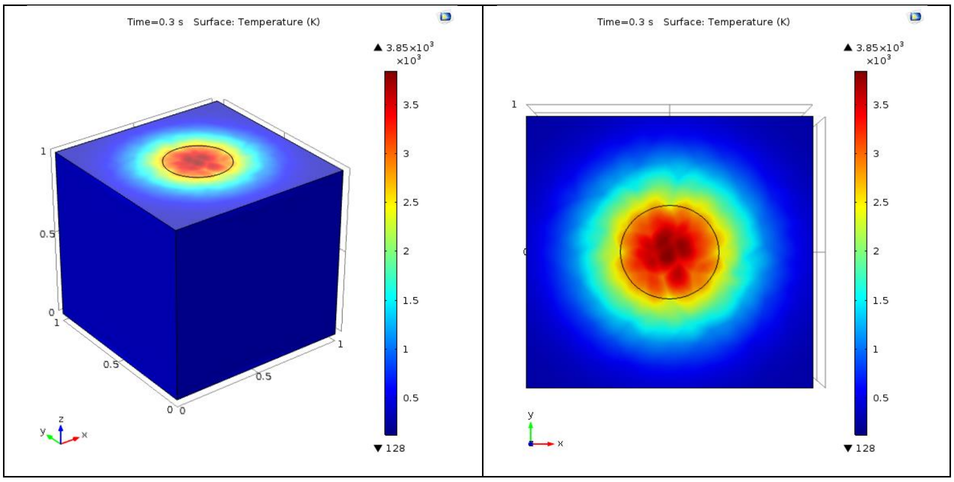


Fig. 10 *Temperature distribution 0.3 s after the start of the cw-CO_2 laser - PMMA interaction simulated by the COMSOL Multiphysics 5.2 Program Package under the same working conditions as in Figs. 6-8, and the laser beam profile standard deviation of 2 mm: a) 3D distribution, and b) 2D distribution*

However, the simulations results appear to be very sensitive on the laser beam standard deviation, and for its value of 5 mm, also, the maximum temperature 0.3 s after the start of interaction reaches 883 K, as it can be seen in Fig. 11, which is much closer to the results obtained experimentally by the thermal imaging (a sample in this simulation was in dimensions 1x1x1 cm).

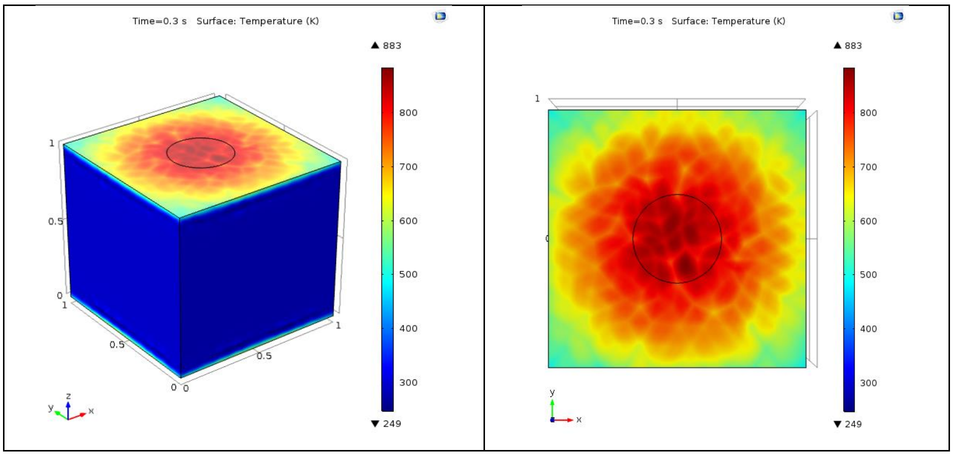


Fig. 11 *Temperature distribution 0.3 s after the start of the cw-CO_2 laser-PMMA interaction simulated by the COMSOL Multiphysics 5.2 Program Package under the same working conditions as in Fig. 10, and the laser beam profile standard deviation of 5 mm: a) 3D distribution, and b) 2D distribution, (same working conditions as in Figs. 6-8, t=0.3 s)*

If the dimensions of modeling sample change to 20x10x3 cm, with the laser beam standard deviation of 5 mm, and other parameters unchanged, the simulation provide the temperature distribution that is pretty close to the one obtained by the thermal imaging, with maximum temperature of 552 K, Fig. 12a), and b).

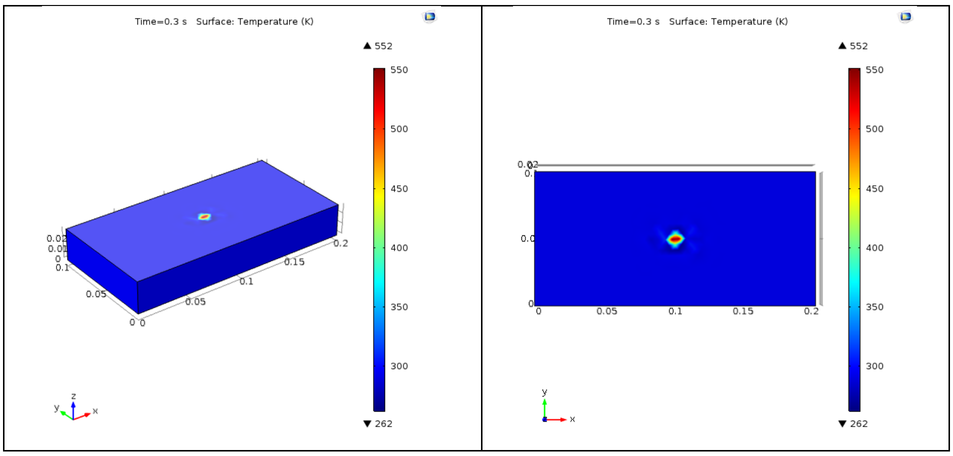


Fig. 12 *Temperature distribution 0.3 s after the start of the cw-CO_2 laser-PMMA interaction simulated by the COMSOL Multiphysics 5.2 Program Package under the same working conditions as in Fig. 11, and the sample size of 20x10x3 cm: a) 3D distribution, and b) 2D distribution.*

In case with the same geometry and dimension with standard deviation of 0.33 mm, and with respect to the phase change (which include a latent energy), the ther-mal distribution slightly changes as it can be seen in Fig.13.

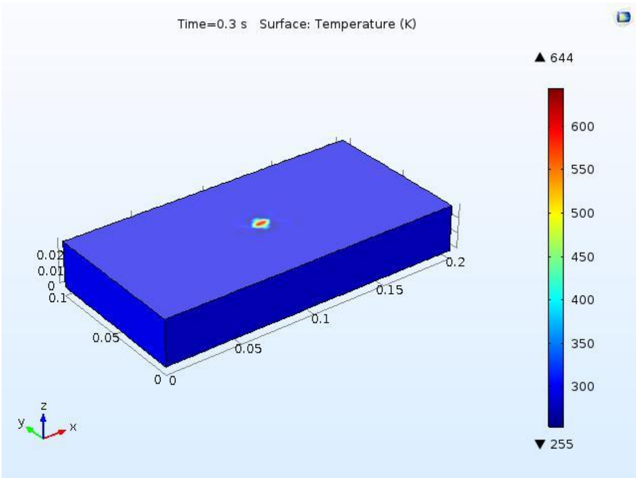


Fig. 13 *Profiles of temperature distribution with the standard deviation of 0.33 mm*

It is possible to include a moving (translation) of beam into simulation. If a speed (0.007 m/s) is put into a model, the lower temperature (622 K) is obtained as a result and that is presents in Fig.14.

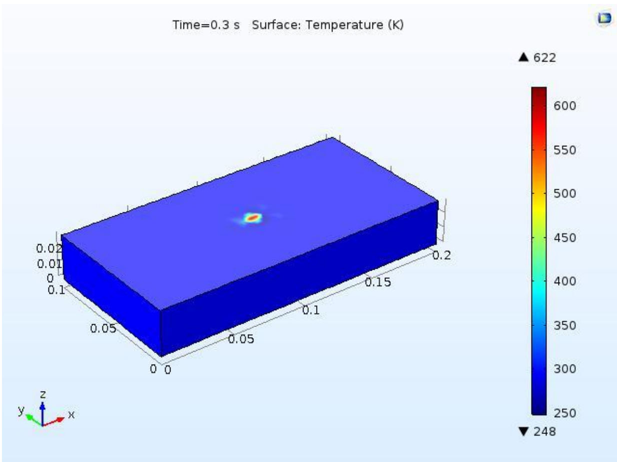


Fig. 14 *Profile of temperature distribution with the standard deviation of 0.33 mm with a translational speed of 0.007 m/s*

Here is underlained that the simulation could be provided with more realistic spot, it means that the standard deviation should be regarded to a real pulse, which diameter is pretty smaller and concentrated ≈ 0.3 mm.

DISCUSSION AND CONCLUSION

Laser methods of PMMA treatment are considered in numerous articles from various points of view: simulations, experiments with different types of laser devices, industrial applications, material processing for optical components, cutting and shaping of panels, tropheys, fiber applications, etc. [3-10, 19-27]. The part of the theory used in these descriptions is applicable also for the other transparent materials, composites, glassy and plastic materials.

During the experiments presented in this work, numerous specimens of different PMMA materials were cut using the cw-CO_2, and Nd^{3+}:YAG laser beams, under the same cutting conditions.

The attempts to decrease the surface roughness of processed material usually increase the manufacturing costs, but improves the performances of a component obtained by that way. From that reason, the surface roughness of PMMA samples after the laser cutting was measured and expressed in terms of the average roughness R_a. Under the used cutting conditions the largest R_a of 0.52 µm is obtained for sample C1, and the smallest (0.3 µm) for sample C2 (Table 1). Such a large deviation of R_a values can be explained by presence of different fillers & pigments in various PMMA samples and some fluctuations of processing parameters observed during the cutting.

A characteristic feature observed for the PMMA laser cutting is the existence of a narrow LAZ zone, similar to amorphous structure, which is similar to those observed after the resistance, induction, or electron beam melting. In general, during the laser beam treatment of materials, a huge energy gradient of about 10^8 W/cm^2 that is fundamentally different from the conditions during the mechanical machining.

However, the temperature distribution produced by the elion technics depends also on the material properties, and its simulation must be supported by the adequate material parameters and conducted using the appropriate thermodynamic and other theories that could provide the reliable predictions of absorbed energy, its conversion into heat, and subsequent heat redistribution.

Under the investigated working conditions, the maximum temperature of 775.1 K (502^{o}C) was provided by simulation, Fig.8, compared to 318.4^{o}C experimentally recorded by the thermal imaging.

The maximum temperature values, obtained in provided monitoring and simulations, either using the thermal imaging or used program packages (COMSOL 3.5, 44.4 and 5.2), have shown some disagreements; it could be explained from the inadequate values of coefficient in thermodynamic equations for heat generation and its conduction. It means that the absorption/reflection coefficients of laser beam interaction with surface, also at presence of filler/pigment components and complex thermodynamic conditions, need more precise determinations.

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AN APPROACH FOR EVALUATION THE SAFETY AND QUALITY OF TRANSPORT AT THE OPEN PIT MINES, BASED ON THE EDAS METHOD[****]

Abstract

Transport of ore and overburden at the open pit mines represents the most important and the most complex process in the open pit excavation technology. Transport organization significantly affects the capacity of machinery for excavation and disposal, excavation productivity, as well as the ore production costs.

This paper describes an attempt to select the most suitable transport system at the open pit mines from the safety and quality point of view. For that purpose, the EDAS method was used. Four types of transport systems were considered – truck transport, railway transport, belt conveyor and hydrotransport. It was found that, from the above mentioned aspect, the truck transport generally has the most favorable characteristics.

Keywords: *transport, open pit mine, safety, quality, EDAS method*

1 INTRODUCTION

Transport at the open pit mines takes place according to a determined cycle, the duration of which depends on the time of: loading, motion of the loaded and empty transport machine, unloading, maneuvering and stoppage in transport. All these operations can be performed with or without interruptions, and therefore, transport at the open pit mines can be divided into:

(1) Continuous (such as hydrotransport, belt conveyor)
(2) Discontinuous (with intermittent effect, such as trucks, trains, scrapers)
(3) Combined (for example truck transport with belt conveyor) [1].

Selection the type of transport for the specific conditions of an open pit mine is determined on the basis of different parameters, such as [1]:

- type as well as physicochemical and mechanical properties of material to be transported (looseness, brittleness, particle size, temperature, etc.);
- way of loading and unloading;
- working environment in which transport machinery will work (dustiness,

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temperature changes, humidity, climate, etc.);

- dimensions of the facilities or machinery where the loading, passage and unloading is performed;
- capacity and operation mode of loading machinery, as well as technology of excavation and disposal;
- direction and transport distances, etc.

The selected type of transport at the open pit mine should ensure the safe transport of required quantities of materials, continuous operation, minimum operational difficulties, security, safety of employees, smooth operation of the basic and auxiliary machinery as well as the greatest possible cost - effectiveness. At the modern open pit mines, three types of transport are mainly applied: (1) railway transport, (2) trucks and (3) belt conveyors. In addition to the mentioned ones, less used are scrapers, cable cars, pipelines, etc. [1]

In this paper, according to the methodlogy of multi criteria decision making, the selection of the most suitable means of transportation at theopen pit mines is discussed. Basically, quality and safety of transport were accepted as the most important criteria in this discussion, but it should be emphasized that the quality of transport is considered through several parameters, that is: the length of the transport distance, the need for supply of power and water, the influence of working conditions and the impact of physical and mechanical properties of the transported material. The tests were carried out using the EDAS method.

2 THE EDAS METHOD

Before a short description of the EDAS method, given in the text, it is necessary to define a weighted average operator.

A *weighted average (WA) operator* of dimension n is a mapping $WA: R^n \rightarrow R$ that has an associated weighting vector $\omega = (\omega_1, \omega_2, ..., \omega_n)^T$ with $\omega_j \in [0,1]$ and $\sum_{j=1}^{n} \omega_j = 1$, is defined as [2]:

$$WA(a_1, a_2, \ldots, a_n) = \sum_{j=1}^{n} \omega_j a_j \qquad (1)$$

where a_j represents the argument variable.

The ***EDAS method,*** as a multi criteria decision making method, was introduced by Keshavarz Ghorabaee et al. (2015), and therefore it can be stated as a newly-proposed method. A fuzzy extension of this method was also developed by Keshavarz Ghorabaee et al. (2016), while a grey extension was proposed by Stanujkic et al. (2017) [3–5].

The basic ideas of the EDAS method are the use of two distance measures, namely the Positive Distance from Average (PDA) and the Negative Distance from Average (NDA); and that the evaluation of the alternatives is done according to higher values of the PDA and lower values of the NDA.

Based on Stanujkic et al. (2017), the computational procedure of the EDAS method, for a decision - making problem with *m* criteria and *n* alternatives, can be presented as follows:

***Step* 1.** Select the available alternatives, the most important criteria that describe the alternatives, and construct the decision-making matrix *X*, shown as follows:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{12} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{1n} & x_{2n} & \cdots & x_{mn} \end{bmatrix}, \qquad (2)$$

where x_{ij} denotes the performance rating of the alternative *i* on the criterion *j*.

***Step* 2.** Determine the average solution according to all criteria, shown as follows:

$$x_j^* = (x_1, x_2, \cdots, x_n), \quad (3)$$

where

$$x_j^* = \frac{\sum_{i=1}^{m} x_{ij}}{m}. \quad (4)$$

***Step* 3.** Calculate the positive distance from average d_{ij}^+ and the negative distance from average d_{ij}^-, according to the type of criteria (benefit and cost), shown as follows:

$$d_{ij}^+ = \begin{cases} \dfrac{\max(0, (x_{ij} - x_j^*))}{x_j^*}; & j \in \Omega_{\max} \\ \dfrac{\max(0, (x_j^* - x_{ij}))}{x_j^*}; & j \in \Omega_{\min} \end{cases}, \quad (5)$$

$$d_{ij}^- = \begin{cases} \dfrac{\max(0, (x_j^* - x_{ij}))}{x_j^*}; & j \in \Omega_{\max} \\ \dfrac{\max(0, (x_{ij} - x_j^*))}{x_j^*}; & j \in \Omega_{\min} \end{cases}, \quad (6)$$

where $\Omega_{\max}$ and $\Omega_{\min}$ denotes the set of the benefit criteria and the cost criteria, respectively.

***Step* 4.** Determine the weighted sum of PDA, Q_i^+, and the weighted sum of NDS, Q_i^-, for all alternatives, as follows:

$$Q_i^+ = \sum_{j=1}^{n} w_j d_{ij}^+, \quad (7)$$

$$Q_i^- = \sum_{j=1}^{n} w_j d_{ij}^-. \quad (8)$$

***Step* 5.** Normalize the values of the weighted sum of the PDA and the weighted sum of the NDA for all alternatives, shown as follows:

$$S_i^+ = \frac{Q_i^+}{\max_i Q_i^+}, \quad (9)$$

$$S_i^- = 1 - \frac{Q_i^-}{\max_i Q_i^-}, \quad (10)$$

where S_i^+ and S_i^- denote the normalized weighted sum of the PDA and the NDA, respectively.

***Step* 6.** Calculate the appraisal score S_i for all alternatives, as follows:

$$S_i = \frac{1}{2}(S_i^+ + S_i^-). \quad (11)$$

***Step* 7.** Rank the alternatives according to the decreasing values of appraisal score. The alternative with the highest S_i is the best choice among the candidate alternatives.

a. Application of EDAS method in a group of decision making

One of the simplest approaches for application of the EDAS method in a group environment can be provided forming a group matrix of decision-making based on the individual matrices obtained from the participants of a group, using the WA operator, i.e. applying Eq. (1).

3 NUMERICAL EXAMPLE OF THE EDAS METHOD APPLICATION

a. Basic postulates of multi criteria decision making for selection of mode of transport

In this case, the evaluation of four potential modes of transport is considered, as follows:

A_1 – Truck transport
A_2 – Railway transport
A_3 – Belt conveyors
A_4 – Hydrotransport

in relation to the following criteria:

C_1 – Transport safety

C_2 – Transport distance
C_3 – Supply of power and water
C_4 – Working environment conditions (temperature changes, humidity, terrain configuration)
C_5 – Physical and mechanical properties of materials

In order to evaluate the alternatives, a team of three experts was formed. At the very beginning of the evaluation, the experts assigned a significance to the selected criteria using the estimates (*E*) in the interval [0,1), as it is shown in Table 1.

Table 1 *Significance of criteria obtained from three experts*

Criteria	E_1	E_2	E_3
C_1	1	1	1
C_2	1	0.9	1
C_3	0.7	0.8	0.8
C_4	0.5	0.6	0.6
C_5	0.9	0.9	0.9

Weights of the criteria were subsequently determined using the following formula:

$$w_i = \frac{\sum_{j=1}^{3} x_{ij}}{\sum_{i=1}^{5}\sum_{j=1}^{3} x_{ij}} \quad (12)$$

Group weights is shown in Table 2.

Table 2 *Group weights*

Criteria	w_i
C_1	1
C_2	1
C_3	0.7
C_4	0.5
C_5	0.9

After that, the experts evaluated the alternatives in relation to the selected criteria. The results, obtained from three experts, are shown in Tables 3, 4 and 5.

Table 3 *Results of the alternatives evaluation, obtained from the first of three experts*

Alternatives	***Criteria***				
	C_1	C_2	C_3	C_4	C_5
A_1	3	4	4	3	4
A_2	1	1	3	1	3
A_3	2	3	2	2	2
A_4	4	2	1	4	1

Table 4 *Results of the alternatives evaluation, obtained from the second of three experts*

Alternatives	***Criteria***				
	C_1	C_2	C_3	C_4	C_5
A_1	3	4	3	3	4
A_2	1	2	3	3	3
A_3	2	3	2	2	2
A_4	4	2	1	4	2

Table 5 *Results of the alternatives evaluation, obtained from the third of three experts*

Alternatives	**Criteria**				
	C_1	C_2	C_3	C_4	C_5
A_1	3	3	3	3	4
A_2	1	2	3	1	3
A_3	2	3	2	2	2
A_4	4	2	1	3	1

b. The results of a group of multi criteria decision making

Group performances of alternatives in relation to the selected criteria – i.e. the transformation of individuals into the group decision matrix, was carried out using the WA operator. The first expert was assigned with significance of 0.4, while the second and third expert were assigned with significance of 0.3 (Table 6).

Table 6 *Group performances of alternatives obtained from three experts*

Alternatives	***Criteria***				
	C_1	C_2	C_3	C_4	C_5
A_1	0.24	0.23	0.18	0.13	0.21
A_2	3.00	3.70	3.40	3.00	4.00
A_3	1.00	1.60	3.00	1.60	3.00
A_4	2.00	3.00	2.00	2.00	2.00

After that, the average solution is determined for each criterion using Eq. (4). The obtained results are shown in Table 7.

Table 7 *Average solution according to all criteria*

Criteria	C_1	C_2	C_3	C_4	C_5
x_j^*	2.50	2.58	2.35	2.58	2.58

In the next steep the positive distance from average d_{ij}^+ and the negative distance from average d_{ij}^- are determined using Eq. (5) and Eq. (6), respectively. The obtained results are shown in Tables 8 and 9.

Table 8 *The positive distance from average*

Alternatives	**Criteria**				
	C_1	C_2	C_3	C_4	C_5
A_1	0.50	1.13	1.05	0.43	1.43
A_2	0.00	0.00	0.65	0.00	0.43
A_3	0.00	0.43	0.00	0.00	0.00
A_4	1.50	0.00	0.00	1.13	0.00

Table 9 *The negative distance from average*

Alternatives	**Criteria**				
	C_1	C_2	C_3	C_4	C_5
A_1	0.00	0.00	0.00	0.00	0.00
A_2	1.50	0.98	0.00	0.98	0.00
A_3	0.50	0.00	0.35	0.58	0.58
A_4	0.00	0.58	1.35	0.00	1.28

The weighted sum of positive distance from average, Q_i^+, and the weighted sum of negative distance from average, Q_i^-, are calculated using Eq. (7) and Eq. (8), respectively; after which the their normalized values, S_i^+ and S_i^-, are determined using Eq. (9) and Eq. (10). Finally, the appraisal score S_i of considered alternatives is calculated using Eq. (11).The mentioned values are shown in Table 10.

Table 10 *Appraisal score and ranking order of the considered alternatives*

Alternatives	Q_i^+	Q_i^-	S_i^+	S_i^-	S_i	***Rank***
A_1	0.93	0.00	1.00	1.00	1.00	1
A_2	0.21	0.71	0.22	0.00	0.11	4
A_3	0.10	0.38	0.10	0.46	0.28	3
A_4	0.51	0.65	0.55	0.09	0.32	2

As it can be seen from Table 9, the best ranked alternative is the alternative denoted as A_1. In other words, the truck transport is chosen as the most suitable type of transport at the open pit mines, taking into account several criteria.

CONCLUSIONS

A group of multi criteria decision making procedure for selecting the most suitable type of transport at the open pit mines is proposed in this paper. This procedure is based on the use of the EDAS method. The usability and efficiency of the proposed procedure is confirmed by the obtained results. According to these results, in terms of safety and quality, the truck transport was proved to be the most adequate.

It should be noted that the proposed criteria can be replaced by other criteria, which is indicative of the fact that the proposed procedure is flexible and conve-nient for solving the similar problems.

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POSSIBILITY OF STONE USE FROM THE QUARRY "BRESJE" IN JAGODINA AS A TECHNICAL CONSTRUCTION STONE[**]

Abstract

In the period May-June 2017, the Laboratory for Geomechanics of the Mining and Metallurgy Institute Bor, performed the laboratory tests of natural stone from the quarry "Bresje" near Jagodina, as a technical construction stone. Tests were carried out to the extent prescribed by the domestic regulations in order to obtain an exploitation permit. The results of physical-mechanical, petrographic and chemical characteristics that allow or limit its use as a technical building stone are presented in this paper.

Keywords: *quarry, Bresje, technical construction stone*

INTRODUCTION

Test samples for physical and mechanical laboratory tests, i.e. partial and complete analysis of the stone, were carried out on selected samples from boreholes and stone monoliths (taken from the main level and the core of boreholes - Fig. 1) in the Laboratory for Geomechanics. Ten partial and one complete analysis were performed.

Figure 1 *The appearance of the main level and taken samples for tests*

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RESULTS AND ANALYSIS OF PHYSICAL - MECHANICAL, MINERAL - PETROGRAPHIC AND CHEMICAL TESTS

Laboratory test results of stone samples were summarized for the partial and complete analysis in Table 1.

Table 1

No.	Technical properties of stone from the quarry "Bresje" near Jagodina		Value (medium)/ parameters
1.	MINERAL-PETROGRAPHIC COMPOSITION SRPS B.B8.003		Gneiss
2.	UNIAXIAL COMPRESSIVE STRENGTH SRPS B.B8.012	- in dry condition	129.76 [MPa]
		- saturated with water	117.51 [MPa]
		- after frost effect	138.50 [MPa]
3.	WATER ABSORPTION SRPS B.B8.010		0.319 [%]
4.	FREEZING TEST FOR NATURAL STONE SRPS B.B8.001 (loss of mass [%])		steady
5.	DENSITY SRPS B.B8.032		2.648 [g/cm^3]
6.	BULK DENSITY SRPS B.B8.032		2.701 [g/cm^3]
7.	POROUS SRPS B.B8.032		1.70 [%]
8.	BULK DENSITY COEFFICIENT SRPS B.B8.032		0.983
9.	VELOCITY OF LONGITUDINAL WAVES SRPS EN 14579 (en)		4407 [m/s]
10.	TESTING OF NATURAL ROCK BY THE MACHINE "LOS ANGELES" SRPS B.B8.045		22.50 [%]
11.	GRINDING RESISTANCE – BEME SRPS B.B8.015		10.328 [cm^3/50 cm^2]
12.	CONTENTS (SRPS B.B8.042):	Cl^-	<10 - 18 [ppm]

ANALYSIS OF TEST RESULTS

Detailed laboratory tests of natural stone have determined the following:

a) Mineralogical-petrographic analysis

According to the genesis, the natural stone from the "Bresje" quarry near Jagodina is a metamorphic rock - gneiss, slate texture and granoblastic with elements of the lepidoblastic structure. Quartz, feldspar and biotite are observed macroscopically on a fresh fracture (intersection) that is a light gray. As a sign of surface effects, reddish (limonized parts of the sample - Figure 2) were observed. The wall is made of quartz, feldspar, biotite and muscovite. The secondary minerals are epidote, coisite and magnetite, and secondary minerals chlorite, sericite and lemonite.

Figure 2 *Fresh cross section of sample (binocular magnification 20X)*

b) Physical properties

These parameters are defined over bulk density with and without pore and cavities, porosity and water absorption. Density ranges from 2.622-2.686 g/cm^3, bulk density ranges from 2.648-2.826 g/cm^3. Porosity from the complete analysis is 1.70%, which puts it in a stone of low porosity. Water absorption is in the range of 0.180-0.586 %, which meets the quality requirements of technical stone according to SRPS B.B2.009: 1986 standard.

c) Mechanical properties

Parameters are defined by the uniaxial compressive strength in a dry and water-saturated state and after the effects of frost (for complete analysis), as well as through abrasion resistance.

Pressure in a dry state ranges from 111.71-181.97 MPa; in a saturated state it goes within the limits of 80.54-171.81 MPa, and after the action of frost, the pressure value of 138.50 MPa is obtained (complete analysis), which meets the quality requirements of technical stone according to SRPS B.B2.009: 1986 standard.

During the partial stone analysis, a significant deviation of pressure strength values of two samples was observed, which is the only characteristic that does not follow the other good properties of the stone in full measure. Nevertheless, the average uniaxial compressive strength is over 120 MPa (in dry state) and can be estimated to be medium high.

The results of abrasion resistance testing results range from 8.315-15.520 cm^3/50cm^2. According to the abrasion resistance value (35 cm^3/50cm^2), the samples meet the requirements according to SRPS B.B2.009: 1986 standard.

From the complete stone analysis, it can be seen that the result of testing stone on resistance by Los Angeles machine is 22.50 %, which is within the allowed limits according to SRPS B.B2.009: 1986 standard.

Based on the obtained value of the Bond working index Wi = 11.28 kWh/t, the conclusion is that it is a medium-sized raw material, or a raw material in which no high grinding resistance is expressed.

a) Chemical characteristics

Based on the chemical analysis of the stone, it was found that the level of total sulfur and chloride, which could negatively influence the concrete preparation, far below the maximum allowed value.

CONCLUSION

According to the established results of the investigation, it can be concluded that the natural stone from the "Bresje" quarry near Jagodina has good physical and mechanical properties.

From the standpoint of technical petrography, the tested natural stone is suitable for use in construction as a technical stone that can be used as a constructive material in the raw or processed state. The properties that limit the use of this stone are the result of mineral composition, structure and texture of tested natural stone (hardness about 7 by Moss), which is not suitable for the production of aggregates for making layers of pavement structures.

On the basis of a comprehensive analysis of the results of laboratory tests and in accordance with the technical conditions from the applicable standards, the natural stone from the quarry "Bresje" near Jagodina can be used as a technical construction stone, that is, as a hydraulic construction stone - broken, semi-finished and processed, the watercourses and all types of hydrotechnical facilities.

In the course of further use of this quarry, it is necessary to carry out more detailed laboratory tests, especially in deeper parts of the deposit, due to the observed decrease in mechanical properties of t stone, which can be a limiting factor for further use.

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LANDFILL STABILITY ANALYSIS AT THE OPEN PIT "GACKO", BOSNIA AND HERZEGOVINA - REPUBLIC OF SRPSKA**

Abstract

This paper gives the stability analysis of the Western and Eastern external landfill at the Open Pit Gacko, together with the problems that occurred during the last field visit.
Keywords: *Western and Eastern external landfill, stability*

INTRODUCTION

Long-term geological explorations pointed to the fact that the Gatac field represents a large coal basin, with the high quality coal reserves that are economically exploitable. In accordance with developed investment - technical documentation, the construction of the energy complex of Mine and Thermo Power Plant Gacko has begun in 1997. In 1982, in the area of the Western exploitation field, the "Gračanica" mine of coal was put into operation, with the annual capacity of 1.800.000 t of coal and 3.200.000 m^3 of overburden. The OP "Gračanica" is limited by the regulated riverbeds of the river Gračanica from the east, Mušnica from the south and Gojković stream from the west.

Since the beginning of the work at the OP "Gračanica", the technology of work has been applied, which has achieved the satisfactory results on the production of deforestation and coal.

The annual average of about 1,700,000 tons of coal and 3,500,000 m^3 of solid mass is detected in the mine. As a part of construction the first block of the Thermal Power Plant Gacko I, a part of infrastructure facilities was built, which will serve for the second phase of construction the Gacko II Thermal Power Plant.

Coal reserves in the Gacko coal basin are of great importance in energy balances of the Republic of Srpska. With the confirmed balance sheet, the reserves of 338 million tones and off-balance reserves of 66 mil. tons, it can be concluded that Gacko coal basin represents a stable source of energy for many years, both in the production of electricity and for the needs of other sectors of consumption. A precondition for such coal treatment is the efforts to improve the quality by selective excavation, homogenization, preparation and refinement, and expand the field of coal use. Figure 1 shows a view of the open pit.

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** *This paper is the result of the Project No. TR 33021 "Research and Monitoring the Changes of the Stress Strain State in the Rock Mass "In-Situ" around the Underground Rooms with Development of Models with Special Reference to the Tunnel of the Krivelj River and Pit Bor", funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia*

Figure 1 *Open Pit Gračanica and Thermo Power Plant*

DEVELOPMENT PLANS

Planned investments in the following period relate to the necessary modernization of the plant and equipment of the Mine and Thermal Power Plant. First of all, this includes: the acquisition of new mining machinery, expansion of ash dumps and landfills.

On the basis of confirmed lignite reserves, further construction of thermal power plants in Gacko is planned. This primarily refers to the R&D "Gacko II", which would enable the energy potential of the Gacko basin to be rounded up to a power generation plant of 2 x 300 MW.

In connection with the planned construction of the TPP "Gacko II", the extensive survey works were carried out and a comprehensive study was conducted on selection the location of the second phase of the Gacko mine as well as the technical project of the TPP "Gacko II".

One of the biggest carrier of the economic and economy development of the region, the Mine and Thermo Power Plant Gacko, also have a greatest impact on the environment of this part of region. Since this thermoenergetic source is located at the top of the river basin of the Trebisnjica River, monitoring and remediation of negative environmental impacts is an ongoing process, which will certainly be taken carefully with necessary activities.

THE MAIN MINING DESIGN

With the Main Mining Design of the Gacko open pit, the method of coal exploitation, as well as the definition of tailings disposal were defined in the entire century of exploitation.

Complete disposal will be done on the external and internal landfills, as follows:

- Outdoor landfill of the exploration Field B,
- Large exterior landfill (existing external landfill in the southwest of the open pit - East and West external landfill),
- External landfill Gelja Ljut (new external landfill to the south of the surface mine), and
- Internal landfill (excavated area of the Gacko open pit - Central Field).

Projected external and internal landfills are shown in Figure 2.

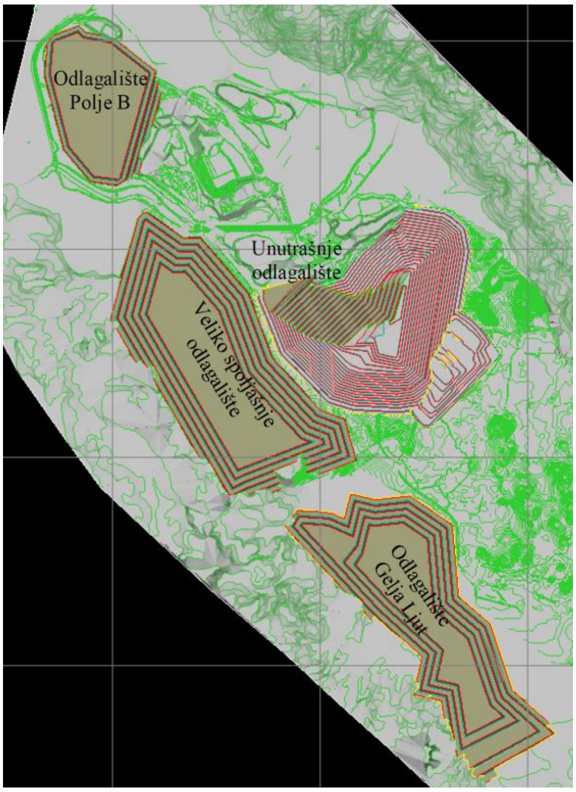

Figure 2 *Designed external and internal landfills*

The following constructive parameters have been adopted on the Large Outdoor Landfill that is located on the current West and East Outer Landfill: the height of landfill 83 m, and the inclination angle of 13º. Constructive parameters were obtained as a result of fulfilling the minimum safety factor for the characteristic final slopes of the landfill. The safety factor, according to the legal regulations for landfills, is Fs≥1,3.

WESTERN EXTERNAL LANDFILL

The disposal of overburden and barren rocks in the Western Outdoor Landfill is done by a system excavator-conveyor-spreader (known as BTO system). Due to an enormous amount of overburden and barren rocks foreseen by the Main Mining Design (113,843,680 [* 1000 m^3]), it is necessary to carry out the certain activities that will improve the geomechanical characteristics in order to satisfy the landfill stability, as well as the possibility of increasing the inclination angle, and thus reducing the soil degradation to whom the revelation and devastation are postponed.

According to the last recording, it was observed that the Western external landfill has a big problem of separation and bursting of deposited mass due to the increasing weight of deposited mass and poor compaction, or planning with a help of auxiliary mechanization

Figure 3 *View of the cracks in the landfill*

Measurements were taken with a manual corn penetrometer on the problematic part of the Western external Landfill (Figure 4).

Figure 4 *Manual corn penetrometer*

Figure 5 *Measuring zones*

The following cohesion values were obtained at several measuring points in three measuring zones (Figure 5):

- First zone - C = 38 to 42 kPa
- Second zone - C = 28 to 32 kPa
- Third zone - C = 15 to 19 kPa

The measurements confirmed that the compactness of material, especially in the second and third areas, was poor, which led to the bursting of deposited masses. The auxiliary machines are very little used. Such anomalies must be avoided to the maximum due to the future Great External Landfill.

Figure 6 *View of the Western External Landfill*

CONCLUSION

Since these landfills (Western and Eastern Landfills) are the basis for formation of a large external landfill with great dimensions, the requirements of geotechnical data are higher. It is necessary to compress and plan material with the auxiliary mechanization. In addition to this basic method of increasing the stability of the landfill, consideration is given to examining two ways of increasing geomechanical data using ash and slag from the thermal power plant. The way and method of mixing with deposited material will be tested in the MMI laboratories. The application of geotechnical data improvement is possible for all existing landfills.

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SELECTION THE OPTIMAL DEVELOPMENT OPTIONS OF MINING OPERATIONS IN THE GACKO COAL BASIN

Abstract

For a concrete example of development the "Strategy of Mining-Technological Opening, Development, Optimization and Maintenance the Continuos Coal Production with Introduction the Process of Coal Enrichment of Dry Separation at the OP - GACKO", it is necessary to carry out the ranking and evaluation the variant solutions and on the basis of fiven estimation to choose the optimal solution for further development of the Open Pit Gacko. This work describes the process of ranking and evaluation the variant solutions.

Keywords: *multicriteria decision making, ranking, OP Gacko*

INTRODUCTION

Operating conditions at the OP Gacko are very complex and expressed through the mining-geological, mining-technical and techno-economic indicators.

For an insight into the current issues and future directions of development the open pit coal mining in the Gacko coal basin, the "Strategy of Mining - Technological Opening, Development, Optimization and Maintenance the Continuos Coal Production with Introduction the Process of Coal Enrichment of Dry Separation at the OP - GACKO" was made. The strategy has defined a number of ways of using the coal resources in order to maintain a continuity of coal production for the needs of the Thermal Power Plant Gacko with achieving the desired economic, social, environmental and other effects.

PRODUCTION STRATEGY OF COAL AT THE OP GACKO

The strategy is a detailed assessment the possible directions of development of the Open Pit Gacko with the required capacity of 2.3 million tons, and speciefied quality. There are three variant solutions. The variant solutions are analyzed in detail from optimization to developemtn of the open pit by the required time periods.

For the purposes of the Strategy of Mining - Technological Opening, Development, Optimization and Maintenance the Continuos Coal Production with Introduction the Process of Coal Enrichment of Dry Separation at the OP - GACKO, a 3D geological model of the coal deposit Gacko was made. Data from 680 drill holes were used in designing the 3D geological model.

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Processing of the deposit began forming the database of exploration drill holes. Some files contain for each drill hole: the name of drill hole, data on elevation, coordinates, data on lithological members in geological pillars of drill holes (which are relevant to the assessment of position the seams in separated geological environments), as well as data on the results of chemical analyses of individual and composite tests.

The all required data were reached in the process of exploration drilling, as well as the carried out laboratory analyses (spatial location of each drill hole is defined by the X, Y, Z co-ordinates, the final depth of each drill hole, lithological members were determined in the process of mapping the drill hole core, and data on quality were obtained by laboratory analyses).

The coal deposit Gacko is presented by seamsof irregular shape. The deposit is constructed of four coal seams with seams and thin seams of barren rocks between and within it. Therefore, each of these seams and and thin seams, either coal or overburden was modeled as a separate seam (Table 1).

Table 1 *Vertical division of deposit on coal seams and thin seams in the 3D model of deposit*

Name of seam	Program seam name
A	B
Roof zone-upper level	U11
Roof zone-intermediate level	U12
Roof zone-lower level	U13
The main coal seam	GUS1
The main coal seam	GUS2
The main coal seam	GUS3
The first floor coal seam	PPUS1
The first floor coal seam	PPUS2
The first floor coal seam	PPUS3
The second floor coal seam	DPUS1
The second floor coal seam	DPUS2
The second floor coal seam	DPUS3

Data about the terrain topography are also entered. Digitization is performed by AutoCAD software package.

Optimization of the open pit was done using the software for long-term strategic planning of the mine - "Whittle Fx". In addition to the structural and qualitative characteristics, contained in a block model of the deposit, the techno - economic parameters, adopted on the basis of detailed analysis of mining and market conditions, were also used in optimization.

The complexity of conditions, in which the objects of mining the deposit Gacko are formed, is expressed through the spatial arrangement and structure of coal seams of the basin Gacko, the parameters of coal quality per individual coal sedries and, the administrative division of the deposit into two exploitation exploration fields, the Central and East, proximity of the town and infrastructure buildings on the northern edge of the deposit and urban planning purpose of the deposit area and immediate surroundings. The aforementioned limiting factors in terms of the future coal mining required a detailed analysis of a large number of variant solutions. One of the main goals of the Strategy development was also to be based on the results of comparative analysis and application the methods of optimization and strategic planning, to chose the most favorable open pit, both from the economic and technological aspects.

During the detailed consideration of operating conditions, optimal contours of structures and mining stsrem, three real variant solutions were distinguished that were analyzed in detail.

The analysis of these variant solutions included a detailed design of objects and parameters of mining systems, defined as the techno-economic indicators, social-societal impact of mining on the environment and degree of influence the mining activities on the environment.

The overall variant solutions can be described as follows:

The first variant involves the formation of the open pit within the administrative space limitations-the regulation line, prospecting geological profile 55 and the existing works on excavation and disposal, with the annual capacity of $2.3 \cdot 10^6$ tons of run-of-mine coal;

Figure 1 *Contour of the open pit - Variant 1*

The second variant is represented by the open pit for excavation only the roof coal seams, with the annual capacity of $3.0 \cdot 10^6$ tons of run-of-mine coal, in order to create a significant accumulation of financial assets for further development of the mine

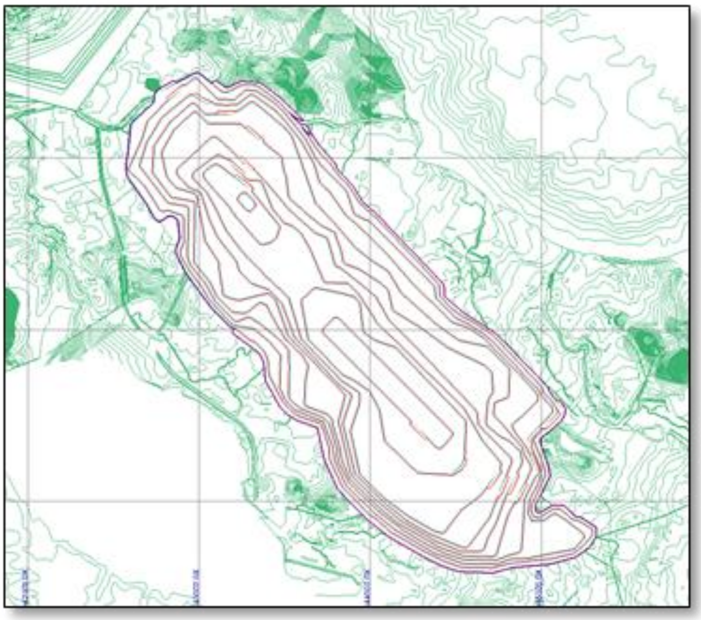

Figure 2 *Contour of the open pit - Variant 2*

The third variant is a continuation of the first, but not limited by the prospecting geological profile 55, with the annual capacity of $2.3{\cdot}10^6$ tons of run-of-mine coal.

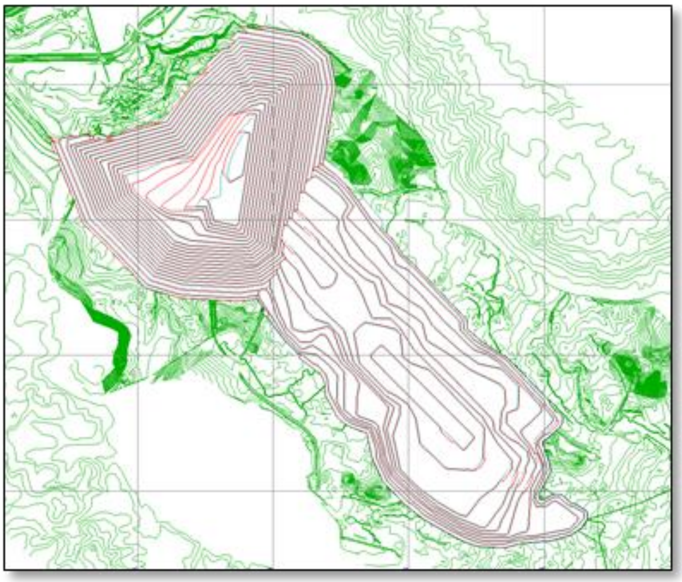

Figure 3 *Contoru of the open pit - Variant3*

As a suitable tool for selection the optimal variant of works development, the method of scoring model was used from the group of multi-criteria decision making.

METHOD OF MULTIU-CRITERIA DECISION MAKING

Making a choice is a study of identifying and selecting an alternative in order to find the best solution based on various factors and in accordance with the expectations of those who make the choice. Every decision is made in the appropriate environment, which is defined as a set of available information, alternatives, values and settings (preferences). A complex decision-making point is the number of criteria for evaluation of alternatives. The objectives are usually conflicting, and in the most cases different groups are present from those who should make a decision.

To facilitate this type of analysis, a set of tools known as the multi-criteria decision making methods is formed by the need to formalize the methods to aid in decision making in situations involving multiple criteria.

Methods of multiple-criteria decision making are a part of the overall field of operational research, and the models are suitable for solving the complex problems with a high degree of uncertainty, conflicting objectives, different types of data and information and aspects, and calculation in complex and development-level systems such as biophysical and socio-economic. This large class of methods is further divided into multi targeted decision-making and multi attribute decision making. These methodologies share the common features such as conflicting criteria, incommensurability units and complexity in the formation-choice of alternatives. The main difference between the two sets of methods is based on the number of alternatives that are evaluated. The multi attribute decision making methods were established for selection the clearly defined alternatives, and multi targeted methods of decision making are more suitable for solving the problems of planning the systems and processes that are characterized by a higher number of objects, when theoretically there are an infinite number of continuous. In the multi targeded decision making (also known as multi targeted programming or vector optimization / maximization / minimization of problems), the alternatives are not predetermined, but instead of a set of target functions optimize the variables in the set of constraints. The requirement is the optimal and most efficient solution. In a single solution, it is not possible to improve the performances of any target, and that at the same time the other targets are not reduced. In the multiple attribute decision making, an avaluation of a small number of alternatives is carried out on the basis of a set of parameters that is often difficult to quantify.

Using the multi-criteria decision making method is suitable for:

- Assessment and integration of multiple factors in the function of objective and transformation the quantitative and qualitative information in the criteria and weighting factors,
- View the complex and heterogeneous criteria in a simple and understandable way, and therefore the results are clear to multiple recipients, regardless of specialty.

The advantage of this method is reflected in these two important aspects:

1. The used criteria are evaluated and given values are constant and comparable with the initial data (as a measure of convenience)
2. The simple form of the output values makes the method clear and usable for various interested participants.

These methods can provide the solutions to increase the complex management problems. They provide a better understanding the specific characteristics in defining the problem, emphasize the role of participants in the decision making process, allow a compromise and collective decision and provide a good platform to understand the model and analyst in a realistic scenario. The methods help improvement the quality of decision making just making the decision clearer, more rational and efficient.

It should be noted that the methods and results are not necessarily comparable. Each of the methods has certain limitations which mainly arise from the initial assumptions. Inconsistency can occur because:

- Formulation the problem of choice does not imply the same structure of priorities,
- A way of information processing on priorities differ from method to method, and
- Methods take differently into account the weight criteria.

Multiple-criteria decision making can be considered as a complex and dynamic process, including the management and engineering level. Management level defines the objectives, selection of the final optimal alternative while engineering level defines the possible alternatives, points out the consequences of the selection anyone of the possible alternatives in terms of different criteria and performs the multiple-criteria ranking of alternatives. The optimization procedure is performed at the engineering level.

At the management level, the managers, decision makers can accept or reject the suggested solutions. The decision making process usually involves five main stages:

1. Defining the problem

2. Formation and establishment of alternative criteria,

3. Determination the weight factor criteria,

4. Evaluations,

5. Selection of appropriate multi-criteria method,

6. Ranking alternatives.

Basic phases višekritetijumskog method of decision-making are:

1. Define the problem, the formation of alternative and setting the criteria.

Problem-making should start by a clear definition of the problem, specifying the alternatives, identification of participants, objectives and possible conflicts with the limitations, degree of uncertainty and risk, and key issues. After this, the problem can be supplemented by defining the criteria for assessment.

2. Criteria for determining the weighting factors.

Other steps include determining the weighting factors of criteria. These weighting factors represent the set of relative measure of their importance in the method of multi-criteria decision making.

3. Formation of the evaluation matrix

At this stage, only the problem of multi-criteria decision making is defined by a way that enables the assessment of alternatives. The model can be represented in the matrix form as

Criteria: C1, C2, C3, ..., Cn

Weights: W1, W2, W3, ..., Wn

Alternatives

$$\begin{bmatrix} A1 \\ A2 \\ \\ Am \end{bmatrix} \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix}$$

where:

x_{ij} - assessment of given alternative(s) by the determined criterion,

w_j - weighting coefficients by the determined criterion,

n - number of criteria,

m - number of alternatives.

4. Selection of appropriate methods

Multi-criteria methods can be selected and applied to the problem in accordance with the order of alternatives. Data and de gree of uncertainity is a key factor for the decision makers when choosing between the multi-criterion methods.

5. Ranking alternatives

Finally, the alternatives are ranked, and the best ranked one represents a solution to the problem.

METHODS OF EVALUATION AND RANKING THE VARIANT SOLUTIONS

As a recommendation for future work of development the open pit, a selection of scoring method was done. This widely accepted expert method allows relatively quick and easy way to identify the best alternative decisions.

It is assumed that it is necessary to decide on one or more variants, in the specific case of the three present variants of development the mining activities.

There are the following phases that are necessary to set up the scoring models:

Phase I

Set a list of criteria that should be considered. The criteria are important factors for evaluation of every decision.

Phase II

Determine the weight of each criterion that indicates its relative importance:

w_i = weighting criteria *i*

Phase III

Determine each criterion measure that shows how well each alternative meets each criterion:

r_{ij} = criteria and measures *i* for decision *j*

Phase IV

Calculate the value for each alternative decision:

S_j = value for alternative decision *j*

The equation for calculating the value S_j as follows:

$S_j = \sum_i w_i \cdot r_{ij}$

Phase V

The order of selected alternatives from the highest to the lowest value is at the same time ranking by the scoring model for alternative decisions. The decision is made for an alternative with the highest number of scores, and it is recommended for implementation.

According to this method, the choice of development variants was carried out in five steps, wherein the first defines a list of criteria, the second defines the weighting criterion, the third defines the measure of satisfaction level, the fourth defines a calculation alternative value for decision-making, and the fifth is ranking of variants.

Phase I: List of criteria

- Degree of utilization the available reserves,
- Service life,
- Quality of supplied coal,
- Investments,
- Net present value of the project.

Phase II

A scale is used for determining the weight, depending on the criterion validity, and in the specific case, since the five-point scale is used for selected list of criteria.

Importance	**Weight (w_i)**
Very important	5
Somewhat important	4
Moderate important	3
Somewhat unimportant	2
Very unimportant	1

Thus, for the selection of variants defined in Table 2.

Table 2 *Criterion of decision making, importance and weight of criteria*

Order No.	Criterion	Importance of	Weight
1	Degree of utilization the available reserves	Somewhat unimportant	2
2	Service life	Somewhat important	4
3	Quality of supplied coal	Medium important	3
4	Investments	Somewhat important	4
5	Net present value of the project	Very important	5

Phase III:

Each alternative of decision is evaluated in terms of satisfaction of each criterion. For selection the possible variants, thefollowing levels of satisfaction have been selected:

Level of satisfaction	Measure (r_{ij})
Extremely high	9
Very high	8
High	7
Almost a high	6
Medium	5
Almost low	4
Low	3
Very low	2
Extremely low	1

The calculation process must be completed for each combination of decisions for alternative for each criterion. Since there are five criteria and three alterna tives for decision making (5 x 3 = 15), the measure 15 is obtained for alternative decisions that are given in the following Table 3.

Table 3 *Measures for making the alternative decisions*

Criterion	Variant 1	Variant 2	Variant 3
Degree of utilization the available reserves	4	5	7
Service life	4	3	6
Quality of supplied coal	8	5	6
Investments	2	4	2
Net present value of the project	5	8	8

Phase IV

It is necessary, according to the given weight, to calculate the value of each alternative for decision - making. Thus, for example, for alternative 1, its value is:

$$S_j = \sum_i w_i \cdot r_{ij} = 2{\cdot}4{+}4{\cdot}4{+}3{\cdot}8{+}4{\cdot}2{+}5{\cdot}3 = 75$$

Based on the determined values, the values of alternatives for decision-making are obtained, which are given in Table 4.

Table 4 *Values of alternatives for decision-making*

Criterion	Weight	Variant 1		Variant 2		Variant 3	
		Measure	**Value**	**Measure**	**Value**	**Measure**	**Value**
	(w_i)	(r_{i1})	(w_i*r_{i1})	(r_{i2})	(r_{i3})	(w_i*r_{i3})	(w_i*r_{i2})
Degree of utilization of available reserves	3	4	12	5	15	7	21
Service life	4	4	16	3	12	6	24
Quality of supplied coal	3	8	24	5	15	6	18
Investments	4	2	8	4	16	2	8
Net present value of the project	5	5	25	8	40	8	40
Total value o			**85**		**98**		**111**

Phase V: Ranking

1. Variant 3 = 111
2. Variant 2 = 98
3. Variant 1 = 85

Based on the scoring method and obtained ranking of variants, it is necessary, as optimal, to adopt the Variant 3, that satisfies the all production and economic criteria according to all techno-economic parameters in the best way.

When considering the variants, the statutory-legal conditions were not used as a criterion which will be used for future mining. This was done in order that the considered variants could be compared on the basis of objective technical-economic parameters, without taking into account the formal-legal framework of mining on the relevant area.

From this aspect, it is important to note that mining by the preferred variants 2 and 3 would be developed in the area both of the Central and Eastern exploration-exploitation field. This includes the provision of appropriate legal permits to perform the exploitation of the entire area of the basin.

However, bearing in mind:

- the current state of coal mining in the area of the Gacko coal basin,
- the necessary amounts and quality of coal supplies for thermal power plant,
- the available time necessary for the provision of legal conditions for continuation of exploitation for the purpose of stable supply of the thermal power plant with fuel (period of validity of the existing Supplementary and Simplified Mining Project), and
- readiness of the study, design and other necessary technical documentation,

it is certain that in the future, and in a very short period of time, an appropriate legal framework for coal exploitation can be provided exclusively for the area of the

Central exploration-exploitation field. In this way, the current development of mining activities in the area of the Gacko coal basin is limited to Variant 1.

Based on the possibility of providing the legal requirements for development of exploitation, it is clear that in the immediately upcoming period, development of mining activities must be carried out within the framework of the Central field, and according to Variant 1. Considering the techno - economical parameters, and evaluation the rank of the considered variants, it is necessary to focus the following activities to provide the conditions for implementation Variant 3, which realizes the most favorable economic, but also social and other effects.

CONCLUSION

Application the method of multi-criteria decision making in selection the optimal alternative, in the cases of complex techno-economic projects (or system), provides a number of advantages which are reflected primarily in the following:

- substantially avoids the subjectivity when deciding on selection the best alternative,
- the results of evaluation and ranking the alternatives are clear decision-maker regardless of whether they have the specific knowledge related to the technical, technological and other solutions which are solved within the engineering part of considering the problems,
- ranking of alternatives presented by numerical value provides better understanding the results,
- a number of methods enable combining the preferences of many experts and the qualitative and quantitative types of criteria are applicable.

The necessary condition for successful application of these methods is to provide the accurate and complete information about the nature of project, and values of parameters by individual alternatives and criteria.

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THE IMPACT OF BLASTING ON THE ENVIRONMENT IN THE OPEN PIT MINING[**]

Abstract

In the open pit mining of mineral raw materials, blasting, whose role is to break the undisturbed mass for easier loading, is the necessary technological phase. In the mass blasting at the open pits of metal ore, there is a rise of cloud composed of gases and dust, blasting mining products, which have negative effects on the surrounding environment. This work presents the calculations of a cloud size, concentration of gases and dust in blasting.
Keywords:

INTRODUCTION

Development of a modern society is based on the need to fill the demand for goods and services, so the industry has to evolve and adapt, to be able to secure and market these products (Kogel et al., 2006). The first step in this process is the supply of raw materials for further processing and transformation. In fact, mining could become one of the major forces in the global economy, which takes a vital position in the supply chain of raw materials (Jorge Castilla-Gómez, et al, 2015). In this scenario, mining is facing one of the biggest challenges that can arise in any industrial activity. It is the exploitation of mineral raw materials from the Earth's crust, and in doing so, no negative effects on the environment are created. Since this is hardly feasible in practice, certain protective measures that reduce the effects or completely neutralize them, are applied in mining.

1 EXPLOITATION OF MINERAL RAW MATERIALS AND POTENTIAL EFFECT ON THE ENVIRONMENT

Exploitation of mineral raw materials consists of several technological phases, which for the ultimate goal have the extraction of mineral raw materials from the Earth's crust to be available for further processing.

Technological phases in the exploitation of mineral resources are:

- Drilling
- Blasting
- Loading

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- Transport
- Disposal
- Crushing
- Processing of mineral raw materials

Regarding the potential impact on the environment, the development of mining activities has certain characteristics compared to other types of work/activities. Environmental and social impacts are diverse and sometimes last long after the completion of all mining activities. Therefore, the ecological impact of mining must be carefully assessed at an early stage of the mining project. The actions and resources needed to mitigate potential impacts have to be also evaluated after the completion of mining activities (Christmann et al., 2007).

Unlike the other industries, mining does not jeopardize the location of activities/ works, as there is no possibility to choose locations for formation the deposits of mineral raw materials. However, the mining company (Investor) can change the mining method by open pit mining with some method of underground mining in order to better preserve the natural resources in a given area, or even to minimize certain types of impact to the environment (ELAW, 2010).

The potential impacts of a certain technological phase in mining to the environment depend on a wide range of local factors such as the nature of ore and rock mass, geological and geotechnical parameters, extraction methods, generated and natural waste (solid, liquids or gases) and nature and vulnerability of local components of the environment.

2 BLASTING

In blasting, i.e. detonation of explosives and explosive mixtures results in a rapid change of state the unstable chemical components of explosives and transition to more stable detonation oxides, which occur in all three aggregate states, mostly in the form of gases and dust. The type of detonation product that will appear depends on:

- characteristics of explosives, that is, the chemical composition of components from which the explosive is made
- method of patronizing the explosive and chemical composition of packaging materials
- method of initiation and flow the chemical reaction of explosive decomposition that depends on the initiation impulse, rock hardness, blasting techniques, age of explosives, rock temperature, humidity, etc.
- chemical composition of rocks that are blasted and percentage content of matter in them that can enter into the chemical reaction with explosives during blasting, or appear as a product of rock destruction.

The quantity of gases produced during blasting at the open pits is about 1000 dm^3/kg of explosives. In gaseous mining products, the toxic gases are also encountered, such as: carbon monoxide, sulfur dioxide, nitrogen oxides, sulfur dioxide, and others depending on the blasting conditions.

In the case of mass-blasting at the open pit, a cloud of gas and dust is formed, windborne polluting the wider environment of the open pit, or in inversion of the atmosphere of the open pit endangers work of workers on the site at the open pit. When detonating explosives, a part of gases reaches the atmosphere (about 50%), the second part (about 20%) is absorbed by the blasting mass, and the third (about 30%) fills the pores, cracks and empty spaces in the rock mass, from which it stands out during loading and contaminates the working environment at the open pit.

3 VOLUME OF A CLOUD OF GASES AND DUST FORMED AFTER BLASTING

Volume of a cloud of gases and dust formed after blasting at the open pits can be determined on the basis of theoretical and empirical formulas (M. Miljković et al., 1998). The volume of a cloud composed of toxic and congested gases of blasting products is increased due to the temperature of explosive detonation T, and amounts (M. Miljković et al., 1998):

$$V_t = b\frac{273+T}{273}A,\ dm^3 \qquad (1)$$

where:

- A - amount of explosives used for blasting in the minefield of the open pit (kg),
- b - amount of gases released in detonation one kilogram of explosive, Table 1 (dm^3),
- T - temperature of gaseous products after blasting. It is initially very high (about 1000°C) and then rapidly decreases to the ambient air tempe-rature.

Table 1 *Amounts of gases realized in detonation of 1kg of explosives*

Type of explosive	**Amounts of V_{ig}, dm^3/kg and % and toxic gases**				
	Total	**CO**		**NO_2**	
		dm^3/kg	**%**	**dm^3/kg**	**%**
Amonex-1	963	21.30	2.20	2.30	0.24
AN-FO mixture	890	11.00	1.20	1.80	0.20
Majdanit 10	980	20.00	2.00	3.10	0.31
Average	994	17.40	1.80	2.40	0.25

3.1 Blasting Parameters at the Open Pit Veliki Krivelj in Bor

Dusty-gas cloud in blasting occurs in three phases as follows:

- outbreaking or ejection from the borehole,
- loosening, crushing, demolishing, initiating and moving of massif, and finally throwing and falling of blasted mass, and
- under the influence of air strikes and seismic earthquakes.

The mass blasting method is applied at the open pit Veliki Krivelj. The average consumption of explosive amount per borehole in a series for AN-FO explosive is 504 kg.*

The cloud volume is composed of toxic and congested gases of blasting products and dusts increased for temperature of explosion detonation T, and calculated for the following blasting series:

* *Supplementary Mining Design for Excavation and Processing of Copper Ore in the deposit "Veliki Krivelj" for a capacity of 10.6 x 10^6 tons of wet ore – Technical Design for Mining, MMI Bor, 2011.*

- V_t = 1 930 615.38 dm^3
  (for a series of blasting of 2100 kg of explosive)
- V_t = 4 596 703.29 dm^3
  (for a series of blasting of 5000 kg of explosive),
- V_t= 45 967 032.96 dm^3
  (for a series of blasting of 50000 kg of explosive),

The amount of toxic gases in the form of gaseous products of blasting depends upon the specific formation of toxic gases by detonation the certain types of explosive (dm^3/kg), Table 1, and it is determined on the basis of formula (M. Miljković et al, 1998):

$$Q_{ig} = \frac{A \cdot V_{ig}}{1000},\ m^3 \qquad (2)$$

where:

- A - amount of explosives used for blasting in the minefield of the open pit (kg),
- V_{ig} - amount of gases released in detonation one kilogram of explosive, Table 1 (dm^3),

The initial amount of a certain toxic gas in the form of gaseous blasting products is:

- Q_{ig} = 1 869 m^3
  (for a series of blasting of 2100 kg of explosive)
- Q_{ig} = 4450 m^3
  (for a series of blasting of 5000 kg of explosive),
- Q_{ig} = 44500 m^3
  (for a series of blasting of 50000 kg of explosive).

Concentration of i-th gas in volumetric percentages in the cloud of gaseous blasting products amounts to (M. Miljković et al., 1998):

$$C_{ig} = \frac{100 \cdot A \cdot V_{ig}}{V_t},\ m^3 \qquad (3)$$

C_{ig} = 78%

Table 1 gives data on formation the certain toxic gases for explosives used for blasting at the open pit.

The resulting cloud after blasting and decomposition of explosives, besides the gaseous products, also contains a large amount of dust. The total amount of dust that rises with the cloud of gaseous products after detonation of explosives according to the forecast is (M.Miljković et al., 1998):

$$I = \frac{0.149 \cdot a^2 \cdot V_b}{t}, kg/s \qquad (4)$$

where:

- I - total amount of dust that rises with the cloud of gaseous products after detonation of explosives is a dust emission within a time interval of 10 to 40 seconds,
- a - specific consumption of explosives (kg/m^3) of blasted rock mass a= A/V_b,
- V_b - volume of a block on a level that is blasted.

I = 186.98 kg/s

The direction, range and concentration of air pollution in the environment due to the occurrence of dust cloud depend on the ground configuration and air flow. If it is blasted when the southeast wind blows, the blasting pollution has a direction of moving towards the village Veliki Krivelj (very rarely). If the wind is from the northwest direction, the blasting pollution is directed towards the flotation tailing dump Veliki Krivelj.

4 CONCLUSION

On the basis of presented amounts of gases and dust in blasting at the open pit Veliki Krivelj, the gaseous blasting products and raised dust threaten the environment by dangerous concentrations of gases and harmful dust. On the basis of this, it can be established that a direct impact on the environment due to the wind rose has on the surrounding village of Veliki Krivelj. In order to deal with it, it is necessary to take the appropriate protection measures as early as possible in order to eliminate the subsequent negative effects.

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SOURCES OF POLLUTION IN LEAD - ZINC CONCENTRATE PRODUCTION IN THE FLOTATION PLANT "KOPAONIK" – LEPOSAVIĆ

Abstract

The aim of this paper is to monitor the operation of the Flotation Plant Kopaonik - Leposavić, where the technological process of flotation of lead - zink ore is carried out, with special reference to the sources of pollution created during in the given technological process. The pollution caused by the technological process of lead-zinc ore flotation in the Flotation Plant "Kopaonik" Leposavić can be divided into three groups: water pollution, soil pollution and air pollution. This work wants to emphasize the importance of mining production sustainable development in near future, strengthening of ecological awareness, development of ecological volunteer activities and implementation of more and more stringent environmental standards. The constant increase in the cost of protection to date is a consequence of continuous improvements of both legal regulations and general ecological awareness.

Keywords: *concentrate, exploitation, pollution, regulation*

1 INTRODUCTION

The Flotation Plant is located in Leposavić, which, together with the mines Crnac, Belo Brdo, Žuta Prlina and Koporić, composes the working organization Kopaonik within the Trepča combine.

The mines Belo Brdo, Žuta Prlina and Koporić were opened in the places with the same names on the slopes of the Kopaonik mountain, on the right bank of the Ibar River. The Crnac mine was opened in the place carrying the same name on the Rogozna mountain on the left bank of the Ibar River. The traces of the mining carried out in the past are still visible in all these locations. A well-preserved branch of the old city water pipeline was found in the village of Crnac, which talks for itself about the intensity of mining.

Not far from Leposavic, on the main road for Kosovska Mitrovica, there is a settlement called Socanica, where the remains of the ancient Roman city are located, as well as the remains of the smelter, which talks on development of mining at that time, as well as that this area is rich in ore resources. The Flotation Plant in Leposavic is located so that it can receive the entire production from all four processing mines. The Flotation Plant has a plant for the primary ore crushing from the mine Crnac, while the plants for the primary ore crushing from other mines have been built in those mines themselves. The Flotation Plant has two sections for selective flotation of lead and zinc minerals. The processing capacity is 1300 tons per day, or 27 tons per hour.

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2 ENVIRONMENTAL POLLUTION WITH LEAD AND ZINC AND HARMFUL EFFECT OF LEAD ON HUMAN BEINGS

Due to the biological effects and high levels of presence, lead is one of the most important heavy metals. In the lithosphere, it is present in a form of lead minerals, which are galenite, (RbS), and anglesite, ($RbSO_4$). The metallurgical process of lead production belongs toa group of dirtiest technologies, since dangerous substances are released during the lead production in a form of gases, dust (containing Rb, As, etc.), tailings and wastewater with high lead content, resulting in contamination of the soil, surface and underground water.

In surface and underground water, lead is found in concentrations up to 0.04 mg/l, while the maximum permissible concentration in drinking water is 0.005 mg/l [1]. Lead has the ability to accumulate in surface layers of soil, where it is predominantly organically bound. It is transported through the soil most often in the form of soluble chelate complexes.

In addition to the building sulfides, lead can be adsorbed to sulfides of other metals, and it has been shown that widespread iron sulphides, pyrite (FeS_2) and mackinawite (FeS) serve as lead, mercury, cadmium and zinc substrates. Lead is a systemic poison, which means that once it enters the body, it is transmitted through the whole body, disrupting the health of a person.

In the Earth's crust, there is about a hundred times more zinc than copper (about 0.001%). The main ores are sphalerite (ZnS) and smithsonite ($ZnCO_3$), used for zinc production. The less represented ores are: zincite (ZnO), franklinite (Zn (Fe9Mn2O4)) and vilemite (Zn2SiO4). Sphalerite always contains some cadmium (II) sulphide, so the production of cadmium is linked to the production of zinc. The total zinc content in the soil ranges from 5 to 1000 mg/kg [2].

The soil formed on the base rocks contains more zinc compared to the soil formed on the acid rocks. Low solubility in water is characteristic of carbonates, oxides and sulfides, which contributes to the low concentration of zinc in natural water (0.01-0.05 mg/l). The increased concentration of zinc in water is most often caused by the industrial pollution, from mining water that are characteristic for zinc-rich mines, which can lead to an increase in zinc concentration in water, up to 50 g/l. Due to the usage of galvanized pipes and containers in the water pipe systems, the zinc content in water is often increased. The maximum permissible content of zinc in drinking water is 3 mg/l, [1].

3 WATER POLLUTION

All mining plants and facilities, active or not, pollute the environment, especially the surrounding water courses. This pollution can be physical and chemical. The content of hazardous and harmful substances in water depends on the primary source of pollution, that is, the volume and content of hazardous and harmful substances in them.

The primary sources of water course pollution can be: surface mines, underground mines, flotation plants, separations, flotation and separation tailings, deposits of coal, ash and ore, transport systems, etc. Polluted water can be surface, underground and mine water, or processing water (waste water). Polluted water then enters the nearby water courses.

There are other pollutants in the Ibar River Basin, and it is often a problem to define a share of mine pollution in the total scope of pollution. Also, the water tests upstream and downstream of the pollution site should be done as a control tool.

Pollution of water courses at the exploitation stage of mineral resources

At the stage of mineral resources exploitation, which involves excavation, loading, transport, unloading and disposal, the water is polluted more or less, and then is transferred to the surrounding water courses and continues to spread further to larger water courses. The pollution of water that is transferred from the mine to the natural hydrographic forms can occur due to the following reasons: separation of hazardous substances from the deposit when contacted with water; physical blurring of water courses due to small particles released into water; erosion of internal landfills; release of waste solids into water; release of oil, lubricants and other oil derivatives into water; mixing of water from the repository of waste water with running water and so on.

Pollution of water courses is characteristic for the periods of increased precipitation and snow melting when eroding activities are increased. This problem is particularly present in the landfill area, where the significant amounts of waste and tailings in the form of sand and silt go into the water, later releasing numerous substances that alter the natural mineral composition of water. It is estimated that more than 40% of heavy metals have come into the water due to the erosion processes of such landfills.

Water courses in the mining plant zone are polluted long after the end of active exploitation, unless the appropriate remediation measures are taken.

Pollution of watercourses at the preparation stage of mineral resources

As a result of the preparation of mineral resources, the organic substances (phenols, etc.) appear as pollutants in the surface watercourses. Furthermore, by drainage of water from the processes related to the preparation of mineral resources, there is a greater or lesser emergence of toxic substances (phenols, cyanides, heavy metal salts, heavy metals, etc.).

Toxic reagents, pyrite pyridines (cyanides) are still used in some flotations, and despite the introduction of closed return water systems, a part of the harmful substances reach the nearby watercourses anyway.

Tailings, associated with the preparation of mineral raw materials, are large water polluters. The flotation tailing dumps overload the soil and, in addition to violation of legislation, contaminate the surface and underground water.

The flotation tailing dump Gornji Krnjin - Leposavic is located near Leposavic settlement, right on the Ibar river bank. The tailings from the lead- zinc ore preparation plant is hydraulically driven to the tailing dump, where the solid and liquid phase of tailings is separated by sedimentation.

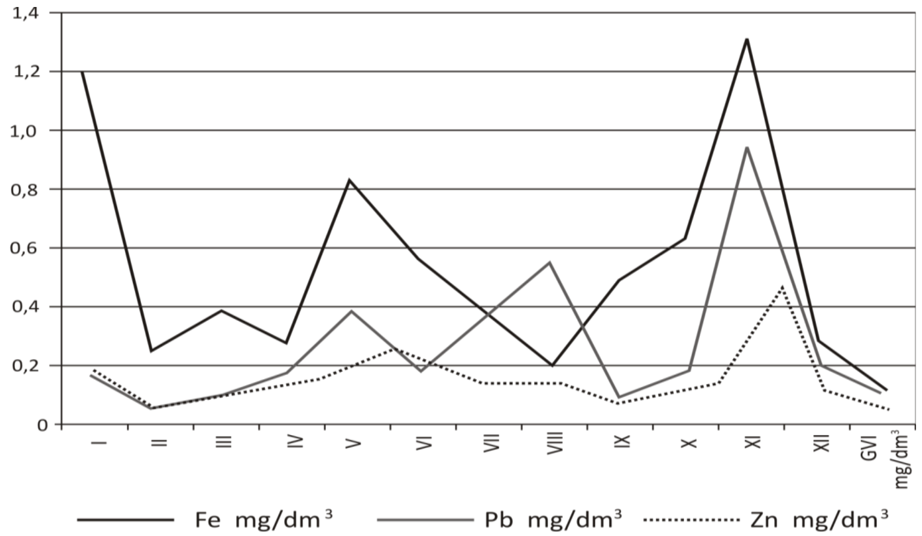
The tailing dump was active from 1970 to 1985. The surface of tailing dump is about 7 ha and about 2,600,000 tons of waste is deposited on it. The chemical composition of tailing dump is: Pb = 0.36%, Zn = 0.33% and Fe = 22%. In 1985, a new tailing dump was built in the immediate vicinity of the old one, and was named "Bostanište".

Figure 1 *Photo of the 'Bostanište' tailing dump*

The flotation tailing dump in Leposavic has a dual effect on water pollution. Firstly, the life and growth of flora and fauna in the river, in river bed, but also on the river banks, are directly affected physically and chemically by the uncontrolled deposition of flotation waste or in case of accidents. Secondly, through groundwater, the aqueous solutions from a flotation-tank lake, usually saturated with heavy metals, flow into the watercourses of the respective reception areas. The harmfulness that can be caused by devastation is acomplete destruction of the plant and animal world in the Ibar River basin, endangering objects and settlements downstream from the tailing dump and permanent contamination of soil and wells in the flooded area [2] with heavy metals.

Table 1 *Physical-chemical parameters of the Ibar downstream of Kosovska Mitrovica (mg/l) (2016).* [3]

Tested parameters	Lowest values	Highest values	Most frequent values
rN value	6,8	7,7	7,2 – 7,6
Chlorides, Sl$^-$	12	28	16 – 24
Ammonia	<0,02	0,3	– 0,1
Nitrite	0,1	0,9	– 0,3
Nitrates	5	<80	15 – 30
Iron	<0,01	0,9	0,1 – 0,5
Sulphates	0,02	12,6	2,8 – 5,9
Phosphates	0,0324	1,2	0,3 – 0,7
Calcium	52,6	79	55 – 69



Graph 1 *Graphical illustration of the Ibar River water quality (2016) [3]*

4 SOIL POLLUTION

Soil contamination is primarily expressed by filling the tailings (the rest of the mineral ore mixed with phase rocks) to the fertile soil, and then by penetration the remnants of reagents used in the process of ore refining. Thus, the fertile arable land becomes completely and permanently degraded, i.e. uncultivable. Furthermore, the deposit of the flotation tailings creates the industrial waste that changes the relief of soil, by its formation, whereas in the second phase, it is a source of small fractions of infertile pollutants, which cover the surrounding fields, thus turning the fertile soil into - infertile, sterile over time.

Contamination of soil near mining facilities is most often done with the help of fluids (water and air).

This means that the transport of contaminated materials is carried out with help of them, that is, they must first come into a contact with contaminated materials. [4]

The primary soil contaminants are: mining plants for exploitation, flotation and separation, deposition of tailings, mining waters, etc.

The subsidence of dust from the air is a consequence of large concentration of dust in the air created by mining operations. Dust created by blasting, moving vehicles, transportation to other areas, etc., is spread around by air movement in the vicinity of mines, and it sets down on the ground. The surface of the land has been inevitably changed in the vicinity of mines where the exploitation has been taking place for a long period of time. Flotation tailings have their negative impact on the surrounding land mainly through the water that washes away the tiny waste and deposits as sludge or sand on the surfaces in the immediate vicinity.

Also, in this case it is possible to pollute a wider environment by deposition of fine dry particles blown from the tailings by the wind. Pollution of the surrounding land can lead to reduction of yields on land in several ways, and the impact will last several years after the exploitation of tailings has ceased.

There are many heavy metals in the flotation tailings, which are not separated as a concentrate during the flotation process. The average content of these metals is different in the mixture of tailings and water in a ratio of 1:10, but it has concentration of 10 to 20 times higher than the allowed one. The penetration of this tailings into the surrounding land can result in multiple and long-term damage to the environment and the living world, including people.

During the exploitation process of mineral raw material deposits, the underground watercourses are crossed and there is an increased inflow of water into the mines. This water is collected into water collectors and taken by pumps or by gravitation out of the mine.

Table 2 *Report on the soil quality control from the Flotation Plant in Leposavic [3]Measuring location: Tailing dump*

	Tailing dump
Pb (%)	0.38
Zn (%)	0.21
Cu (%)	0.001
Cd (%)	0.0002
Fe (%)	5.02
Ca (%)	3.83
Mg (%)	2.02

Passing through the layers of ore and rocks, the water reacts chemically and becomes a solution. This is especially characteristic for mines of metal mineral raw materials where aggressive water is formed containing a lot of harmful substances. This water is sometimes taken to the watercourses, and thus they have a detrimental effect on the surrounding land..

5 AIR POLLUTION

Air pollution during preparation phase of mineral resources exploitation occurs in almost all technological phases. Somewhere this pollution is particularly visible, but frequently is difficult to notice pollution, which does not mean that it is less harmful. The most frequent air pollution occur in: drilling and mining of surface mines, operation of crushing plants, transportation of mineral raw materials and tailings, raising dust from landfill and ash dumps, oxidation on separation tailing dumps, etc.

The most important air pollutants can be divided into two groups: dust and gases. Both groups of pollutants are very present in mining.

Exploitation of mineral raw materials is carried out by destruction of massif, and fragmentation of particles to dimensions smaller than one millimeter, even microns, occurs in this process. This dust goes into the air and spreads through the air in surroundings.

The drilling phase, crushing and further shredding of the material result in a formation of potentially dangerous mineral dust. Using water when drilling partially alleviates this problem, but there are additional problems if there are clay primers in drilled rocks.

Air pollution by gas is present in the operation of diesel-powered equipment and the oxidation tailings and coal depots. Diesel equipment is mostly used in mining for the truck transportation, in the operation of auxiliary machinery and rarely, in the operation of various generators. The exhaust gases are discharged through the exhaust pipes of engine and immediately sprayed and diluted in the ambient atmosphere. The content of hazardous components in the exhaust gases depends on the quality of diesel fuel, tfuel combustion, quality of drive engine, exhaust gas purification device, etc.

The air quality (mean values of precipitated results) in parts of the city or the surrounding area exposed to the impact of the flotation tailings is most often presented in table as shown in the attached Table 3 with data of directed measurers of atmospheric precipitation sludge, and Table 3 with data from a non-directed atmospheric sludge measurer.

Table 3 *Values of directed atmospheric precipitation sludge measurers for October 2016 [3]*

Ord. No.	Sample mark		Total solid substances $mg/m^2/day$	Insoluble solids $mg/m^2/day$	Soluble solids $mg/m^2/day$	Ash $mg/m^2/day$	Flammable substances $mg/m^2/day$
1.	1	E	119.92	58.39	56.53	15.01	43.38
2.		W	227.54	132.52	95.02	88.10	44.42
3.		N	146.03	87.57	58.46	45.05	42.52
4.		S	244.00	178.47	65.53	109.54	68.93
5.	2	E	142.73	78.47	64.26	48.75	29.72
6.		W	175.21	139.89	35.32	86.63	53.26
7.		N	193.87	149.54	44.35	118.23	31.31
8.		S	185.16	131.38	53.78	88.80	42.58
9.	3	E	110.72	61.78	48.94	23.36	38.42
10.		W	89.98	45.15	44.83	16.77	28.38
11.		N	133.17	79.50	54.17	30.58	48.92
12.		S	231.07	160.43	69.64	111.07	49.36

Table 4 *Values of non-directed atmospheric precipitation sludge measurers for October 2016 g.* [3]

Ord. No.	Sample mark	Total solid substances $mg/m^2/day$	Insoluble solids $mg/m^2/day$	Soluble solids $mg/m^2/day$	Ash $mg/m^2/day$	Flammable substances $mg/m^2/day$	Lead concentrate $\mu g/m^2/day$	Sample quantit y ml
1.	1	233.56	138.46	95.10	87.24	51.22	216.08	420
3602.	2	193.65	129.55	64.10	81.91	47.64	195.65	550
3.	3	164.84	92.75	72.09	42.42	50.33	107.39	210
MDK po St. RS		300-450					100-250	

Measuring points: 1. Flotation Plant - east of the tailing dump; 2. Gornji Krnjin - north-west of the tailing dump; 3. Kutnje - southeast of the tailing dump

CONCLUSION

It is easy to conclude that the Flotation Plant is a problem and an economic challenge for Leposavic, surrounding towns, the Ibar River, environment in general, whereas on the other hand, the Flotation Plant as a whole with the mines represents the economic security for a large number of peope living and working here.

The problem is additionally increased by the fact that the flotation equipment was already outdated at the time of construction. The lack of modern equipment and elements, both for the ore processing, as well as for the environmental protection, is manifested in a form of environment pollution and contamination by the side products of flotation technology. The consequence of all of this is a difficult economic situation in the whole country, all the misfortunes that we have faced, and, to a great extent, the low level of awareness about environmental protection and the consequences that nature can bring back to us as a boomerang.

Whether our country joins or not the EU, the mining companies should comply with the environmental standards and appropriate environmental legislation. Thus, the population in the mining sites would be protected from the existing sources of pollution and import of dirty technologies. All this presents an additional financial burden for the company. Globally, the mining companies will themselves have to turn to cleaner technologies to relieve the ever-increasing cost of environmental protection.

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SELECTION THE MOST FAVORABLE PUMP TYPE AND CONFIGURATION OF PUMP SYSTEMS AT THE OPEN PIT GRAČANICA - GACKO**

Abstract

Coal mining at the OP Gacko - Central Field takes place on two spatially separated locations: the Central and Overlaying exploitation zone. The deposit Gacko has a high coefficient of watering due to the large catchment areas, high values of maximum rainfall and presence of aqufers, as well as the continuing flow from the existing water flows and channels. Due to these reasons, a correct selection and sizing the structures of water protection system are very important from the techno-economic aspects.

Keywords: *Open Pit Gacko - Central Field, water protection, analysis of pump stations, operating and capital costs of pumping*

INTRODUCTION

After completion of the coal mining in the West Field of Gacko coal basin, which took place within the OP Gračanica, and its expansion in the far western part of the Central Dield, further coal exploitation continues at the new OP Gacko - Central Field.

Coal mining at the open pit Gacko – Central Field will take place on two spatially separated locations, worksites, in the Central exploitation zone and Overlaying exploitation zone. In the Central exploitation zone, the mining operation of the main coal seam are realized, the first and second floor seam of the coal seam, and in Overlaying exploitation zone, coal from overlying series are mined that consist of three coal seams. All coal seams are complex, and the overlaying coal seams are characterized by a distinct stratification or a large number of interseams of waste which are separated by interseams of coal. The mineable zones are characterized by different geological structure, applied technology and the depth at which coal mining is carried out. In addition, development of the open pit in the next period can be divided into two specific sub-periods. In the first sub-period, in which the mining in the zone of overlying coal seams shall be carried out by 2025, the development of works is mainly planned with slower progression of works by a depth, and mainly in the Central exploitation zone. After the end of coal mining in the Overlaying exploitation zone, the works shall be continued ex-

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clusively in the Central exploitation zone. The second subperiod of exploitation is characterized by widening the open pit, or an intensive development of work by a depth [2, 3].

GENERAL TERMS

Within the complex of coal mining, the protection system of the open pit on water must provide the safety development the activities at the open and favorable conditions for the high-capacity and economical operation of the basic exacavation, transport and disposal equipment [1].

Analyzing the available data on the quantity of water evacuated in the last decade from the open pit, it was found that the coefficient of deposit watering Gacko K>3.5 as the deposit Gacko classified as deposits with high coefficient of watering.

The most important natural factors that influence the selection and sizing the structures of defense system at the open pit of water are [2, 3]:

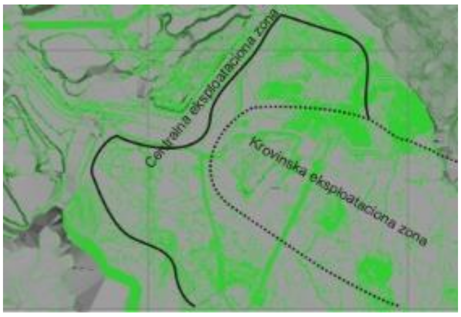
- Large catchment area, which amounts to 36 km^2, out of which 20 km^2 is the area of high mountains, 9 km^2 is the plateau Gacko field and the other space of 7 km^2 of degraded by the mining activities (external and internal dumps, ash landfill, etc.). In development the solutions to protect the facilities at the open pit from inflow of water, the development of mining operations or change the nature of the soil in terms of water inflow was taken into account.
- Precipitation leve, characterized by a very high maximum values for the legally prescribed return period and a distinct uneven during the year.
- The presence of two types of aquifers:
- Aquifers in the footwall Jurassic limestones and calcareous - lmarly flysch formation, and
- Aquifers in the Neogene Carbonaceous formation.
- Aquifers and inflow of water from permanent natural waterways and canals.

Overall, it can be said that the protection of the open pit Gacko - Central field of water takes place in a complex hydrological, hydrogeological and technological – technical conditions and as a technologically complex medium contains different types of drainage facilities (water-proof screen, canals, water collectors, pumping stations, gravity pipelines and pressurized pipeline, overfalls, piezometers, etc.). The designed conditions of works until the end of lifetime of the open pit mine Gacko - Central Field by the five-year exploitation periods are shown in Figure 1.

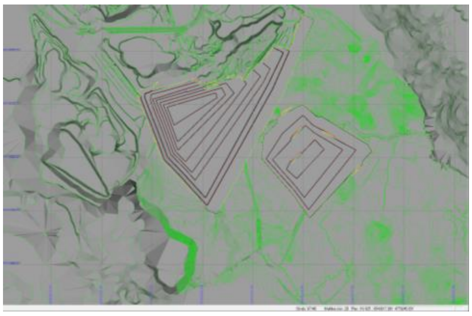
In defining the system of protection of the open pit Gacko - Central field of water, as the starting point, the existing system, technology and equipment were taken into account that are used for a longer time for the evacuation of water from the open pit zone. Since this is the equipment that is modern, fit the needs of exploitation and for which the staff for maintenance has been already trained, preference, it was concluded to use the existing equipment and equipment with similar characteristics for water drainage from the open pit zone.

WATER DRAINAGE FROM THE CENTRAL EXPLOITATION ZONE

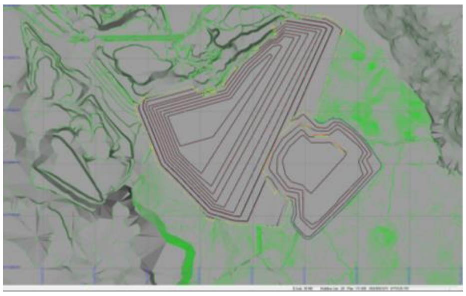
Protection of the open pit from surface water from the east, south and west side of the open pit was done by relocation and regulation of the river Gracanica and Mus-nica and Gojkovića stream. With regulated riverbeds, the defensive embankments were built in order to prevent penetration of surface water into the open pit at the time of high water levels. Protection of the open pit of surface water on the north side of the open pit was made by a peripheral channel. In addition to this, development of peripheral channels which would constitute a protection of the surface water from the east and south sides.



Initial Balance works, 2016. years



Status of work at the end of 2020



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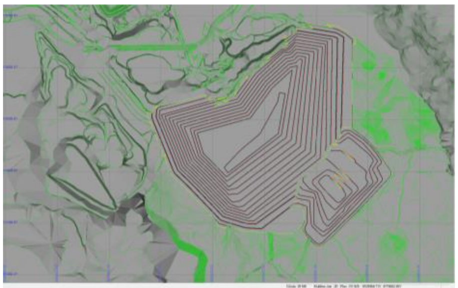

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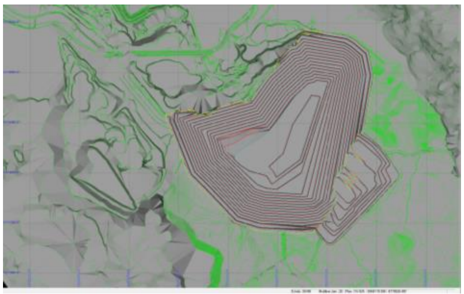
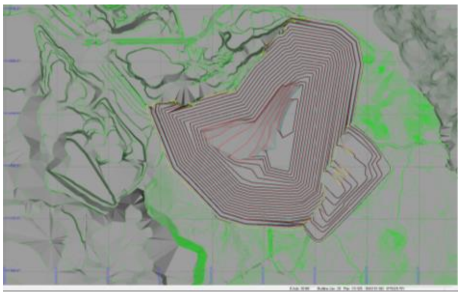


Status of work at the end of 2035



Status of work at the end of 2037

Figure 1 *Designed status of works to the end of exploitation the open pit Gacko - Central Field*

In the central part of the excavated area of the Field B at the open pit Gracanica, there are the water collector VS-B1 and pumping station PS -2. From water collector VS-B1, water is pumped into a circumferential channel. In the south of the ash and slag landfill, there is a water collector VS-A1 where water is pumped into the river Gracanica. In the north of the Field C (expansion of the open pit Gračanica in the central part of the field, which has until now been in operation) is a water collector VS1. Also in the Field C, a water collector VS exists near dispatcher. At the lowest floors in the Field C, there are two water collector VS-VS-C1 and C2, and with development of works, the water collector VS-C2 will be terminated. All water from the Central mineable zone is pumped into the river Gracanica. Within the overlying coal series, or in the area overlying the exploitation zone, there is a water collector

VS-PZ1, where water is pumped into the old riverbed Musnica. The existing structures for protection the open pit in the Central and Overlaying exploitation zones are shown in Figure 2. The pumps at the open pit are mainly shown in Table 1 [2, 3].

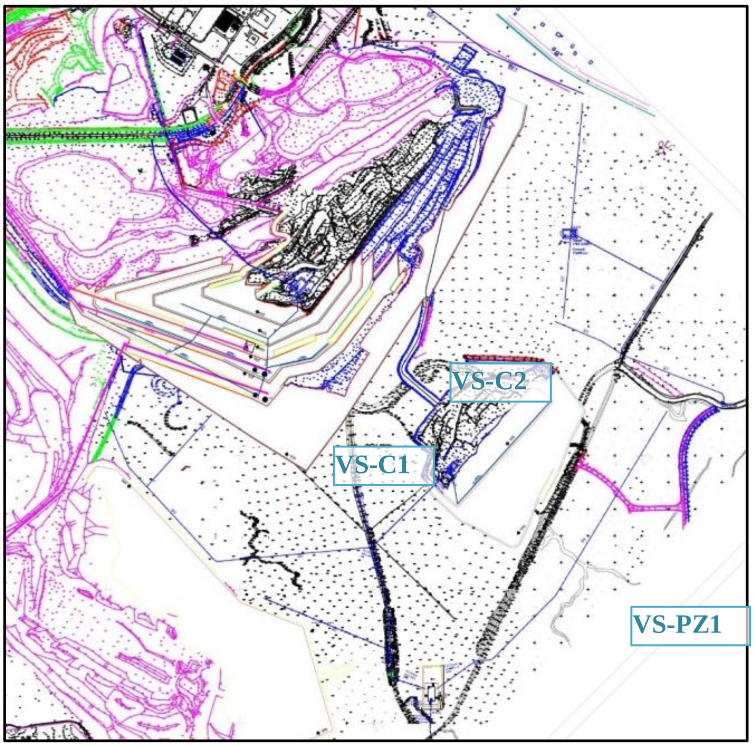


Figure 2 *Drainage facility in 2016*

Table 1 *Available pump stations at the open pit Gacko – Central field*

Rb	Pump designation	Manufacturer	Pump power (KW)	Voltage (V)	Pcs.	Note
1	BS 2250 MT	Flygt	54	380	15	Submersible
2	BS 2250 HT	Flygt	54	380	5	Submersible
3	BS 2400 MT	Flygt	90	380	2	Submersible
4	BS 2400 HT	Flygt	90	380	5	Submersible
5	CS 3240	Flygt	275	6 000	5	Submersible
6	DH 86-50	Jugoturbina	500	6 000	2	On a pontoon

Conceptually, it predicted for the future period that all water, surface and groundwater, which are found in a contour of the Central exploitation zone shall be collected in the central water collector, and then to drain by the pumps and pipeline, initially in the river Gracanica, and later in the southern circumferential channel.

As a separate issue within the definition and sizing the protection facilities of the open pit of water, the problem of drainage water from the Central exploitation zone was allocated. In designing this part of the drainage system, it was started from the following settings:

- Advantage in the selection the pump types of pumps at the open pit. Considering the characteristics of the eligible pumps can pump engagement type CS 3240 and BS 2400 HT.
- Selected type of pumps will be engaged in the exploitation area of the Central zone to the end of exploitation in order to avoid the reconstruction of the pumping plants, pontoon, pipelines and electro supply system because the available pumps are supplied with electricity at different voltages.
- Having in mind the deepening of the open pit during exploitation, it is necessary to provide, at the appropriate floors, the cascading water pumping and thus to ensure the water drainage outside a contour of the open pit.

ANALYSIS OF PUMP SYSTEM

In the function of determining the most advantageous system for water drainage [4, 5, 6, 7, 8] from the Central zone, different types of pumps were analyzed for various height differences between the floors (cascade) of repumping. The following types of pumps were analyzed: Flygt CS 3240 and Flygt 2400 in two variants of the vertical redistribution the floors of repumping (Variants 1 and 2). As an illustration of the analyzed vertical redistributions, a distinctive intersection is given with the positions and heights of cascading water collectors and pumping systems (Figure 3). Vertical redistribution of floors cannot be done at the discretion, but the vertical arrangement of pumps was already determined in a large extent by diagram of efforts and diagram of hydraulic pump efficiency.

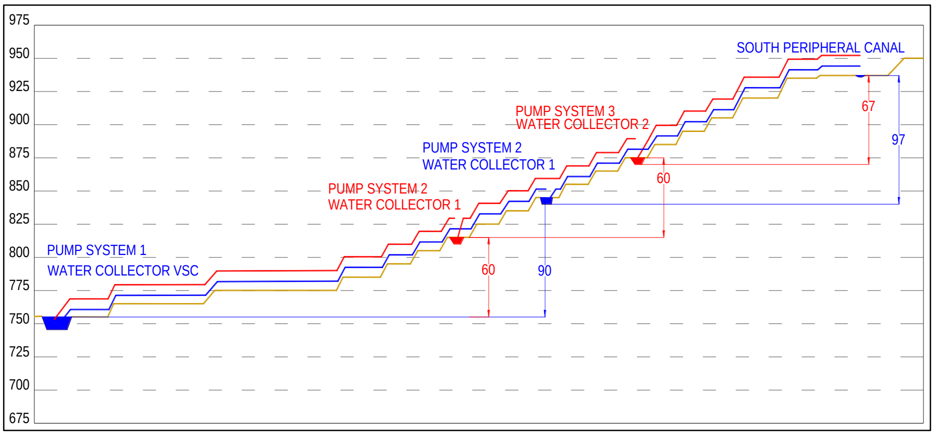


Figure 3 *Scheme of cascade pumping variants in 2035 (— Variant 1,— Variant 2)*

Calculation the parameters of pump operation for water pumping from the Central zone is carried out using on-line application, Xylect 1.41.1 of Xylem corporation with manufacturing the Flygt pumps, which kept their brand. The calculation results are shown in Tables 2 and 3.

Table 2 *Parameters of operation the pumps type CS 3240 with a vertical distribution according to the Variant 1 and Variant 2*

Pump types CS 3240	**Variant 1**					**Variant 2**				
Year	2020	2025	2030	2035	2037	2020	2025	2030	2035	2037
Repumping floor 1										
Elevation VSC (m)	840	830	780	750	710	840	830	780	750	710
Length of pipeline route (m)	412	448	267	426	554	248	215	267	349	515
No. of elbows (pcs.)	18	20	18	18	12	9	10	18	12	12
Pumping height (m)	97	107	60	90	80	50	50	60	60	60
Pumping elevation (m)	937	937	840	840	790	890	880	840	810	770
Total pump efficient coefficient (%)	72.9%	62.1%	80.1%	78.2%	79.3%	75.4%	79.9%	80.2%	80.1%	69.8%
Pump capacity (l/s)	151	104	198	195	199	154	202	198	197	115
Engaged pump power (kW)	211	184	169	252	226	120	162	169	195	105
Specific consumption of el.energy (kWh/m^3)	0.415	0.555	0.387	0.379	0.348	0.232	0.237	0.285	0.293	0.274
Repumping floor 2										
Length of pipeline route (m)			222	296	292	164	233	122	167	220
No. of elbows (kom.)			12	18	16	9	10	9	12	12
Pumping height (m)			97	97	80	47	57	50	60	60
Pumping elevation (m)			937	937	870	937	937	890	870	830
Total pump efficient coefficient (%)			77.5%	76.6 %	80.0%	77.1%	80.3%	79.2%	80.2%	72.2%
Pump capacity (l/s)			188.8	181.1	203.6	177	200	200	198	128
Engaged pump power (kW)			249	245	199	128	178	192	177	110
Specific consumption of el.energy (kWh/m^3)			0.252	0.397	0.326	0.216	0.263	0.222	0.264	0.257
Repumping floor 3										
Length of pipeline route (m)					290			100	206	180
No. of elbows (kom.)					14			9	12	10
Pumping height (m)					67			47	67	50
Pumping elevation (m)					937			937	937	880
Total pump efficient coefficient (%)					80.4%			78.8%	80.3%	77.5%
Pump capacity (l/s)					199.8			203	201	185
Engaged pump power (kW)					187			144	202	131
Specific consumption of el.energy (kWh/m^3)					0.276			0.21	0.297	0.211
Repumping floor 4										
Length of pipeline route (m)										221
No. of elbows (kom.)										12
Pumping height (m)										57
Pumping elevation (m)										937
Total pump efficient coefficient (%)										74.3%
Pump capacity (l/s)										144
Engaged pump power (kW)										116
Specific consumption of el.energy (kWh/m^3)										0.241

Table 3 *Parameters of operation the pumps type BS 2400 with a vertical distribution according to the Variant 1 and Variant 2*

Pump types BS 2400	**Variant 1**					**Variant 2**				
Year	2020	2025	2030	2035	2037	2020	2025	2030	2035	2037
Repumping floor 1										
Elevation VSC (m)	840	830	780	750	710	840	830	780	750	710
Length of pipeline route (m)	412	448	267	426	554	248	215	267	349	515
No. of elbows (kom.)	18	20	18	18	12	9	10	18	12	12
Pumping height (m)	97	107	60	90	80	50	50	60	60	60
Pumping elevation (m)	937	937	840	840	790	890	880	840	810	770
Total pump efficient coefficient (%)	63.3%	57.6%	47.3%	55.5%	53.9%	42.7%	42.2%	45.9%	47.5%	47.8%
Pump capacity (l/s)	36	33	45	38	41	47	50	49	45	45
Engaged pump power (kW)	57.3	60.8	58	62.2	61.8	56.4	57.2	57.6	58	58.1
Specific consumption of el.energy (kWh/m^3)	0.447	0.5135	0.3592	0.4512	0.4199	0.3333	0.3256	0.3592	0.3602	0.363
Repumping floor 2										
Length of pipeline route (m)			222	296	292	164	233	122	167	220
No. of elbows (kom.)			12	18	16	9	10	9	12	12
Pumping height (m)			97	97	80	47	57	50	60	60
Pumping elevation (m)			937	937	870	937	937	890	870	830
Total pump efficient coefficient (%)			56.2%	56.8%	53.7%	40.8%	45.9%	43.4%	47.0%	47.9%
Pump capacity (l/s)			36.3	35.7	41	48	45.6	49.4	45	46.6
Engaged pump power (kW)			62.3	60.9	61.5	56	57.6	57.6	57.5	59.3
Specific consumption of el.energy (kWh/m^3)			0.4767	0.4713	0.4156	0.3246	0.3505	0.3227	0.3571	0.353
Repumping floor 3										
Length of pipeline route (m)					290			100	206	180
No. of elbows (kom.)					14			9	12	10
Pumping height (m)					67			47	67	50
Pumping elevation (m)					937			937	937	880
Total pump efficient coefficient (%)					50.3%			41.8%	48.4%	42.5%
Pump capacity (l/s)					44.6			50.2	38.5	47.3
Engaged pump power (kW)					60.3			57.1	53.3	56.4
Specific consumption of el.energy (kWh/m^3)					0.377			0.3142	0.382	0.3322
Repumping floor 4										
Length of pipeline route (m)										221
No. of elbows (kom.)										12
Pumping height (m)										57
Pumping elevation (m)										937
Total pump efficient coefficient (%)										45.9%
Pump capacity (l/s)										45.6
Engaged pump power (kW)										57.6
Specific consumption of el.energy (kWh/m^3)										0.3504

Comparison the alternative solutions was done on the basis of calculated and presented technical indicators, as follows:

- The total engaged pump power (Figure 4)
- Specific electricity consumption in kWh/m^3 (Figure 5)
- Specific consumption of electricity per meter pressure height in kWh/m^3/m (Figure 6),
- Mean coefficient of the total pump efficiency (Figure 7)

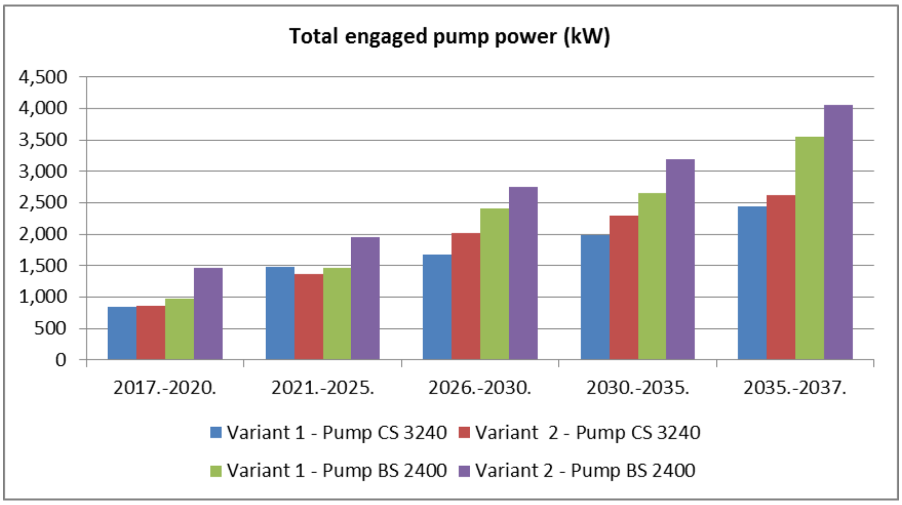


Figure 4 *Total engaged pump power (kW)*

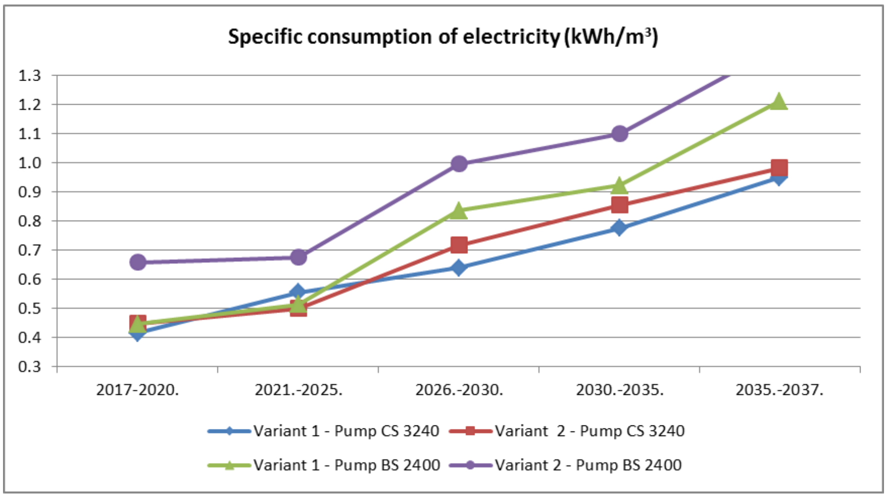


Figure 5 *Specific electricity consumption (kWh/m^3)*

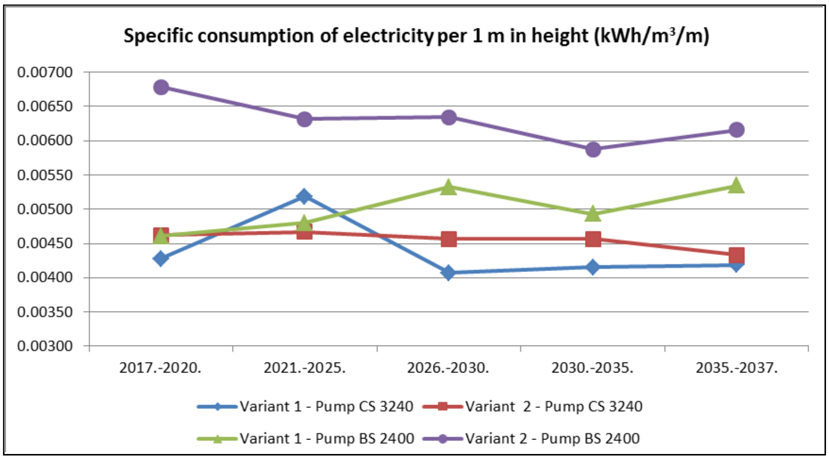


Figure 6 *Specific energy consumption per 1 m of pressure height (kWh/m^3/m)*

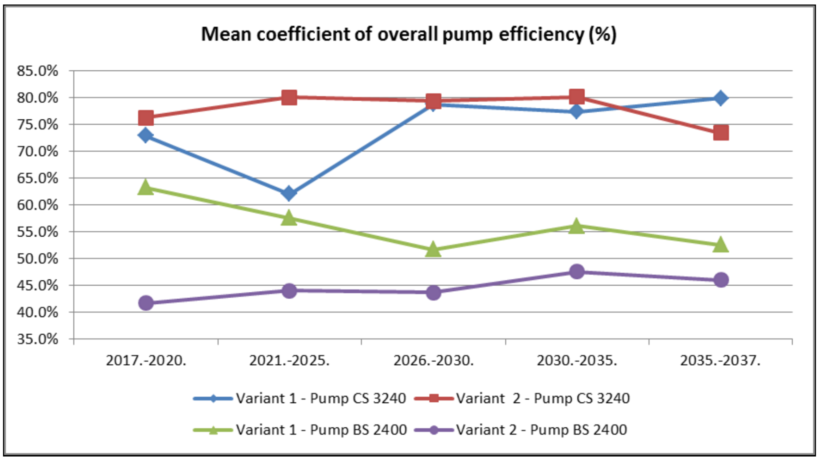


Figure 7 *Total mean coefficient of pump efficiency (%)*

Based on shown diagrams, it can be easily concluded that engagement the pump type CS 3240 in the Variant 1 of vertical distribution of pumps, according to all analyzed parameters, has the best results. The only exception is engagement of these pumps in the period 2021 - 25. During this period more favorable is the Variant 2 of vertical distribution of pumps, or it is most favorable to construct another one cascading water collector and a pumpstation. This is due to the fact that the required discharge height this case is 107 m above the optimum height realized by a pump. Also, by engagement the pump type CS 3240, the better results are achieved than is the case for pump type BS 2400.

In order to realistically assess the effectiveness of design solutions for water drainage from the Central zone of exploitation the open pit Gacko - Central field, in addition to the technical indicators of the equipment operation, it is necessary to analyze the economic indicators by individual variants. Economic indicators by variants mean the calculation of standardized costs of water drainage, Tables 4 - 7.

Table 4 *Operative costs of pump type CS 3240 with position in the Variant 1*

Period (years)	**2017-2020**	**2021-2025**	**2026-2030**	**2030-2035**	**2035-2037**
Expected inflow of water (m^3/year)	6,800,000	7,400,000	8,100,000	8,300,000	8,550,000
Specific consumption of electric power (kWh/m^3)	0.415	0.555	0.639	0.776	0.950
Costs of el. energy (€/year)	112,880	164,280	207,036	257,632	324,900
Other standardized costs (€/year)	33,864	49,284	62,111	77,290	97,470
Maintenance costs (€/year)	15,883	30,413	29,281	29,567	44,197
Total (€/year)		243,977	298,427	364,488	466,567

Table 5 *Operative costs of pump type 3240 CS with position in the Variant 2*

Period (years)	**2017-2020**	**2021-2025**	**2026-2030**	**2030-2035**	**2035-2037**
Expected inflow of water (m^3/year)	6,800,000	7,400,000	8,100,000	8,300,000	8,550,000
Specific consumption of electric power (kWh/m^3)	0.448	0.500	0.717	0.854	0.983
Costs of el. energy (€/year)	121,856	148,000	232,308	283,528	336,186
Other standardized costs (€/year)	36,557	44,400	69,692	85,058	100,856
Maintenance costs (€/year)	25,646	29,187	43,681	43,828	84,422
Total (€/year)	184,059	221,587	345,681	412,415	521,464

Table 6 *Operative costs of pump type BS 2400 with position in the variant 1*

Period (years)	2017-2020	2021-2025	2026-2030	2030-2035	2035-2037
Expected inflow of water (m^3/year)	6,800,000	7,400,000	8,100,000	8,300,000	8,550,000
Specific consumption of electric power (kWh/m^3)	0447	05135	08359	09225	12125
Costs of el. energy (€/year)	121,584	151,996	270,832	306,270	414,675
Other standardized costs (€/year)	36,475	45,599	81,249	91,881	124,403
Maintenance costs (€/year)	36,054	51,677	74,325	83,301	111,472
Total (€/year)	194,113	249,272	426,406	481,452	650,550

Table 7 *Operative coste of pump type BS 2400 with position in the Variant 2*

Period (years)	**2017-2020**	**2021-2025**	**2026-2030**	**2030-2035**	**2035-2037**
Expected inflow of water (m^3/year)	6,800,000	7,400,000	8,100,000	8,300,000	8,550,000
Specific consumption of electric power (kWh/m^3)	06579	06761	09961	10993	13986
Costs of el. energy (€/year)	178,949	200,126	322,736	364,968	478,321
Other standardized costs (€/year)	53,685	60,038	96,821	109,490	143,496
Maintenance costs (€/year)	48,402	62,596	87,845	105,404	130,843
Total (€/year)	281,035	322,759	507,402	579,862	752,661

In addition to the operating costs, capital costs are also considered, containing a value of the existing and new pumps and pipelines. The total cost of water drainage from the Central zone included the mining operations in development the water collector, installation and relocation the pump stations and pipeline, maintenance costs and depreciation of involved equipment. Values of the above costs are given in Table 8.

	Pumps CS 3240 Variant 1					Pumps CS 3240 Variant 2 -					Pumps BS 2400 Variant 1					Pumps BS 2400 Variant 2				
Year	Operative costs	Procurement of pumps and pipelines	Mining operations, installation and relocation	Depreciation	**Total**	Operative costs	Procurement of pumps and pipelines	Mining operations, installation and relocation	Depreciation	**Total**	Operative costs	Procurement of pumps and pipelines	Mining operations, installation and relocation	Depreciation	**Total**	Operative costs	Procurement of pumps and pipelines	Mining operations, installation and relocation	Depreciation	**Total**
2017	163		35	37	**234**	184		50	37	**271**	226		72	13	**311**	328		35	13	**376**
2018	163		35	37	**198**	184		50	37	**271**	226		72	13	**311**	328		35	13	**376**
2019	163		35	37	**198**	184		50	37	**271**	226		72	13	**311**	328		35	13	**376**
2020	163	99	35	45	**297**	184	389	50	56	**679**	226	991	72	72	**1,361**	328	1,221	35	80	**1,664**
2021	244		55	45	**299**	222		55	56	**333**	289		93	72	**454**	384		55	80	**519**
2022	244		55	45	**299**	222		55	56	**333**	289		93	72	**454**	384		55	80	**519**
2023	244		55	45	**299**	222		55	56	**333**	289		93	72	**454**	384		55	80	**519**
2024	244		55	45	**299**	222		55	56	**333**	289		93	72	**454**	384		55	80	**519**
2025	244	375	55	63	**674**	222	1,027	55	109	**1,412**	289	560	93	100	**1,042**	384	498	55	105	**1,042**
2026	298		62	63	**360**	346		82	109	**536**	498		147	100	**746**	594		62	105	**762**
2027	298		62	63	**360**	346		82	109	**536**	498		147	100	**746**	594		62	105	**762**
2028	298		62	63	**360**	346		82	109	**536**	498		147	100	**746**	594		62	105	**762**
2029	298		62	63	**360**	346		82	109	**536**	498		147	100	**746**	594		62	105	**762**
2030	298	41	62	67	**401**	346	938	82	157	**1,523**	498	300	147	121	**1,066**	594	510	62	137	**1,303**
2031	364		62	67	**426**	412		82	157	**652**	557		156	121	**834**	682		62	137	**881**
2032	364		62	67	**426**	412		82	157	**652**	557		156	121	**834**	682		62	137	**881**
2033	364		62	67	**426**	412		82	157	**652**	557		156	121	**834**	682		62	137	**881**
2034	364		62	67	**426**	412		82	157	**652**	557		156	121	**834**	682		62	137	**881**
2035	364	577	62	98	**1,003**	412	1,524	82	238	**2,256**	557	750	156	165	**1,628**	682	673	62	177	**1,594**
2036	467		89	98	**556**	521		144	238	**904**	753		207	165	**1,125**	878		89	177	**1,144**
2037	467		89	98	**556**	521		144	238	**904**	753		207	165	**1,125**	878		89	177	**1,144**
Σ	**6,118**	**1,091**	**1,213**	**1,275**	**8,459**	**6,678**	**3,877**	**1,583**	**2,437**	**14,574**	**9,128**	**2,601**	**2,681**	**2,004**	**16,414**	**11,371**	**2,901**	**1,213**	**2,180**	**17,665**

The structure of total costs by type is shown in Figures 8 to 11. Figures 12 to 15 show the ratio between the fixed and relative costs.

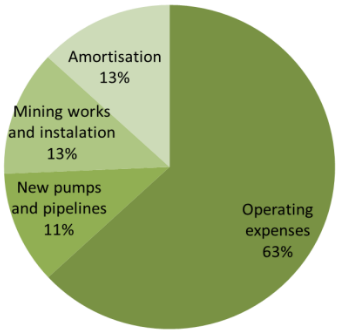


Figure 8 *Structure of the total operation costs of pump type CS 3240 in the Variant 1 1CS 3240 in the Variant 1*

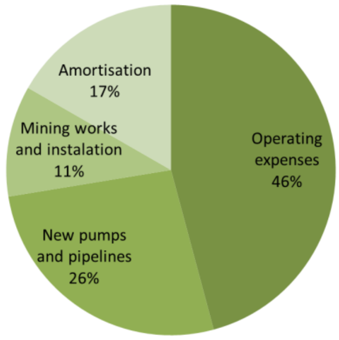


Figure 9 *Structure of the total operation costs of pump type CS 3240 in the Variant 2*

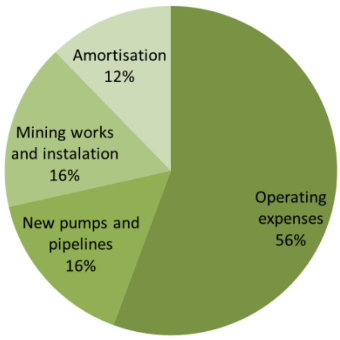


Figure 10 *Structure of the total operation costs per years in €, pump type BS 2400 in the Variant 1*

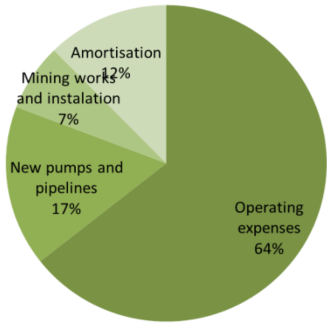


Figure 11 *Structure of the total operation costs per years in €, pump type BS 2400 in the Variant 2*

Based on the following presentation, a dominant share of total costs in all four variants is covered by the operation costs of 46 to 64%, while the lowest share is covered by the mining operations and installation of 7 to 16%.

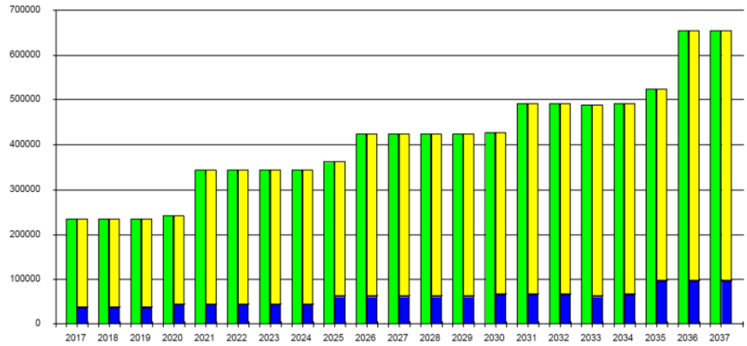


Figure 12 *Fixed ( ) and relative ( ) operation costs per year in €, pump type CS3240 in the Variant 1*

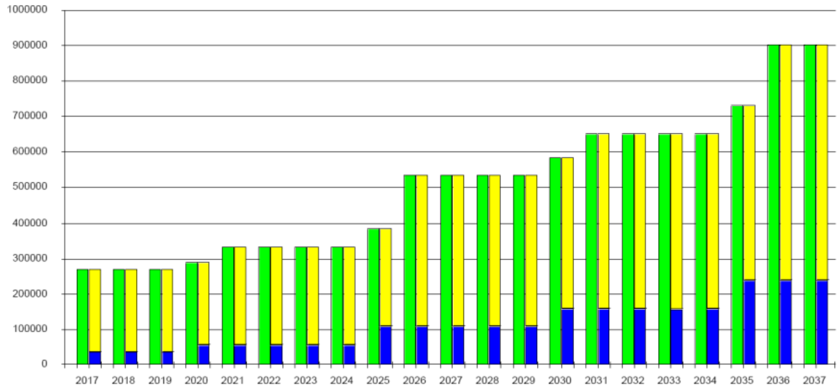


Figure 13 *Fixed ( ) and relative ( ) operation costs per year in €, pump type CS 3240 in the Variant 2*

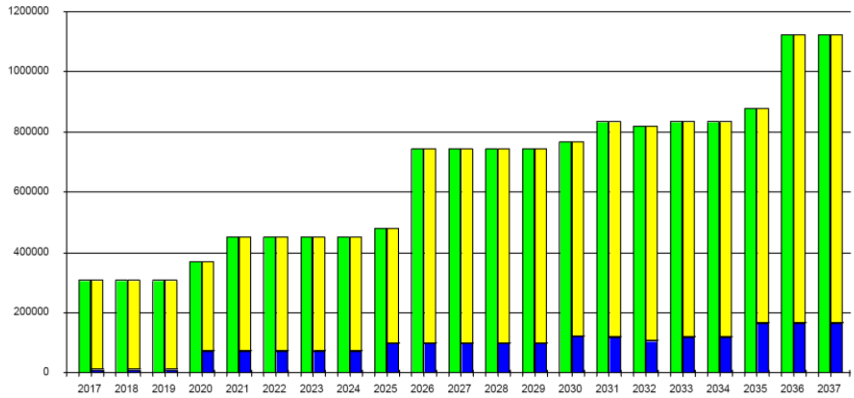


Figure 14 *Fixed ( ) and relative ( ) operation costs in €, pump type BS 2400 in the Variant 1*

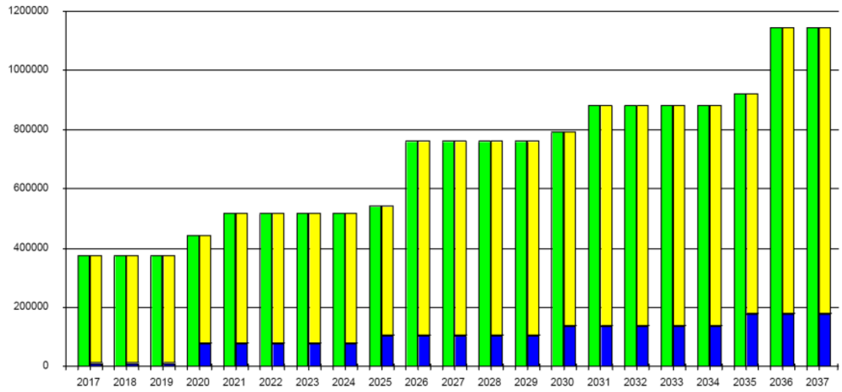


Figure 15 *Fixed ( ) and relative ( ) operation costs in €, pump type BS 2400 in the Variant 2*

Based on the presented graphics, it can be concluded that in all four variants the costs increase progressively per years. The largest increase in variable costs was recorded in the last years of exploitation as a result of a significant increase in depth of the open pit. The unit costs per years amounts on average 0.0874 €/m^3. The share of the relative costs in a structure of the total costs amounts on average about 85%.

Figures 16 and 17 gives the diagrams of the total operation costs of various pumps by the analyzed vertical positions of pumping floors.

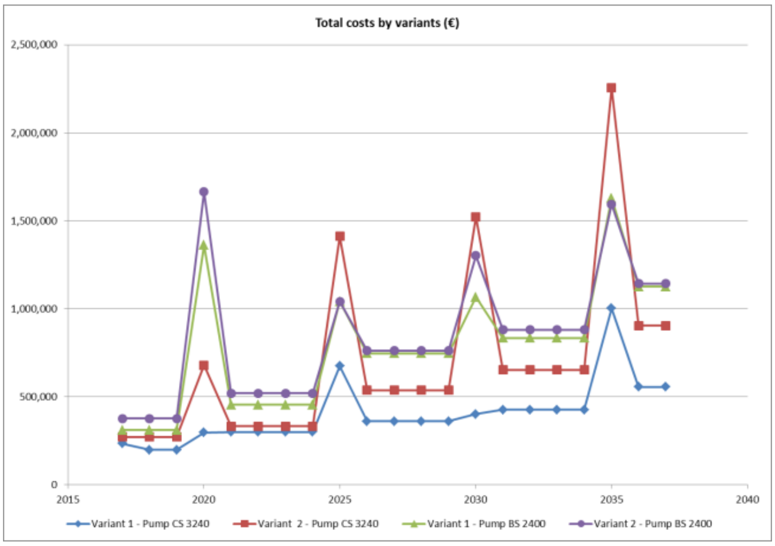


Figure 16 *Total costs of waterdrainage from the Central zone of exploitation*

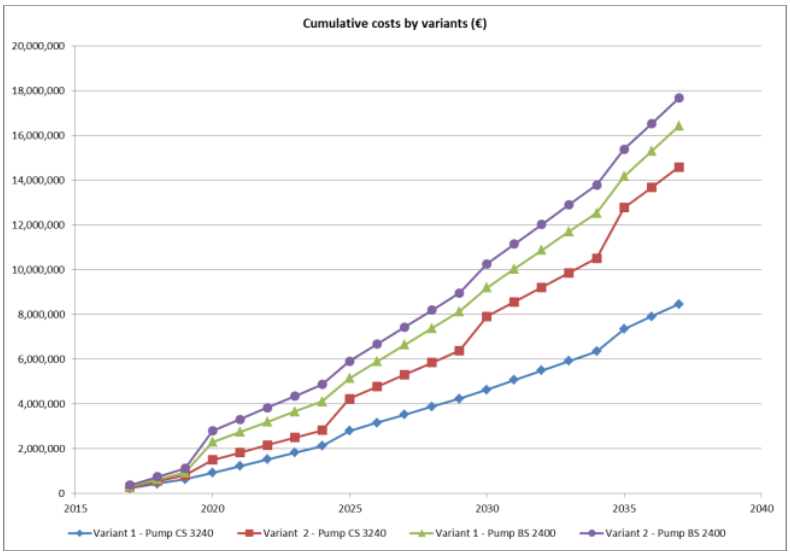


Figure 17 *Cumulative costs of water drainage from the Central zone of exploitation*

Based on the graphics in Figure 17, it can be concluded that most of the total costs are in the Variant2 with the pumps BS 2400. In 2035, a record increase of the total costs shall be recorded in the amountof € 2,000,000.00 (Figure 16) that is realized by the pump model CS 3240, what is a result of need for procurement a large number of pumps in increasing the depth of the open pit.

Based on the results of economic analysis, it can be seen that the total costs of water drainage from the Central zone of exploitation are the lowest for the case of engagement pump type CS 3240 in the vertical distribution according to the Variant 1. This case is from an economic point the most favorable throughout the exploitation periods without the most favorable technical parameters of operation. This typical case just shows that the selection of variants cannot be performed only on the basis of technical or only on the basis of minimizing the cost of procurement the pumps, but both factors must be taken into account.

The presented methodology was used in designing the subsystem of water drainage from the Central exploitation zone within the framework of the Main Mining Design for the open pit Gacko - Central Field, and the results of analysis present a part of the design solution.

CONCLUSION

Using the applied methodology of work analysis of pumps with pumps of different characteristics and different system configurations, analyzing in detail the technical and economic operating parameters of the system, it is possible to select the most favorable ones from a technical and economic point of view. Analysis the technical application conditions of the pump must be carried out for a longer time period in which the system will be applied to the specific operating conditions, pumping height, the fluid characteristics being pumped, the conditions of supply of energy, the dynamics of deepening the open pit, and the progress of mining operations in the plan, the dynamics of relocation the water collectors and pipelines, a distance of the final recipients and others.

Economic parameters of the system drainage water must cover the capital costs of equipment purchase and operating costs of their work, but also the scope and costs of mining operations and auxiliary operations such as construction the water collectors, installation of facilities, their relocation, the extension of the pipeline, and secondly, considering that these works represent a significant part of the total system costs.

Based on the structure of the total costs, it can be said that all analyzed systems of water drainage are characterized by a low share of fixed costs, and that the scope for improvement the cost-effectiveness should be sought in application the modern and energy-efficient types of pumps with features that correspond to the specific operating conditions and not in a savings in rpocurements, especially when it is case with the open pits, characterized by high watering.

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SELECTION OF INDUSTRIAL PROCESS FAN WITH APPLICATION OF SOFTWARE

Abstract

This paper presents the procedure of fan selection by the software ProSelecta2 on the example of an industrial process fan with given technical characteristics. For the selected fan, the detailed technical characteristics are given, as well as a drawing of the fan with built-in dimensions. In brief, the basic alternative options for selecting the fan using this software are explained.

Keywords*: industrial process fan, software ProSelecta2*

1 INTRODUCTION

Process air fans have a wide application in the industry and they represent an important component of equipment and plants in many branches of the process engineering. These fans generate a forced circulation of air that can be used for cooling, drying, ventilation, extracting, combustion in furnaces, etc. The fan manufacturer Nicotra Gebhardt, which is the author of the ProSelecta2 software, has the classified industrial process fans in four series covering the application area for capacity up to 100000 m^3/h, and total pressure rise up to 8000 Pa [1]. Maximum medium temperature is 300ºC. There are also the fan versions for explosive and dusty environment, as well as various variants of drives, various types of materials and accessories. This paper will be show a fan selection procedure on the example of industrial process fan for clean air with maximum temperature of 35ºC, capacity of 71632 m^3/h and total pressure rise of 3706 Pa.

2 EXPERIMENTAL AND RESULTS

The fan selection starts in the 'Selection-input data' window (Figure 1) where the criteria for selection are listed. In this case, the industrial process fan of P4M series was selected. The fans of this series consist of a base frame, spiral housing in a robust steel construction with a single circular axial suction connection, and a rectangular tangential discharge connection, as well as a welded impeller with backward curved blades mounted on the shaft of the electromotor-direct drive. In this window you enter the values of the required capacity, the total pressure rise, as well as the density and maximum temperature of medium. It contains the sub-options for the selection of drives, materials and degree of anti-explosion protection. In this case, a direct drive was selected with an electromotor with a frequency inverter for the net frequency of 50 Hz and arbitrary number of poles, non-alloy steel as a material and a standard fan version without anti-explosion protection. For the given pa-

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rameters, the program gives the listing of fans from which the user selects one fan. A fan with the P4M-T3B62-RBC label was selected here.

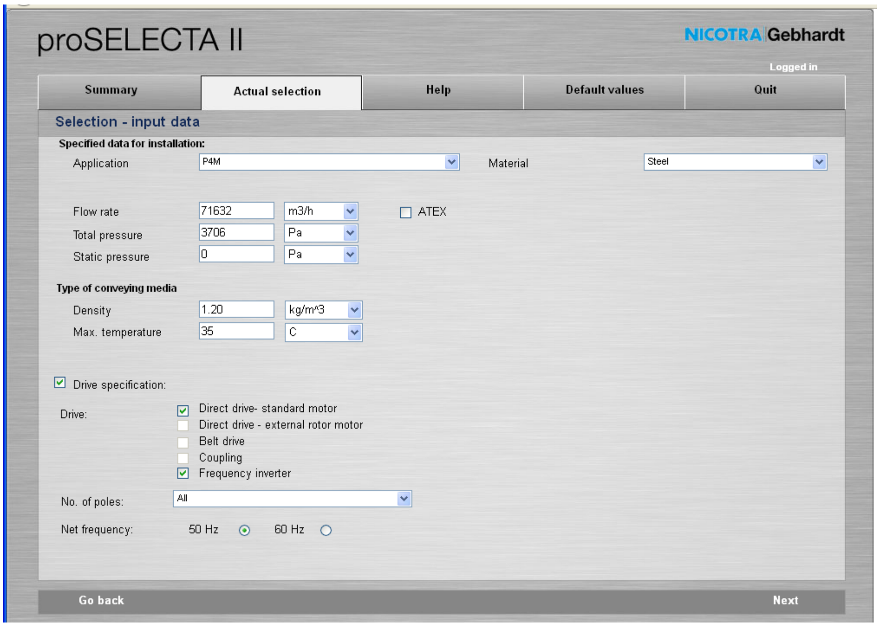

Figure 1 *Criteria for the fan selection-window "Selection-input data"*

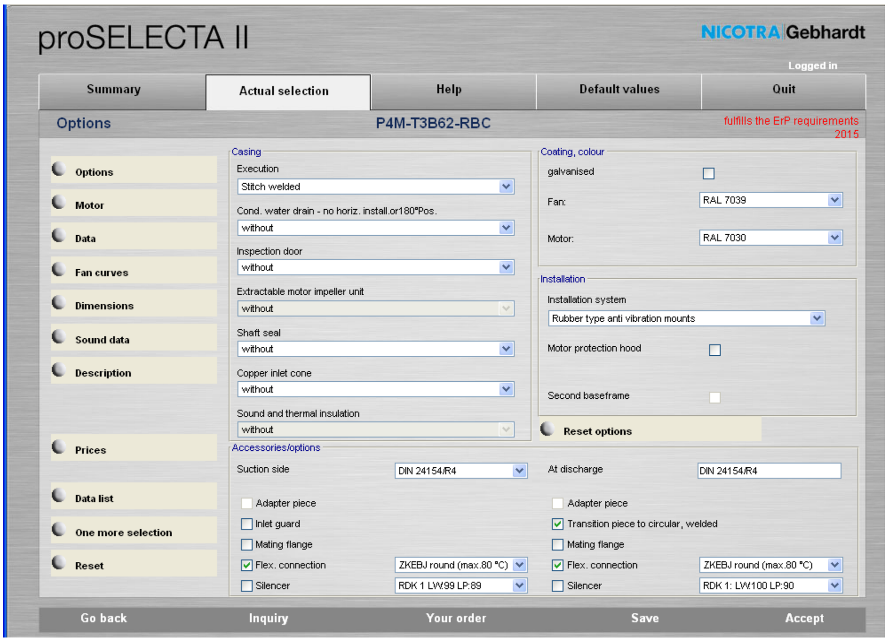

Figure 2 *Options for the fan selection-window "Options"*

The fan selection is continued selecting the corresponding equipment of selected fan in the ‘Options’ window (Figure 2). In this window, the user has the ability to define the characteristics of the housing, type of anti-corrosion coating, methods of installation and options regarding suction and discharge connection. In this case, the options related to the selection of a flexible connection, i.e. a compensator on suction connection and discharge connection, as well as a transition piece from rectangular to circular on a discharge connection are checked, while all other options are left as default. The method of installing the fan here is via rubber type anti-vibration pads.

In the "Motor selection" window, the user has the option of selecting an electromotor from the list of electro motors. An electromotor marked ACM315 M-6/HE was selected here.

The angular position of fan discharge connection and rotation direction is defined in the ‘Inquiry’ window.

Having completed the selection of fan and electromotor the software shows output data in the windows “Data“, “Fan curves“, “Dimensions“, “Sound data“ and “Description“. Technical characteristics of the fan are given in the ‘Data’ window at the operating point and at the best efficiency point. Operating curves of the total pressure rise or static pressure rise, efficiency and power consumption on shaft in relation to volumetric flow rate are given in the ‘Fan curves’ window. Figure 3 shows a diagram of the total pressure rise, efficiency and power consumption on a fan shaft in the function of volumetric flow rate for a fan speed of 1185 rpm and air density of 1.2 kg/m^3.

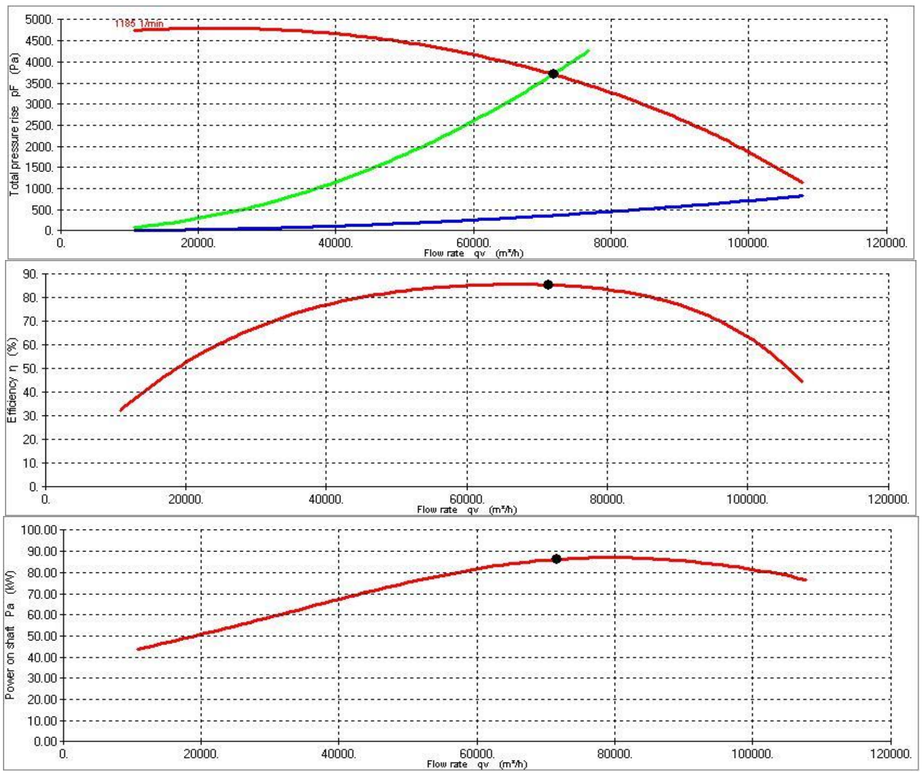

Figure 3 *Total pressure rise, efficiency and power consumption on a fan shaft in the function of volumetric flow rate of the fan P4M-T3B62-RBC*

A drawing with the built-in dimensions of the fan is given in the 'Dimensions' window. The fan sketch is shown in Figure 4. In the 'Sound data' window, the values of noise level in db for various frequencies are given (see Table 1). In the 'Description' window, a technical description of the fan is given. Using option 'Print inquiry' in the 'Inquiry' window, the user has the ability to print all output data. The output data with the technical characteristics of the fan and electromotor are shown in Table 2.

Table 1 *Noise level for the fan P4M-T3B62-RBC*

	LWA	**63 [Hz]**	**125 [Hz]**	**250 [Hz]**	**500 [Hz]**	**1000 [Hz]**	**2000 [Hz]**	**4000 [Hz]**	**8000 [Hz]**	**LPA (1m)**	
Casing brake trough level L_2:	100	70	85	90	95	94	93	89	85	83	dB
Level for free intake L_5:	110	86	100	102	105	103	101	98	93	100	dB
Level for free outlet L_6:	112	87	101	104	107	106	103	99	94	102	dB

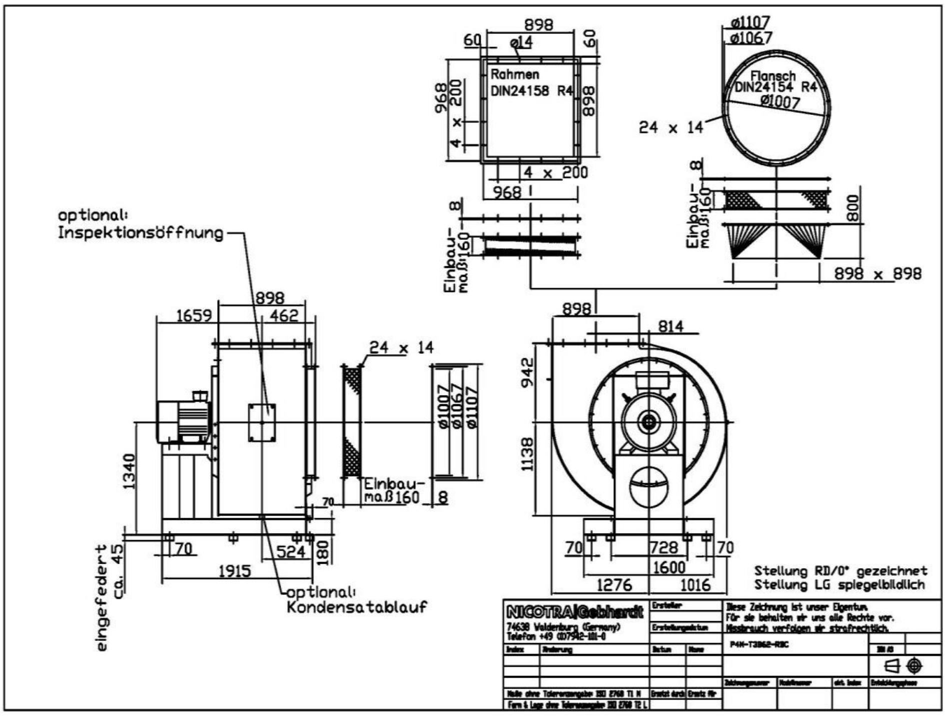

Figure 4 *Drawing with built-in dimensions of the fan P4M-T3B62-RBC*

3 DISCUSSION

As the presented procedure for the fan selection shows, the fan selection using the specified software is quite easy when the selection criteria are known. The fan P4M-T3B62-RBC belongs to a series of direct-drive fans where the impeller is mounted on a shaft of electromotor. In the other process fans series, the impeller may be mounted on its own shaft with bearings where the power transmission from electromotor is carried out via a coupling or a pulley. The advantage of the selected fan relative to the other series is the reduced size of machine, and there is no power loss in bearings or belt transmission for the belt drive option. By selection the frequency inverter, it is possible to achieve the set operating point of the fan, i.e. precise regulation of its operation, as well as more favorable starting conditions. The selected fan works at the operating point in an optimal operating regime with high efficiency

Table 2 *Technical characteristics of the fan P4M-T3B62-RBC and electromotor ACM 315M-6/HE*

PROCESS AIR FAN			**P4M-T3B62-RBC**		
Efficiency status (single speed motors)			**fulfills the ErP requirements 2015**		
Fan data in operating point: (warranty according to DIN 24166)					
Offered accessory which is in contact with the transport medium can alter the characteristic curve and lead to a performance reduction.					
Gas type:			Atmospheric air		
Air flow by inlet:		q_v		71632	m^3/h
Total pressure increase		p_F	3706	3706	Pa
Static pressure increase		p_{sF}	3341	3341	Pa
Pressure at inlet:		p_a	101300	101300	Pa
Density of media:	inlet	ρ	1.2	1.2	kg/m^3
Temperature media:	inlet	t	35	20	°C
Max. allowable media temperature:	inlet	t_{max}		35	°C
Speed:		n		1185	1/min
Max. allowable impeller speed:		n_{max}		1831	1/min
Efficiency:	at optimum	η_{opt}		86	%
Efficiency:	at operating point	η		86	%
Required power:	at fan shaft	P_a	86.22	86.22	kW
Required power:	at motor shaft	P_m	86.22	86.22	kW
Max. required power:	at motor shaft	P_{max}	87.91	87.91	kW
Inertia:	at fan shaft	l		67.63	$kg{*}m^2$
Start-up time by direct start, calculated with Siemens-motor:		t_A		5.9	sec
Sound pressure in 1 m distance, free suction:		L_{PA5}	100	100	dB
Sound pressure in 1 m distance, casing break out (without motor)		L_{PA2}	83	83	dB
Sound data according to DIN45635 part 38 (without sound attenuation equipment)					

MOTOR DATA

Motor type:	Standard							
Manufacturer:	AC				Type:	ACM 315 M-6/HE		
Degree of protection:		IP55*			Mounting type:	B3		
Insulation class:		F			Eff-/Temp.Cl.:	IE2		
Rated power:	P_{mot}	90.00		kW				
Rated speed:	n_{mot}	985		1/min	Weight approx.:	G	1013	kg
Frequency:	f	50		Hz				
Voltage:	U	400/690		V	Sound pressure:	L_{PA}	68	dB
Rated current approx.:	l	by 400 V:	160.00	A	Sound power:	L_{WA}	82	dB

ErP-data at optimum efficiency and density 1.20 kg/m^3		
Measurement- / Efficiency category	B / total	
Design status of VSD	has to be installed	
Overall efficiency (η_{opt})	80.7	%
Achieved efficiency grade (N_{ist})	78.3	
Required efficiency grade in 2013 / 2015 (N)	61 / 64	
Air flow rate (V_{opt})	66837	m^3/h
Pressure rise (Δp_{opt})	3922	Pa
Fan speed (n_{vopt})	1185	1/min
Motor power input (P_{1opt})	90.22	kW
Specific ratio (d_{dpopt})	1.039	

CONCLUSION

Application of ProSelecta2 software significantly facilitates the designer work on a fan selection as it enables faster fan selection than selecting a fan by calculation [2], and it provides a detailed information about the selected fan in a digital format as an output. The example of fan selection in this paper does not include all the possibilities of this software that, besides the industrial process fans, enables the selection of other types of fans from the production program of Nicotra Gebhadt.

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[1] Catalog “Industrial Process Fans“; Nicotra Gebhardt; Issue 1.1, June 2012.

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[1] Willis B. A., Mineral Procesing Technology, Oxford, Pergamon Press, 1979, pg. 35. (for the chapter in a book)

[2] Ernst H., Research Policy, 30 (2001) 143–157. (for the article in a journal)

[3] www: http://www.vanguard.edu/psychology/apa.pdf (for web document)

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