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Academic Dr Milenko Ljubojev,
Principal Research Fellow
Mining and Metallurgy Institute Bor
Full member of EAS
E-mail: milenko.ljubojev@irmbor.co.rs
Phone: +38130/454-109, 435-164

Editor

Vesna Marjanović, B.Eng.

English Translation

Nevenka Vukašinović, prof.

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Preprinting

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19210 Bor, Zeleni bulevar 35
E-mail: milenko.ljubojev@irmbor.co.rs
Phone: +38130/454-110

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Original Scientific Paper
Mining

Mario Klanfar, Vjekoslav Herceg*, Luka Mrvoš*, David Šarko**

DECREASING OF THE AIR HUMIDITY BY THE VENTILATION CONTROL IN THE ST. BARBARA MINE

Abstract

The St. Barbara mine is a visitor mine having a large amount of timbering support which is deteriorating fast due to the high humidity conditions. The air conditioning system of mining is not suitable and also expensive for implementation in a shallow non-productive mine. As there are no usual air contaminants in the visitor mines, ventilation could be powered only when a dew point of outside air is below the strata temperature. Applying this rule would certainly avoid condensation, but also raises a potential for partial dehumidification of mine walls as moisture can evaporate in these conditions. A microclimate analysis, based on one-year data, has showed that these favorable conditions of the outside air occur through the major part of the year. Their availability is mostly 100%, but during summertime there are periods when it drops down to 13%. A real time monitoring system with programable microcontroller allows the automatic ventilation control and adjustment to the psychrometric conditions.

Keywords: *visitor mine, ventilation, dehumidification, automatization, timbering support*

INTRODUCTION

Visitor mines are popular touristic attractions in many places with the past mining activities. There is an increasing trend in restoration the abandoned mines, which must have a large number of visitors to be economically viable and support the needed maintenance costs. One of such mines is the St. Barbara mine in Rude, which has a large amount of timbering support and wooden elements built to achieve the authenticity. Timbering is usually applied as a temporary roof support and deteriorates fast due to a high humidity, so decreasing humidity would aid a service life of timbering. Deep production mines have the ventilation systems with cooling and dehumidification as the most critical needs of air conditioning [1], but these systems are not suitable and expensive for shallow and non-productive mines. On the other hand, the visitor mines do not have to be ventilated all the time because there are no contaminants. Ventilation could be powered on only while the favorable outside air conditions occur, which is an inexpensive way to dehumidify the mine.

ST. BARBARA MINE

The St. Barbara mine is located 30 km southwest of Zagreb in the small village of Rude near the town of Samobor. In the surrounding area, a dozen locations were re-

* *Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb*

corded where various types of ore were mined. The copper ore mining was recorded as early as from 1210 and lasted until 1851. The excavated quantities are estimated at about 2500 tons of copper. The iron ore exploitation was carried out in the period from 1850 to 1859. A total of 26.000 tons of iron ore (siderite) was excavated during this period. The ore was mostly smelted in Rude, and some in Slovenia. Iron ore is bound to the iron sandstones and fine-grained conglomerates of the Paleozoic age, and is spatially and genetically related to the copper ore. The zone of ore occurrence is 1.5 km long. The main mineral is hematite, and siderite appear only in the central part of deposit. During the 20th century, gypsum was also excavated, and mining was abandoned due to the high content of anhydrite (about 15%). Geological exploration in the area has also been carried out on several occasions during the 20th century. Active exploitation in the St. Barbara mine was completed in 1956 when it was abandoned. At the initiative of the local cultural and artistic society, the renovation of deteriorated mine began in 2002 and was completed in 2012. Within that, 350 m of mine headings were renovated with the aim of making the old mine a monument of mining and geological cultural heritage. The mine was opened with three adits (Vlasic, Holy Trinity and Kokel) which portals were collapsed. To date, the St. Trojstvo and Kokel adits have been restored, as well as the old mining faces between them. In order to promote the authenticity, a permanent wooden support was installed along the entire mine at the required locations.

ROOF SUPPORT SYSTEM AND VENTILATION

Excavation of the adit was characterized by the poor engineering-geological characteristics of the rock mass, mostly mullock with the change of finer granulation and large blocks. So that the excavation is completely supported by a wooden trapezoidal base, at a frame spacing that varied from 0 to 0.5 m depending on pressures. The St. Trojstvo adit was supported 167.5 m in total and the Kokel adit 51.5 m. The oak logs about 20 cm in diameter were used for columns and beams. The spaces behind the frame are also closed by the oak boards. Out of the 350 meters of the Mine currently available for visitors, 219 m is supported by the wooden frames. In total, more than 600 wooden frames were used for support.

Mine ventilation is achieved by an axial pressure fan installed on the portal of the St. Trojstvo [2]. The fan is mounted on an air channel, made of 80 mm diameter concrete pipe. A 8.0 m long air channel joins the side of the St. Trojstvo. The incoming fresh air current flows through the adit St. Trojstvo (elevation +306.9 m) by the excavation sites to the adit Kokel and exits on the portal Kokel (elevation +330.6). Due to the elevation difference of 23.7 m between the inlet and outlet of the air current and relatively small resistance of the mine, the natural potential of air flow is also present for most of the year. In the winter months, the natural air flow moves from the lower adit to the higher one, while in the summer months it moves inversely (Fig. 1).

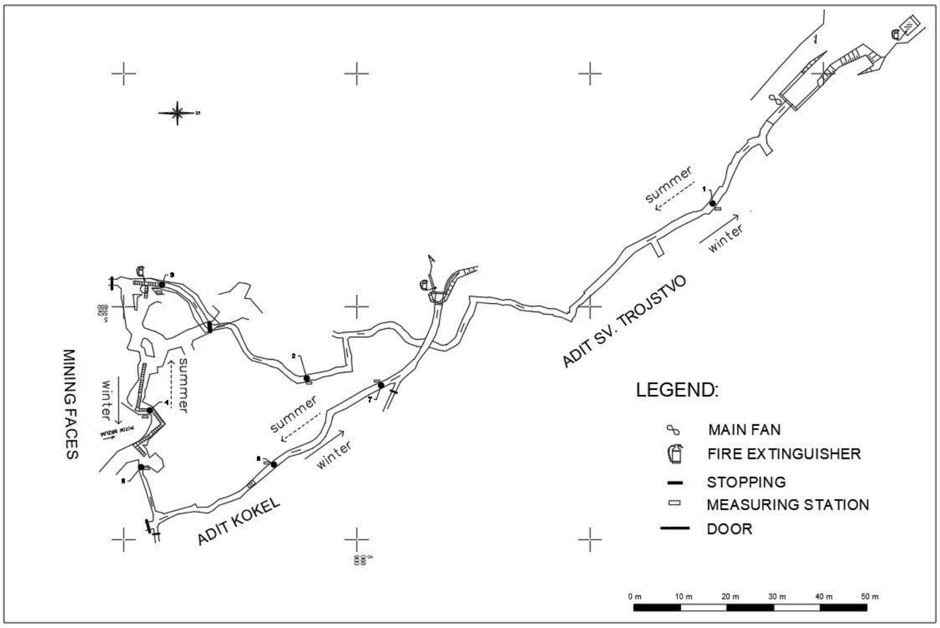

Figure 1 *Mine map*

HUMIDITY CONTROL

The basic idea is that outside fresh air always has some capacity to receive water vapor, as it is practically never saturated to 100%. How much water vapor it can accept depends upon humidity and temperature, but also psychrometric changes undergoing during entrance and flow through the mine. Theoretically, we can highlight three possible psychrometric processes (Fig. 2): 1 – Outside air has higher temperature than mine strata, and high relative humidity, where dew point is above strata temperature. As fresh air enters the mine it cools down to the dew point, when condensation of water vapor occurs. This is unfavourable condition and ventilation should be off. 2 – Outside air is higher in temperature than mine strata and has low relative humidity, thus dew point is below strata temperature. Entering the mine, air is cooled down to the strata temperature, relative humidity raises but not to the saturation point so air can still accept some water vapor, and moisture from walls can evaporate to the air. 3 – Outside air temperature is lower than strata temperature. As air enters the mine it is heated, and relative humidity drops drastically. Air can accept large amount of water vapor before saturation occurs. This is the most favourable condition as heating the air increases its capacity for water vapor no matter how humid the outside air is.

Overall, the two important states of the air can be distinguished. One, where a dew point is above the strata temperature, in which the condition mine should not be ventilated because condensation will certainly occur.

The other one is a dew point below the strata temperature, where it is safe to ventilate without condensation, but the amount of moisture evaporated from the walls will depend upon the psychrometric state of the outside air.

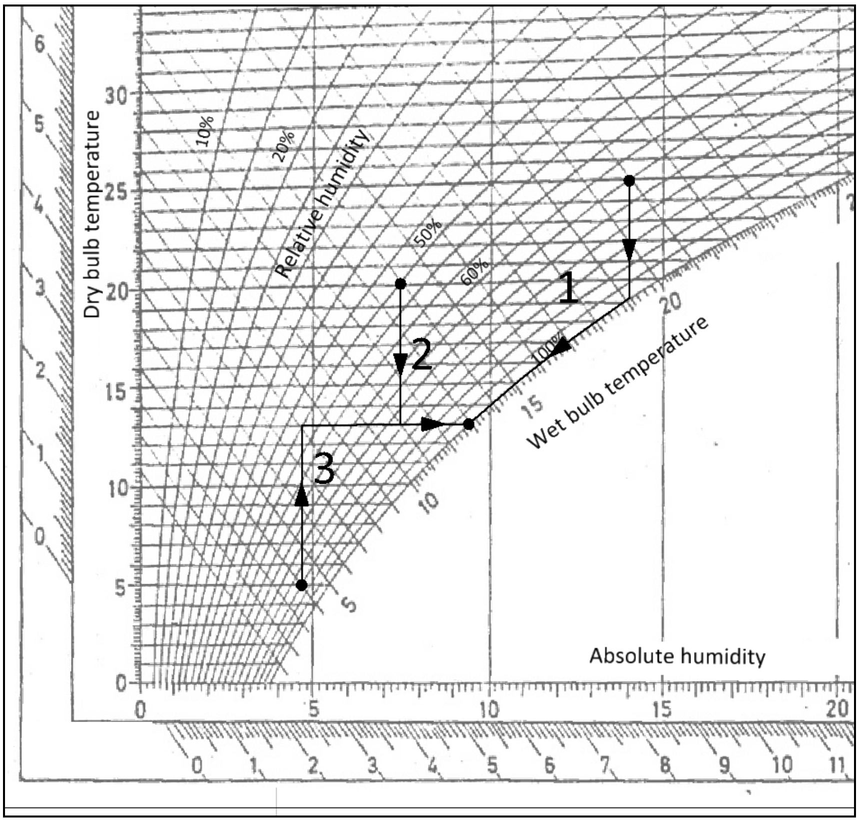

Figure 2 *Mollier diagram processes*

MICROCLIMATE ANALYSIS AND VENTILATION CONTROL

Slow seasonal changes and annual medians [3] show potential for the above-mentioned humidity control, but to exploit daily changes, the higher sample rate data needs to be observed. In order to estimate a possibility of ventilation without condensation, an analysis was done on the basis of one-year data with hourly interval of temperature and humidity recorded [4]. By this way, the season and daily variations in a dew point temperature were considered. Hourly temperatures and humidity were averaged on monthly basis. The resulting trendlines (Fig. 3) show a daily repeating pattern where increasing temperature during the daylight causes relative humidity to drop, and the opposite effect takes place during the night. A dew point was then calculated using the well-known equations (Eq 1-Eq 2) that utilize a dry bulb temperature and relative humidity as the input parameters [5].

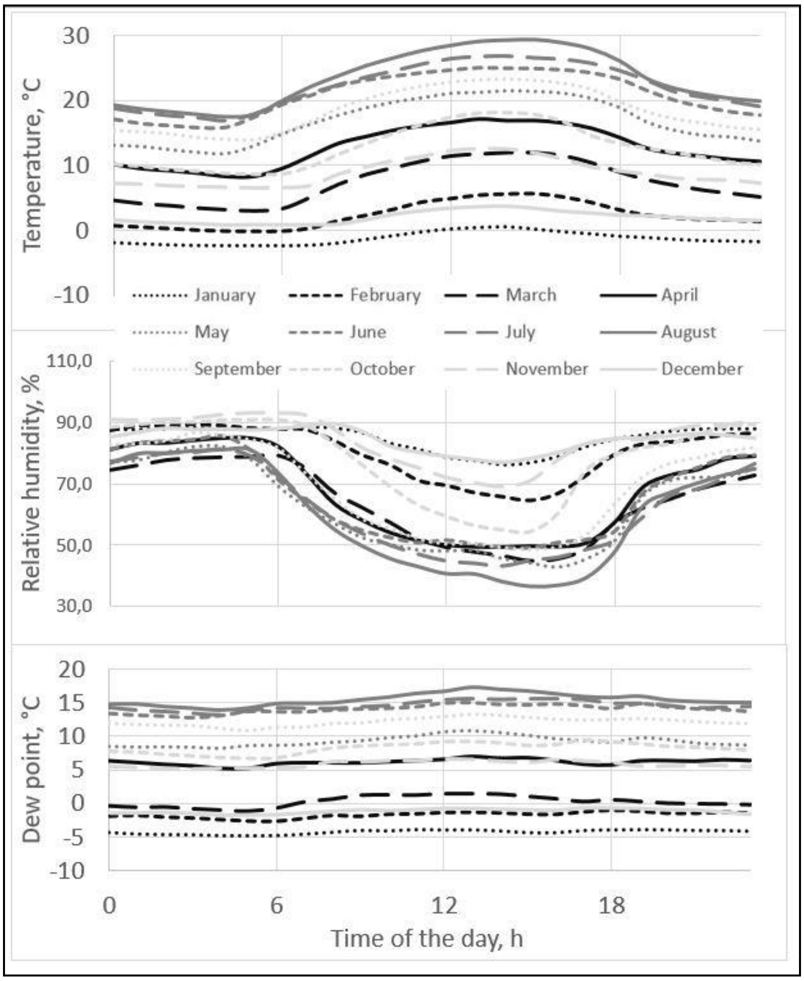

Figure 3 *Dew point analysis*

Given results show that the daily variations in a dew point are negligible and hardly usable, but the seasonal changes show a large drop of dew point below the strata temperature, what could be exploited for dehumidification.

$$e = \varphi \cdot 611 \cdot 10^{\frac{7,5t}{237,7+t}} \quad [eq\ 1]$$

$$t_d = \frac{237,7\ log\frac{e}{611}}{7,5\ -\ log\frac{e}{611}} \quad [eq\ 2]$$

where:

e – water vapor pressure,
t – air temperature,
φ – relative humidity,
t_d – dew point temperature.

Considering that the average strata temperature is 13°C [6], Fig. 4 shows a percenttage of available time when a dew point is below the strata temperature. It evident that most part of a year this condition is true, with some transition period in June and September, while the least occurrence of this condition can be expected in August.

	0h	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
January	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
February	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
March	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
April	100	100	100	100	100	100	100	100	100	100	97	97	100	100	97	97	97	93	93	97	97	93	97	97
May	100	94	90	94	94	94	90	87	87	84	81	77	71	68	74	77	81	77	81	81	84	87	84	87
June	40	37	43	47	47	23	33	33	40	33	33	30	23	27	27	27	27	27	33	23	27	33	30	30
July	29	32	39	39	42	35	32	29	29	29	23	23	26	23	23	23	23	23	26	26	26	23	26	29
August	19	19	29	29	29	26	23	23	26	26	23	19	16	13	13	13	16	16	19	13	16	19	23	19
September	60	67	67	63	73	73	70	67	60	53	43	47	43	37	40	40	47	50	53	50	57	57	60	57
October	97	94	94	94	97	97	100	100	100	100	97	94	94	97	97	100	94	87	90	100	97	94	94	94
November	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
December	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Figure 4 *Availability of favorable conditions (%)*

In order to reduce humidity, the mine should be ventilated only when a dew point of the fresh outside air is below the strata temperature. How much of moisture from the walls will be evaporated indirectly depends on a dew point. Lower it is – the air has more capacity for water vapor. Additionally, the temperatures could be used for a fan reversal to enhance the airflow by the natural ventilation. The basic algorithm for fan control (Fig. 5) would compare the outside and strata temperature to decide whether reverse the fan airflow. By comparison a dew point to the strata temperature, a decision to power on or off the fan is made. Today's advances in control technology enable a continuous parameter monitoring of the mine microclimate [7]. By knowing these parameters in real-time, it is possible to automatically control the ventilation systems using a PID controller. [8]

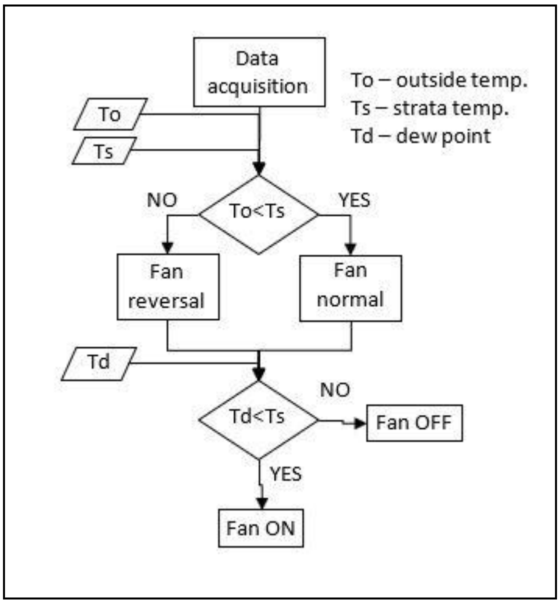

Figure 5 *Fan control flowchart*

CONCLUSION

Service life of a timbering inside the mine can be extended if the air moisture on its surface is reduced. Expensive mining systems for the air conditioning are not suitable for small visitor mines because of their cost and complexity. One way to partially dehumidify the mine is to exploit the outside fresh air capacity to absorb water vapor. This can be only done if right psychrometric conditions are met, whose occurrence is proved by the analysis to exist for most part of the year. The highest affinity to absorb water vapor will occur in winter, while summertime contains periods where the full saturation and even condensation can occur. Visitor mines are not polluted by the production process and if safety allows, the ventilation can be merely controlled by the psychrometric state of the outside air.

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Original Scientific Paper
Mining

Jasmin Jamaković, Sunčica Mašić***

CARBON DIOXIDE EMISSION OF A BELAZ DUMP TRUCK ON AN EXAMPLE OF THE OPEN PIT "TURIJA" BROWN COAL MINE BANOVIĆI

Abstract

This work sets out the methodology and presents the calculation results of the amount of carbon dioxide emitted into the atmosphere of the BelAz dump truck at the Open Pit "Turija" BCM Banovići d.d., based on the fuel consumption monitoring data. Properly determined fuel consumption enables the calculation of the amount of carbon dioxide emitted and preventive measures, as well as the choice of its reduction strategy. Data collection took six months, then the data were analyzed, and thus the results were given for all dump trucks by months.

Keywords: *fuel, open pit mining, BelAz dump truck, maintenance, BCM Banovići, carbon dioxide*

1 INTRODUCTION

The main activity of the Brown Coal Mine "Banovići" d.d. Banovići is the production, processing and trade of brown coal, which is based on the balance reserves of about 165,249,697 million tons of brown coal. Most of these reserves are intended for excavation by the undergrouns pit exploitation (about 95 million tons), and the rest (of about 70 million tons) by the open pit exploitation. Coal is produced by the open pit and underground exploitation in two mines that operate within this company, namely: the Mine "Open Pit exploitation of coal" (with two open pits) and the Mine "Underground exploitation" (with one pit "Omazići").

After the period of delayed exploitation, the reactivation was started at the open pit "Turija", while at the open pit "Grivice", from the day of opening, a continuous exploitation is carried out starting from the northern outcrop to the deepest coal reserves on the south side.

The open pit "Turija" was selected for the subject research. A total of 14 dump trucks are used for transport at the open pit Turija, namely: 12 diesel-electric dump trucks BelAz 75131 with a capacity of 136 t and 2 diesel-electric dump trucks BelAz 75137 with a capacity of 136 t. The BelAz dump trucks are with a diesel-electric DC traction [5].

A comprehensive research and collection of data on truck transport parameters at a specific location made it necessary to conclude which parameters most affect the fuel consumption, and thus the amount of carbon dioxide emitted into the atmosphere, with a constant load when driving useful and useless minerals. In order to

* *BCM "Banovići"d.d. Banovići, B&H*
** *University in Tuzla Faculty of Mining, Geology and Construction Engineering, B&H*

perform the subject analysis, it was necessary to first determine the average fuel consumption (l/h) for each considered transport unit (dump truck). For dump trucks in the conditions of work at the open pit "Turija" BCM Banovići, taking into account all relevant influencing factors, the average fuel consumption can be defined as well as the amount of carbon dioxide emitted into the atmosphere, and measures for its reduction. Reduction of the fuel consumption results into reduction of carbon dioxide emitted into the atmosphere and increase of energy efficiency.

2 METHODS OF DATA COLLECTION AND PROCESSING

2.1 Methods of data collection

In the long-term practice of the BCM "Banovići", the method of data collection on the work and downtime of dump trucks has become established. The mode of operation in the production facilities of the BCM Banovići is a three-shift eight-hour system in the I, II and III shift. The data used in the preparation of this paper were taken from the database of the Department of Mining Technical and Operational Preparation of the Mine "Open Pit Coal Exploitation". The data were processed using the Microsoft Excel licensed by the BCM "Banovići".

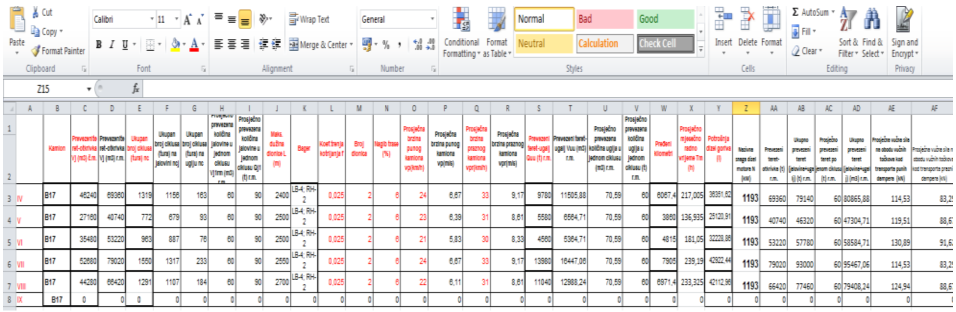

Figure 1 *Layout of a Microsoft Excel Sheet with inserted data for processing*

2.2 Methods of data processing

2.2.1 Determining of fuel consumption

The most accurate method for determining a truck fuel consumption is to obtain data from the actual mining operations. However, if such a possibility does not exist, various equations and data published by the original equipment manufacturer for trucks can be used for estimation purposes.

For a specific example, the fuel consumption can be obtained on the basis of data collected by the Department of Mining Technical and Operational Preparation of the "Open Pit Coal Exploitation" Mine.

2.2.2 Determining the amount of carbon dioxide emitted into the atmosphere

CO_2 emission from burned fuel can be determined by an on-site measurement. However, the on-site measuring devices (units) that continuously monitor emission equipment can be expensive and require permanent maintenance (Mining Environmental Management, 2008). Another possibility is to determine CO_2 emission using the mathematical equations [1].

CO_2 emission from diesel fuel in (t/h) can be written as:

$$CO_2 = FC \times CF$$

where FC is diesel consumption (l /h) and CF is the conversion factor. CO_2 emission conversion factors for diesel fuel can be calculated as:

$$CF = CC \times 10^{-6} \times 0.99 \times (44/12)$$

where CC is the carbon content of diesel fuel (g/l) and 0.99 is the oxidation factor.

According to the Environmental Protection Agency (EPA, 2005), the conversion factor for CF diesel fuel is 0.00268. This factor is calculated on the basis of carbon residues in one liter of diesel. The carbon content of diesel is CC = 733 g/l (EPA, 2005). The oxidation factor for all oil and its products is 0.99. This practically means that 99% of the fuel burns, while 1% remains unoxidized [1].

3 DIESEL FUEL CONSUMPTION AND QUANTITY OF CARBON DIOXIDE

Based on the data of the Operational Technical Preparation Service, the operating parameters of the BelAz dump truck with internal markings B-1 were calculated; B-2; B-4; B-5; B-6; B-7; B-8; B-9; B-10; B-11; B-15; B-16; B-17 and B-21. The BelAz dump trucks on the OP "Turija" transport both waste and coal during their work. The average volumetric mass of waste in the solid state is $\rho_{čmj}$=2.25 (t/m^3), the average volumetric mass of waste in the loose state is ρ_{rmj}=1,5 (t/m^3), and the average looseness coefficient for waste is k_{rj}=1.5.

Table 1 and Figures 1 and 2 show for illustration the data of calculated operating parameters of the BelAz internal code B-1 [2].

Table 1 *Operating parameters of the BelAz internal code B-1*

Month	Dump truck	Transported cargo-overburden Vt (m^3) č.m.	Transported cargo-overburden Vj (m^3) r.m.	Total No. of cycles (tours) nc	Total No. of cycles (tours) on waste ncj	Total No. of cycles (tours) on coal nc	Average amount of transport. waste in one cycle Vj1rm (m^3) r.m.	Average amount of transport. waste in one cycle Qj1 (t) r.m.	Max. section length L (m)	Excavator	Rolling friction coeff. f	No. of routes	Route slope (%)	Average full truck speed vp(km/h)	Average full truck speed vp(m/s)	Average empty truck speed vpr (km/h)	Average empty truck speed vpr (m/s)	Transport. cargo-coal Quu (t) r.m.
IV	B1	46920	70380	1253	1173	80	60	90	2400	LB-4; RH-2	0.025	2	6	24	6.67	33	9.17	4800
V	B1	35880	53820	947	897	50	60	90	2500	LB-4; RH-2	0.025	2	6	23	6.39	31	8.61	3000
VI	B1	37840	56760	978	946	32	60	90	2500	LB-4; RH-2	0.025	2	6	21	5.83	30	8.33	1920
VII	B1	37800	56700	1000	945	55	60	90	2550	LB-4; RH-2	0.025	2	6	24	6.67	33	9.17	3300
VIII	B1	29080	43620	805	727	78	60	90	2700	LB-4; LB-2	0.025	2	6	22	6.11	31	8.61	4680
IX	B1	34440	51660	1000	861	139	60	90	2600	LB-4; LB-2	0.025	2	6	24	6.67	33	9.17	8340

Transport. cargo-coal Vuu (m^3) r.m.	Average transport. amount of coal in one cycle (m^3) r.m.	Average transported amount of coal in one cycle (t) r.m.	Traveled kilometers	Average monthly working time Tm (h)	Diesel fuel consumption (l)	Nominal power of the diesel engine N (kW)	Transported cargo-overburden (t) r.m.	Total transported cargo (waste + coal) (t) r.m.	Average transported cargo per one cycle (t) r.m.	Total transported cargo (waste + coal) (m^3) r.m.	Average traction force at circumference of traction wheels when transporting full dump trucks (kN)	Average traction force at circumference of traction wheels when transporting empty dump trucks (kN)	Average cycle time (s)	Average cycle time (s)	Average transported cargo per cycle (m^3) r.m	Average distance traveled per cycle Lu=2L(km)	Average full truck driving time tp (s)	Average empty truck driving time tpr (s)	Average transport. waste per one cycle (m^3) r.m.
5647.06	70.59	60	6014.4	230.01	39107.13	1176	70380	75180	60	76027.06	112.90	82.11	0.18	660.84	60.68	4.8	360.00	261.82	60.68
3529.41	70.59	60	4645	178.245	33045.41	1176	53820	56820	60	57349.41	117.80	87.40	0.19	677.59	60.56	4.904963	391.30	290.32	60.56
2258.82	70.59	60	4890	188.7	32289.6	1176	56760	58680	60	59018.82	129.02	90.32	0.19	694.60	60.35	5	428.57	300.00	60.35
3882.35	70.59	60	5100	192.78	34341.76	1176	56700	60000	60	60582.35	112.90	82.11	0.19	694.01	60.58	5.1	382.50	278.18	60.58
5505.88	70.59	60	4347	155.295	28165	1176	43620	48300	60	49125.88	123.16	87.40	0.19	694.49	61.03	5.4	441.82	313.55	61.03
9811.76	70.59	60	5200	176.46	27252.48	1176	51660	60000	60	61471.76	112.90	82.11	0.18	635.26	61.47	5.2	390.00	283.64	61.47

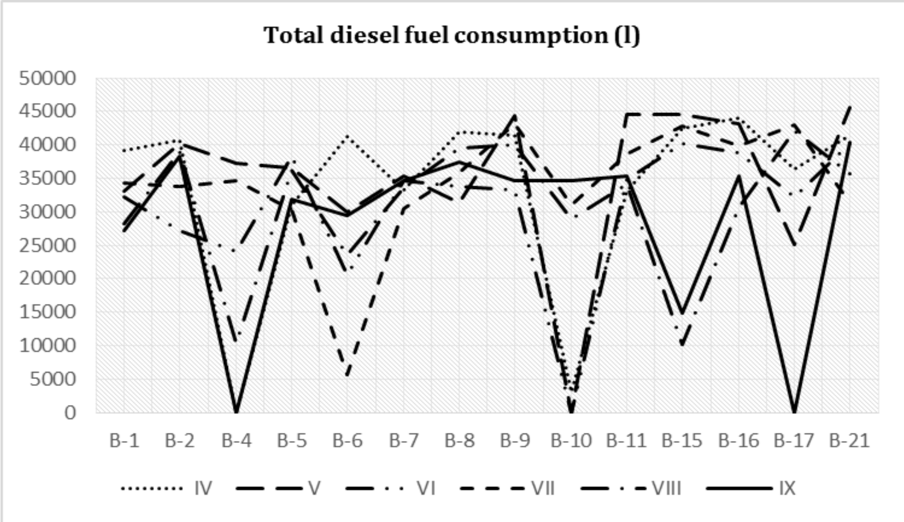

Figure 2 *Total diesel fuel consumption (l) in the IV, V, VI, VII, VIII and IX month*

In the six months of monitoring, the dump trucks run a total of 443692 (km).

In order to determine the amount of carbon dioxide emission into the atmosphere, it is necessary to consider the consumption of diesel fuel in liters per hour.

For each individual BelAz, diesel fuel consumption and CO_2 emission into the atmosphere were calculated.

Table 2 and Figure 3 give an illustrative presentation of the results obtained for the BelAz internal designation B-1.

Table 2 *Diesel fuel consumption (l/h) and CO_2 emission into the atmosphere of the BelAz dump truck*

BelAz B-1				
Month	**Diesel fuel consumption (l/h)**	**Emission CO_2 (t/h)**	**Average monthly working hours (h)**	**CO_2 (t)**
IV	170.02	0.46	230.01	104.8049
V	185.39	0.50	178.245	88.56017
VI	171.12	0.46	188.7	86.53812
VII	178.14	0.48	192.78	92.0361
VIII	181.36	0.49	155.295	75.48033
IX	154.44	0.41	176.46	73.03665

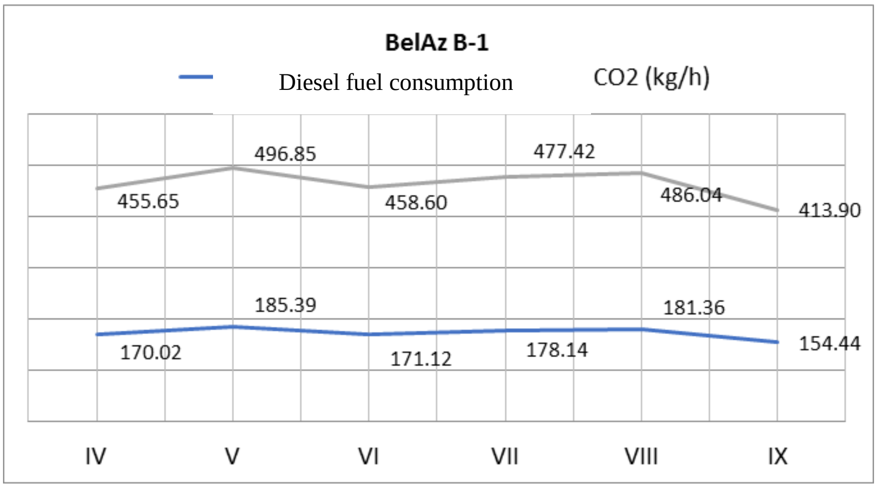

Figure 3 *Diesel fuel consumption (l/h) and CO_2 emission (t/h) of he BelAz dump truck internal code B-1*

Figures 4 and 5 show the consumption of diesel fuel (l/h) and the average amount of CO_2 in (t/h) that the dump trucks at the OP "Turija" emitted into the atmosphere during each month of monitoring.

Table 3 *Diesel fuel consumption (l/h), average monthly working hours (h) and CO_2 emission into the atmosphere of the BelAz dump truck*

Month		B-1	B-2	B-4	B-5	B-6	B-7	B-8	B-9	B-10	B-11	B-15	B-16	B-17	B-21
	Emission of CO_2 (t/h)														
IV		0.46	0.44	0	0.47	0.45	0.45	0.44	0.46	0.44	0.43	0.42	0.42	0.45	0.42
V		0.5	0.51	0.49	0.46	0.52	0.5	0.44	0.5	0	0.47	0.49	0.49	0.49	0.46
VI		0.46	0.46	0.49	0.48	0.49	0.48	0.41	0.49	0	0.45	0.47	0.47	0.48	0.44
VII		0.48	0.49	0.49	0.48	0.58	0.49	0.46	0.47	0.45	0.48	0.47	0.47	0.48	0.46
VIII		0.49	0.47	0.48	0.48	0.46	0.44	0.43	0.47	0.44	0.46	0.48	0.48	0.48	0.45
IX		0.41	0.45	0	0.42	0.43	0.4	0.42	0.43	0.42	0.43	0.41	0.41	0.00	0.4
	Diesel fuel consumption (l/h)														
IV		170.02	163.23	0	174.73	169.08	168.39	164.31	173.48	165.75	161.32	158.05	158.05	167.52	156.15
V		185.39	189.26	181.43	172.57	193.1	185.68	165.09	188.08	0	177.09	181.54	181.54	183.45	171.04
VI		171.12	172.47	181.52	177.86	182.88	179.31	152.63	183.97	0	168.79	176.32	176.32	178.01	163.29
VII		178.14	184.7	183.03	180.28	214.58	181.29	171.55	177.11	168.87	178.29	176.68	176.68	179.45	170.55
VIII		181.36	174.52	177.54	179.03	172.24	163.06	162.19	173.66	164.25	171.54	177.74	177.74	180.49	167.94
IX		154.44	166.25	0	156.64	159.26	149.81	156.31	159.03	155.16	160.22	154.52	154.52	0	149.82
	Average monthly working hours (h)														
IV		230.01	249.135	0	177.735	243.78	197.37	255.765	238.935	18.87	204.765	268.515	268.515	217.005	265.45
V		178.245	212.16	205.275	212.16	155.295	190.23	189.465	235.62	0	251.43	245.565	245.565	136.935	266.98
VI		188.7	157.335	132.6	215.73	112.455	193.545	221.085	180.795	0	206.55	227.715	227.715	181.05	246.07
VII		192.78	182.58	189.72	167.79	26.52	168.555	209.1	243.27	183.345	217.005	242.76	242.76	239.19	183.85
VIII		155.295	223.635	58.395	202.725	136.17	206.55	243.525	230.775	176.46	199.155	57.63	57.63	233.325	212.67
IX		176.46	230.52	0	204	184.62	231.03	239.7	218.025	223.125	220.83	95.88	95.88	0	270.04
	Total CO_2 emission (t)														
IV		104.80	108.98	0	83.22	110.46	89.07	112.62	111.08	8.38	88.52	113.73	113.73	97.42	111.08
V		88.56	107.61	86.66	98.12	80.36	94.66	83.82	118.76	0	119.32	119.47	119.47	67.32	122.38
VI		86.53	72.72	91.79	102.83	55.11	93.00	90.43	89.13	0	93.43	107.60	107.60	86.37	107.68
VII		92.04	90.37	94.56	81.06	15.25	81.89	96.13	115.46	82.97	103.68	114.9	114.94	115.03	84.03
VIII		75.48	104.59	73.890	97.26	62.85	90.26	105.85	107.40	77.67	91.55	27.45	27.45	112.86	95.71
IX		73.04	102.71	0	85.63	78.79	92.75	100.41	92.92	92.78	94.82	39.70	39.70	0	108.42

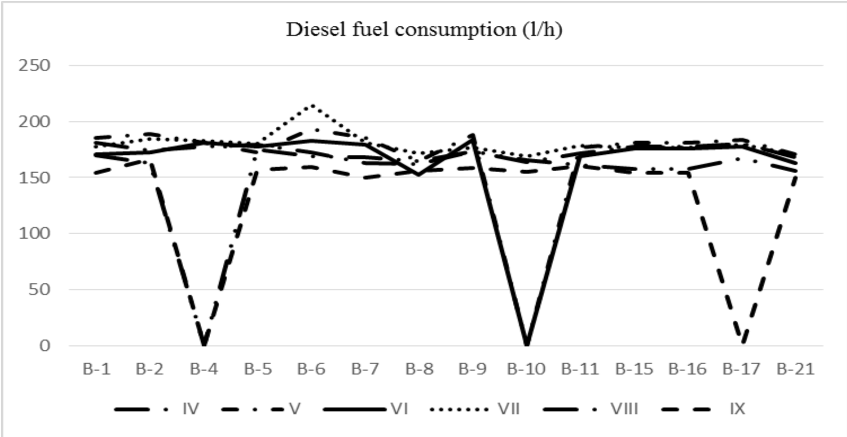

Figure 4 *Diesel fuel consumption (l/h) in the IV, V, VI, VII, VIII and IX month*

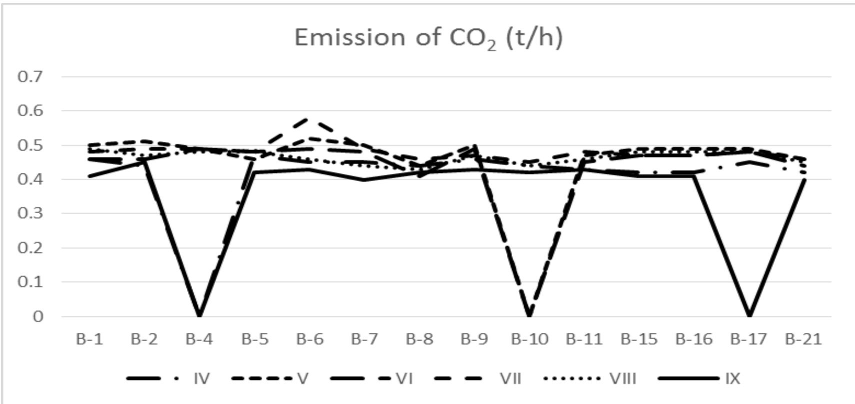

Figure 5 *Emission of CO_2 (l/h) in the IV, V, VI, VII, VIII and IX month*

In the IV month, the BelAz dump truck with the internal code B-4 was left out of consideration because it was not in operation. The B-5 dump truck had the highest amount of CO_2 emission (t/h) and the highest fuel consumption (l/h) this month, and the lowest B-15.

In the V month, the largest amount of CO_2 (t/h) was emitted into the atmosphere by the B-4 dump truck, which had the highest fuel consumption (l/h) in this month, and the lowest B-8.

In the VI month, the BelAz dump truck with the internal code B-10 was left out of consideration because it was not in operation. The highest amount of CO_2 (t/h) was emitted into the atmosphere by the B-9 dump truck, which had the highest fuel consumption (l/h) this month, and the lowest B-4.

In the VII month, the largest amount of CO_2 (t/h) was emitted into the atmosphere by the B-6 dump truck, which had the highest fuel consumption (l/h) in this month, and the lowest B-10.

In the VIII month, the largest amount of CO_2 (t/h) was emitted into the atmosphere by the B-1 dump truck, which had the highest fuel consumption (l/h) in this month, and the lowest B-8.

In the IX month, the largest amount of CO_2 (t/h) was emitted into the atmosphere by the B-2 dump truck, which had the highest fuel consumption (l/h) in this month, and the lowest B-7.

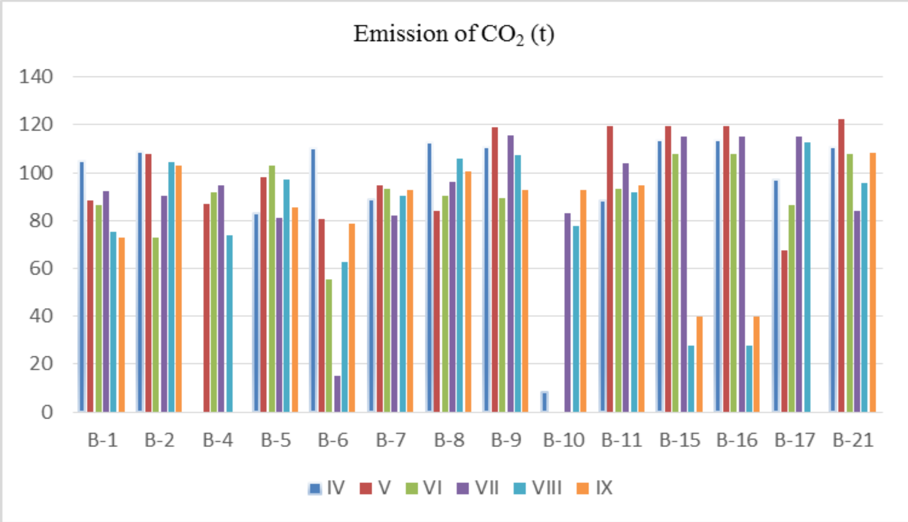

Figure 6 *Total amount of emitted CO_2 (t) in the IV, V, VI, VII, VIII and IX month*

In the IV month, the highest amount of CO_2 (t) was emitted into the atmosphere by the BelAz with internal code B-15 and B-16, which had the highest effective operating time in that month, and although the BelAz B-5 emitted the highest amount of CO_2 per hour.

In the V month, the highest amount of CO_2 (t) was emitted into the atmosphere by the BelAz with the internal code B-21, which had the highest effective operating time in that month, and although the BelAz B-4 emitted the highest amount of CO_2 per hour.

In the VI month, the highest amount of CO_2 (t) was emitted into the atmosphere by the BelAz with the internal codes B-15 and B-16 which had the highest effective operating time in that month, and although the BelAz B-10 emitted the highest amount of CO_2 per hour.

In the VII month, the highest amount of CO_2 (t) was emitted into the atmosphere by the BelAz with the internal code B-9, which had the highest effective operating time in that month, and although the BelAz B-6 emitted the highest amount of CO_2 per hour.

In the VIII month, the highest amount of CO_2 (t) was emitted into the atmosphere by the BelAz with the internal code B-17, which had the highest effective operating time in that month, and although the BelAz B-1 emitted the highest amount of CO_2 per hour.

In the IX month, the highest amount of CO_2 (t) was emitted into the atmosphere by the BelAz with the internal code B-21, which had the highest effective operating time in that month, and although the BelAz B-2 emitted the highest amount of CO_2 per hour.

The amount of carbon dioxide emitted into the atmosphere during a given month depends on the effective operating hours of the dump truck in that month. The average maximum amount of CO_2 (t) emitted during the six months ranged from 107.69 to 122.38 (t) During the two months when all the dump trucks were operating, it averaged from 112.86 to 112.86 (t).

4 PREVENTIVE MEASURES AND CHOICE OF MAINTENANCE STRATEGY TO REDUCE THE CARBON DIOXIDE EMISSIONS

Based on the findings after research, the suggestions can be made to improve and reduce fuel consumption, which directly affects the amount of carbon dioxide emissions released into the atmosphere. Fuel consumption is affected by the adequate maintenance and servicing of the BelAz dump trucks, so it is necessary to do it on time. Simplify access to the points for regular service, because this simplifies service and reduces the amount of time spent on regular maintenance procedures. Continue to check the tire pressure regularly as too low tire pressure impairs the lateral guidance of the tires, prolongs the braking distance and thus reduces driving safety. Also, a low tire pressure increases the rolling resistance, thereby increasing the fuel consumption.

Checking the condition of tires and pressure in them is very important for safety and consumption. A tire is the only contact surface between a vehicle and ground, and has the task of withstanding carrying, movement, shock absorption, braking and acceleration, while rolling resistance has a direct impact on fuel consumption. Maintaining and improving the road surface can significantly reduce the fuel consumption. When designing, take into account the lengths of routes intended for transport and their slopes. Reducing the length of route and its slope allows for a shorter dump truck cycle and transport of larger quantities of cargo with lower fuel consumption. Provide a sufficient number of auxiliary machinery and equipment, and regular maintenance of the route. If possible, maintain a constant speed during transport. Apply an adequate organization of technological process, because it has a significant impact on the fuel consumption.

CONCLUSION

Many parameters, such as the age and vehicle maintenance, load, speed, cycle time, mine layout, work schedule, idle time, tire wear, rolling resistance, engine operating parameters and gear change patterns can affect the fuel consumption in the open pit exploitation. The fuel consumption of BelAz dump truck with the internal code B-1 was considered at the OP "Turija"; B-2; B-4; B-5; B-6; B-7; B-8; B-9; B-10; B-11; B-15; B-16; B-17 and B-21 during six months of observation. The amount of carbon dioxide emitted into the atmosphere during a given month depends on the effective operating hours of a dump truck in that month. The average maximum amount of CO_2 (t) emitted during the six months ranged from 107.69 to 122.38 (t). During the two months when all the dump trucks were operating, it averaged from 112.86 to 112.86 (t).

The average amount of CO_2 emitted per BelAz into the atmosphere over six months ranged from 0.17 to 0.29 (t/h). In the months when not all trucks were working, the total amount of CO_2 emitted ranged from 2.78 to 3.58 (t/h) on average. During the two months when all the dumpers were working, it averaged 3.45 to 3.73 (t/h). For difficult working conditions and the length and background of the route, and slopes, we can expect the obtained average CO_2 emissions in irregular months, except for the winter period when diesel fuel consumption increases by 20%, and thus CO_2 emissions. Also, the consumption and emission of CO_2 is affected by adequate maintenance and servicing of the BelAz dump trucks, so it is necessary to do it on time.

Analyzing the results of the processed data, it was found that the fuel consumption in some months is directly proportional to the amount of transported cargo and amount of carbon dioxide emitted. Analyzing the relationship between the transported cargo and diesel fuel consumption, it can be concluded that a higher consumption of diesel fuel and carbon dioxide emissions and vice versa. For the same amount of transported cargo, changes in the working conditions affect the fuel consumption. A lack of auxiliary equipment and climatic conditions (precipitation, storm) cause production to be difficult. In the months when the technological process was difficult due to a lack of auxiliary machinery and equipment, the adverse weather conditions (storms or heavy rainfall), the fuel consumption was increased compared to a consumption in the stable operating conditions, as well as the carbon dioxide emissions. In such conditions, and in the case of an increase in the number of effective hours achieved for transport the same amount of cargo, the fuel consumption was higher for transport of less cargo.

Changes in the length of route as a result of moving the excavator to a new position and changes in the slope of route affected the change in fuel consumption and CO_2 emissions. Due to the increased length of transport route and inadequate organization of the technological process, poor working conditions, some dump trucks recorded higher fuel consumption when transporting smaller amounts of cargo.

Based on the collected and processed data of hourly fuel consumption for engines of 1193 (kW) and 1176 (kW), it can be concluded that the dump truck at the OP "Turija" worked in difficult working conditions. The highest CO_2 emissions from freight transport were in older BelAz, with over 70,000 engine hours, served by less experienced drivers, while relatively newer BelAz emitted less CO_2. With the BelAz B-8, the replacement of engine showed a reduction in diesel fuel consumption, which was expected. The greatest impact on fuel consumption has the quality of the road surface, weather conditions, and operation of auxiliary machinery.

It can be concluded that the dump truck at the OP "Turija" worked in difficult working conditions. -and relatively newer generations emit less CO2. With the BelAz B-8, the replacement of the engine showed a reduction in diesel fuel consumption, which was to be expected. The greatest impact on fuel consumption has the quality of the road surface, weather conditions, and the work of auxiliary machinery.

Analyzing the data, it can be generally concluded that the ratio of the amount of transported tailings to the amount of coal $\left(\frac{\text{t waste}}{\text{t coal}}\,\text{r.m.}\right)$does not significantly affect the consumption of diesel fuel (l/t r.m.) and the emission of CO_2 of a damper truck BelAz at the OP "Turija". The reason lies in the fact that the sections for waste and coal transport were approximately the same, and the road surfaces were approximately the same quality.

The presented method of processing, analysis and extraction of important information on operating parameters and carbon dioxide emissions in this way was done for the first time in our area and can be repeated at the other open pits that use the dump trucks to transport cargo. The contribution of this paper to the professional literature is that for the first time a certain amount of CO_2 emitted by the BeLAZ at the open pit on the basis of collected data and method used. Determining the fuel consumption is used to determine the preventive measures and strategies for maintaining the transport system in order to reduce it, as well as the emission of exhaust gases into the atmosphere.

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Original Scientific Paper
Mining

Daniel Kržanović, Radmilo Rajković*, Nenad Vušović**, Sandra Milutinović**

RECONSTRUCTION OF THE NORTHWESTERN SLOPE OF THE OPEN PIT SOUTH MINING DISTRICT MAJDANPEK FOR THE PURPOSE OF RECONSTRUCTION THE ACTIVE LANDSLIDE***

Abstract

The exploitation of copper ore in the Majdanpek Copper Mine takes place at the open pit South Mining District. The operation takes place in the complex conditions, and a special feature is that the capital infrastructure facilities: the state road M24, 35 kV transmission line and ri-verbed of the Mali Pek River are located in the northwestern contour of the open pit. Due to the occurrence of landslide in this part of the open pit, the continuity of the ore exploitation process in the mining system of excavation-processing was endangered, as well as the stability of infrastructure facilities.

Reconstruction of the northwestern slope of the open pit will eliminate all existing and potential risks and create the conditions for functioning of the mine and town of Majdanpek.

Keywords: *material landslide, infrastructure facilities, Geovia Gems software*

1 INTRODUCTION

The town of Majdanpek is located in the northern part of eastern Serbia, in the narrow valley of the Mali Pek River. The open pit South Mining District Majdanpek is located in the south of the town of Majdanpek, in its immediate vicinity. The open pit operates within the company Majdanpek Copper Mine, which is a part of the company Serbia Zijin Copper doo (former Mining and Smelting Basin Bor Group).

The Majdanpek copper mine, in terms of production, technical and technological sense, is a complex mining system that has activities from the geological explorations of mineral resources, exploitation and processing of ore to a number of accompanying activities as the necessary support to core business [1]. Production and processing of ore in the Majdanpek Copper Mine is of a great importance for the copper production in the system of the company Serbia Zijin Copper doo.

One of the specifics that affects the complexity of exploitation at the open pit is that the capital infrastructure facilities are in the northwestern contour of the open pit: state road M24 Pancevo - Kovin - Požarevac - Majdanpek - Negotin - Bulgarian border, 35 kV transmission line and Mali Pek riverbed. The occurrence of landslide in this part of the open pit jeo-pardizes the conti-

* *Mining and Metallurgy Institute Bor*
** *Technical Faculty Bor*
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nuity of the ore exploitation process in the mining system of excavation - processing, as well as the infrastructure facilities, which may adversely affect the functioning of the town of Majdanpek [2].

Figure 1 shows the landslide in the northwest slope of the open pit South Mining District with the disposition of infrastructure facilities.

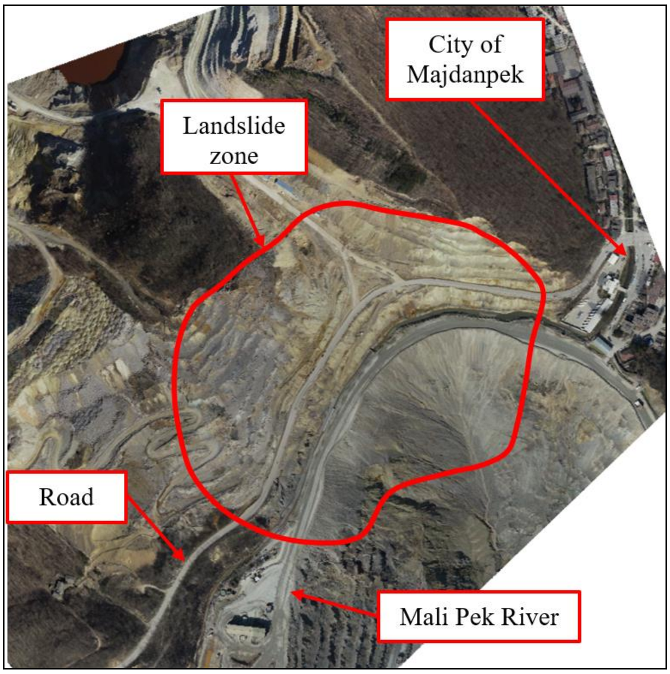

Figure 1 *View of the landslide in the northwest slope of the open pit South Mining District with the disposition of infrastructure facilities*

2 GEOTECHNICAL CHARACTERISTICS OF THE NORTHWESTERN PART OF THE OPEN PIT

A landslide is located in the northwestern part of the open pit South Mining District, characterized by the complex geometry and dynamics of movement.

Based on the conducted engineering geological explorations at the open pit, the geotechnical profiles were defined and modeling of the sliding body was performed. As an unstable terrain, a part of the terrain with approximate dimensions of 450 × 420 m was set aside, while the dimensions of moved material (colluvium) are 320 × 330 m. The material affected by the colluvial process are: the man-made formations (road embankment), complex of medium and completely degraded shales and gneisses and medium and completely degraded andesites.

In addition to sliding, the following modern geodynamic processes and phenomena are present in the subject area, such as the surface disintegration, scattering and landslides.

Figure 2 shows the engineering geological section in the landslide zone on the northwest side of the open pit South Mining District.

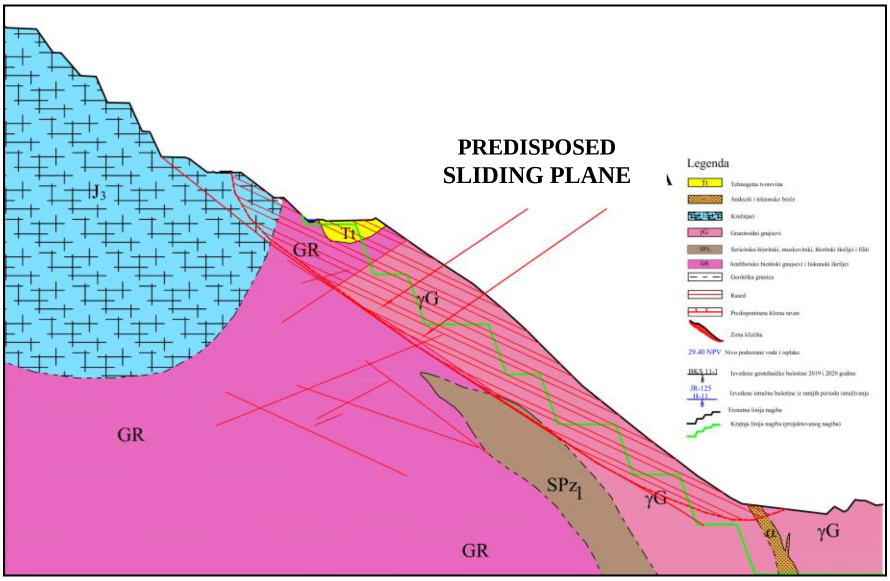

Figure 2 *Engineering geological section in the landslide zone on the northwest side of the open pit South Mining District [3]*

3 MODELING OF LANDSLIDE SOLID

Design of the final project boundary, i.e .the northern and northwestern boundaries of the open pit, was done on the basis of a defined solid landslide in the area limited by the terrain, as the upper surface and sliding plane boundary as wsell as the lower limiting surface.

Solid is made on the basis of geotechnical interpretation of a landslide, i.e. using the defined vertical geotechnical profiles, which represent the closed polygons (3D rings). A solid is a part of an irregularly shaped space bounded by a surface obtained by the triangulation. Solid has its own characteristics such as volume, bulk density, color, etc.

Solid, formed by the TIN (Triangle Irregular Network) method, represents a triangulation by a network of irregular triangles based on the geotechnical interpretation of a landslide by the vertical profiles and solid characteristics (solid volume, surface (envelope), number of nodes in the formed surface, number of triangles, etc.) [4] .

Figure 3 shows the generated solid landslide in the northwestern zone of the South Mining District in the Gems software.

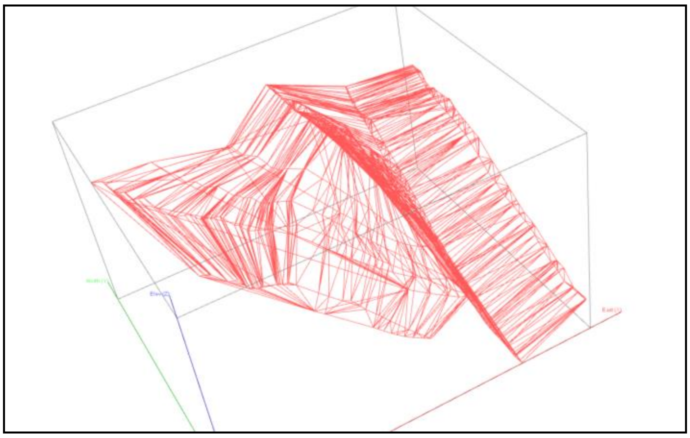

Figure 3 *Shows a 3D view of landslide position in the northern and northwestern zones of the open pit South Mining District*

Figure 4 shows a 3D view of landslide position in the northern and northwestern zones of the open pit South Mining District.

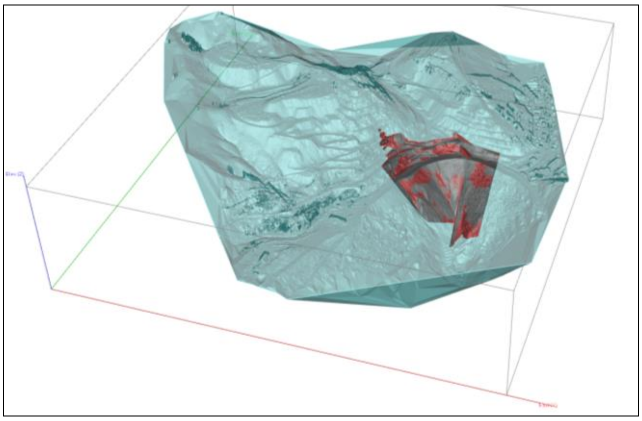

Figure 4 *3D view of a landslide solid in the northern and northwestern zones of the open pit South Mining District*

4 CONSTRUCTION OF THE FINAL BOUNDARY OF THE NORTH-WESTERN SLOPE

The basic condition that had to be met during the reconstruction of the final contour of the northwestern part of the South Mining District is to provide a stable slope of this part of the open pit, to enable relocation of the existing transmission line route, highway and Mali Pek riverbed, which are endangered by the active landslides on the Andesite finger. An additional condition is that the transport system for ore transport from the open pit North Mining District must not be endangered [5].

Based on the defined conditions, adopted geometric elements of the open pit and generated landslide solid, the final contour of the reconstructed northwestern part of the surface area of the South Mine District was constructed. The final contour was constructed in the **Gems** software, in the Pit Design module [4].

Figure 5 shows a 3D view of the final northwestern reconstructed contour of the open pit South Mining District with a characteristic cross-section.

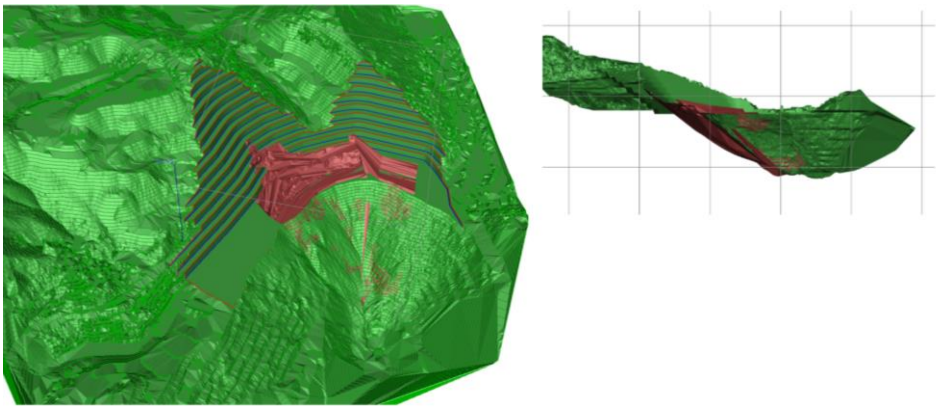

Figure 5 *3D view of the final northwestern reconstructed contour of the open pit South Mining District with a characteristic cross-section*

5 CONCLUSION

The appearance of a landslide on the northwest side of the open pit South Mining District endangered the process of ore exploitation in the Majdanpek Copper Mine, as well as the safety and health of people, and also the safety of process equipment. In addition, the landslide endangers the civilian infrastructure facilities, such as the high-voltage transmission line, the Majdanpek-Kucevo highway and the Mali Pek riverbed, which are located in the northwestern contour of the open pit, thus endangering the normal functioning of Majdanpek.

By reconstruction of the northwestern slope of the open pit, the material was removed from the landslide zone, thus eliminating all existing and potential risks to the functioning of the mine and the town of Majdanpek.

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Energetics

Boško Vuković, Rajko Jakšić**

THE EFFECT OF CLIMATOLOGICAL AND HYDROLOGICAL PARAMETERS ON THE PERFORMANCE OF MINING WORKS IN A FUNCTION OF PROVIDING THE ENERGY FUEL FOR STABLE OPERATION OF THE THERMAL POWER PLANT GACKO

Abstract

This paper presents the climatological and hydrological effects on the calorific value of coal as an energy fuel for the Thermal Power Plant Gacko. Since the average annual rainfall is approximately 1,700 l/m^2, and that groundwater levels are quite "high" even in the dry season, humidity is a parameter that significantly affects the reduction of coal calorific value of coal in operating conditions. Previous experiences in coal production, as well as the laboratory tests, have shown that the humidity in coal is increasing, due to the increased rainfall and flooding of floors due to the increased groundwater levels. Also, in the dry period, under the effect of wind and solar radiation, coal on the landfills of the Thermal Power Plant quickly loses moisture thus increasing the heat value and also the production power of generator and achieve greater production and economic effects [7].

Keywords: *humidity, climatology, hydrology, energy fuel, lower calorific value*

INTRODUCTION

The main subject of coal exploitation at the open pit "Gacko" is to provide the sufficient quantities of coal for the needs of the Thermal Power Plant "Gacko", the required quality with minimum operating costs. As the conditions of coal exploitation in certain parts of deposit of the return zone will constantly deteriorate (greater stratification, greater change in coal quality, etc.), and the requirements of the Thermal Power Plant Gacko are becoming more stringent, it is necessary to manage the coal quality in operational conditions maintaining the exploitation quality of coal within the set (required) limits [7]. The negative impact of increased moisture content, on reducing the calorific value of coal, in the period of rain and snowfall, occurs in the entire technological process, i.e. from the coal exploitation in the deposit, transport of coal to the crusher, at the landfill of crusher, transport of coal from the crusher to the landfill of the Thermal Power Plant and at the landfill of the Thermal Power Plant itself. Coal as a pure carbonaceous substance partially absorbs moisture, but waste layers (clays and marls) are porous and absorb moisture, which significantly reduces the calorific value and grindability of coal.

1 CLIMATE CHARACTERISTICS OF THE GACKO ENERGY BASIN

The climatic type that prevails on the plateau of the Gacko Filed (subalpine climate - under valley climate according to

* *Mine and TPP Gacko*

the Köppen classification of climate which is unsurpassed and current to this day) directly affects the intensity, quality and scope of mining works during the year, especially during the two spring and autumn precipitation maximums because this is the climate type, which has a Mediterranean fluviometric regime (the highest amount of precipitation occurs in the winter half of the year 72%.). The annual distribution during the year clearly shows that in the summer half of the year only 10 to 15% of the total amount is excreted annually. The annual course and distribution of precipitation is extremely unfavorable and uneven during the year, which has always been a basic feature of the Mediterranean precipitation regime. The mine achieves the best results in the summer part of the year when there is a small amount of precipitation, low humidity and when the machinery can work smoothly and gives maximum effect during working hours.

During the autumn and spring, the climate of the Gacko Basin is crucially influenced by the Mediterranean cyclones (Genoese and Cypriot depressions and smaller cyclones that form in the Adriatic Sea) which cause precipitation because their trajectories are mainly directed towards the Dinaric Mountain system where the Gacko mining energetic basin is situated.

Snow, as a type of solid precipitation has a very significant impact on the mine work, both in its height and the amount of water that melts on sunny days and at low temperatures when it turns into snow ice, ice and glaze. In that way, the work and transport of mining material on the roads on which mining machines move becomes more difficult. The average number of days with snow cover of more than one centimeter is 75. The average number of days with snow is 44 days. In recent years, due to the climate changes, which are on the scene for a long time, the number of days with snow and its height, as well as the number of days with snow cover, has been decreasing. The maximum height of the snow cover measured in the last 25 years was 115 cm, and it was measured on March 4, 2005.

Rain, as a type of liquid precipitation has a very bad effect on radar works, especially when a larger amount appears for a short period of time. Then the torrential flows are created leading to a sudden penetration of water into the mine, both by surface and underground. A huge amount of water flows into the existing water reservoirs and the pumping capacities are maximally loaded because they have to discharge a huge amount of water, via pipelines to the rivers Mušnica and Gračanica.

As for the hydrological situation, during the year it is most favorable in the summer period of the year, when the precipitation is minimum (small amount of precipitation and low humidity) and the mechanization of the mine can work smoothly and easily. At the time of two precipitation maxima which are one in early spring and one in late autumn, the hydrological situation is much more difficult, due to the large amount of precipitation and greater penetration of groundwater and surface water into the mine.

The value of daily amounts (24 hours) of precipitation is sometimes extremely high to exceed the monthly amount. The absolute daily amount of precipitation (24 hours) was measured on October 13, 1975 and amounted to 198.4 l/m^2, which exceeds the maximum value of the daily amount of precipitation for a return period of 100 years.

The maximum daily amount of precipitation (24 hours) that occurs once in 50 years is 174.0 l/m^2. The number of days with precipitation during the year is 136, which means that the precipitation occurs every two to three days. The annual number of rainy days has been declining in recent years due to the large impact of climate changes, which have been intensified, especially in the last ten years.

Diagram 1 shows the spatial distribution and average amount of precipitation for the return reference period of over 70 years [3]. Table 1 shows the amount of precipitation for the return reference period of over 70 years.

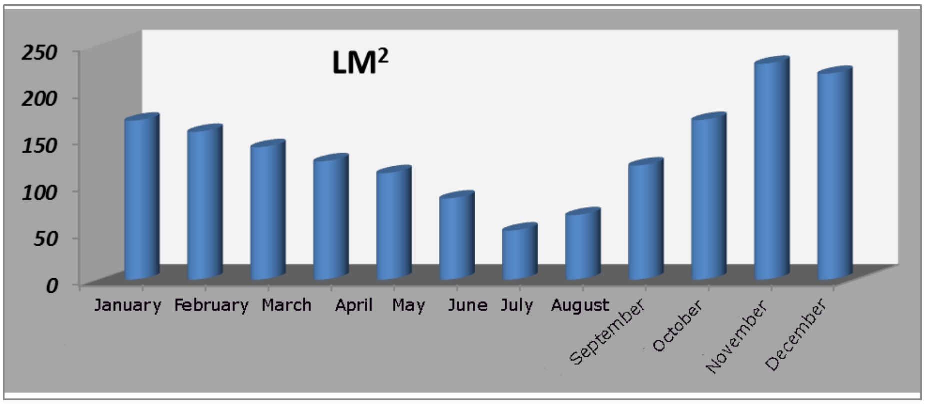

Diagram 1 *Spatial distribution and average amount of precipitation for the return reference period of over 70 years (Source: Meteorological Station of the Mine and TPP Gacko)*

Table 1 *The amount of precipitation for the return reference period of over 70 years*

Month	**Amount of precipitation l/m^2**
January	169.3
February	157.4
March	141.0
April	126.0
May	113.4
June	86.36
July	52.19
August	68.57
September	121.5
October	170.0
November	229.9
December	219.24
Total	**1654.80**

Relative humidity is as an important climatic element, which affects the work in the spring in many ways. During the hot summer months, the relative humidity is very low, especially in the afternoon (20% even less) when it is accompanied by very high tropical temperatures and, in addition, there are huge whirlwinds of marlycoal dust, which further complicates the human work in the mine since the normal human biorhythm requires a humidity of 45 to 65%.

In the winter months, the relative humidity is very high (90% even higher) followed by a large amount of snowfall and ice, which also further complicates the work in the mine and reduces the calorific value of coal.

Diagram 2 shows the mean monthly and mean annual air humidity (%). Table 2 shows the values of average monthly and average annual air humidity [3].

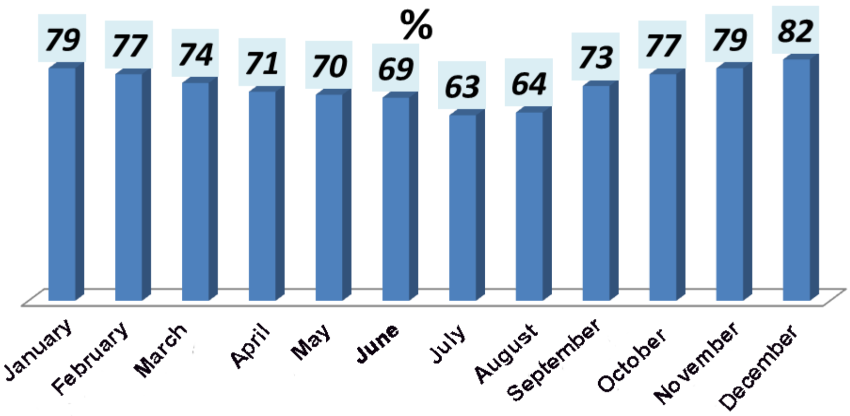

Diagram 2 *Mean monthly and mean annual air humidity (%)*
(Source: Meteorological Station of the Mine and TPP Gacko)

Table 2 *The values of average monthly and average annual air humidity* [3]

Month	Amount of precipitation l/m^2
January	79
February	77
March	74
April	71
May	70
June	69
July	63
August	64
September	73
October	77
November	79
December	82
Medium annual	**73**

Wind, as a very important climatic factor, has multiple effects on the mine operation and its facilities. Due to the high strength of wind, especially the north wind, which is the most common in the wind roses, which can exceed speeds over 100km/h, delaying and receiving arrows due to high vibrations and wear and movement, must stop working, according to the design constraints. The wind rose is given in the diagram for 2021, where the representation of certain directions during the year can be seen and it is less, more similar to the previous years.

During the summer half of the year, during long dry periods, due to wind gusts from the floor and mining machine, the large whirlwinds are created, sand and dust, which further complicate operation in the mine and mining machines, because then the huge concentration of solid pollutants in the air and relative air humidity at the annual minimum.

Diagram 3 shows the direction, frequency and strength of wind for 2021 (%) [3].

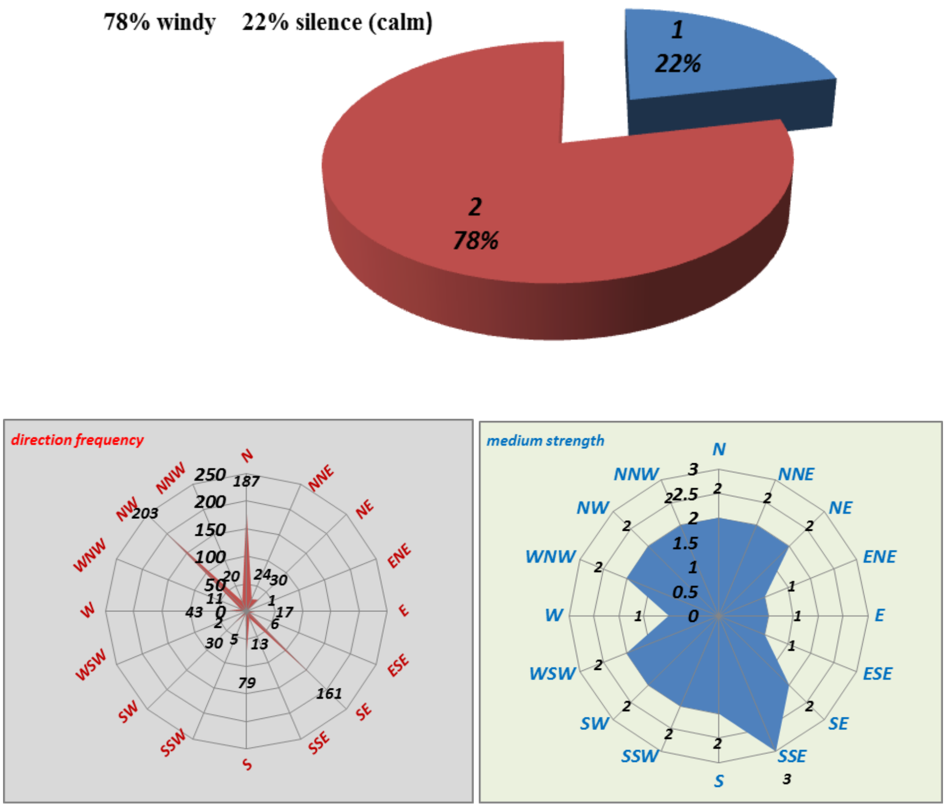

Diagram 3 *Wind direction, frequency and strength for 2021*
(Source: Meteorological Station of the Mine and TPP Gacko)

Table 3 shows the values of wind direction, frequency and strength for 2021 [3].

Table 3 *The values of wind direction, frequency and strength for 2021*

Direction	Direction frequency	Wing strength	Medium strength
S	230	0	0
N	187	465	2
NNE	24	60	2
NE	30	51	2
ENE	1	1	1
E	17	24	1
ESE	6	8	1
SE	161	342	2
SSE	13	37	3
S	79	177	2
SSW	5	10	2
SW	30	56	2
WSW	2	3	2
W	43	65	1
WNW	11	18	2
NW	203	349	2
NNW	20	45	2
Total	**1062**	**1711**	

High summer temperature, low relative humidity in the summer half of the year as well as winter high relative humidity and a large amount of precipitation directly affect the combustible coal matter deposited in the landfills of the thermal power plant, i.e. on qualitative characteristics, which are manifested by variations in the calorific value of energy fuel. High tropical temperatures, especially in the last ten years, are constantly increasing as well as the number of tropical days during the summer. During 2021, there were 34 tropical days on the territory of Gacko, which has never been recorded so far. In some earlier climatic periods, the number of tropical days was 5 to 7. Tropical days previously appeared only in July and August, and in recent years occur in June and September, which further aggravates the situation and leads to increasing warming, lower relative humidity and less precipitation during the summer half of the year. This climate type negatively affects the coal landfills, almost all year round. In the winter part of the year, since the landfill is in the open, the landfill is saturated, under the effect of a huge amount of precipitation, which reduces the calorific value of combustible coal, especially in its surface part, which is exposed to the direct rainfall. In the summer part of the year, when the precipitation is minimum (there are no raindrops for days), the relative humidity is very low (20% in the afternoon and even lower), high tropical daily temperature (over 30^0C), the landfill self-ignites and the coal heat decreases.

Diagram 4 shows the average monthly absolute minimum and maximum air temperatures for 2021. Table 4 shows the values of average monthly absolute minimum and maximum air temperatures for 2021, as well as the spatial distribution and annual course of air temperatures [3].

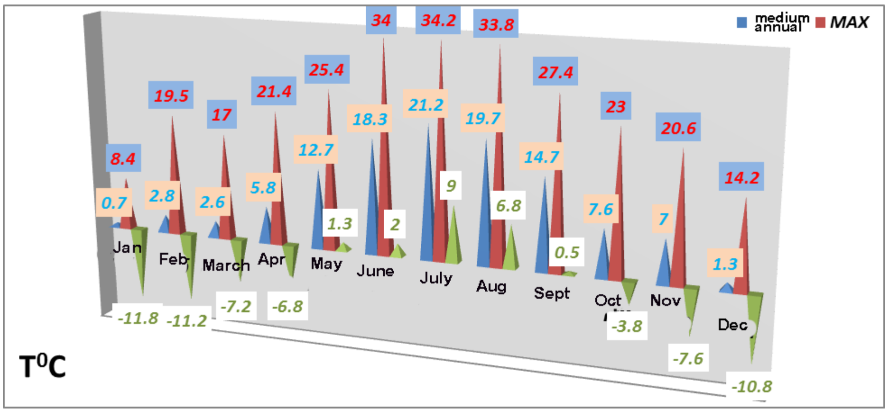

Diagram 4 *Mean monthly absolute minimum and maximum air temperatures for 2021 (Source: Meteorological Station of the Mine and TPP Gacko)*

Table 4 *The values of average monthly absolute minimum and maximum air temperatures for 2021 as well as the spatial distribution and annual course of air temperatures.*

	January	Febr.	March	April	May	June	July	August	Sept.	Octo.	Novem.	Decem.	Medium annual
Medium	0.7	2.8	2.6	5.8	12.7	18.3	21.2	19.7	14.7	7.6	7.0	1.3	**9.5**
Max	8.4	19.5	17.0	21.4	25.4	34.0	34.2	33.8	27.4	23.0	20.6	14.2	**23.2**
Min	-11.8	-11.2	-7.2	-6.8	1.3	2.0	9.0	6.8	0.5	-3.8	-7.6	-10.8	**12.0**

2 HYDROLOGICAL CHARACTERISTICS OF THE GACKO ENERGY BASIN

Hydrology of the Gatačko field is very similar to the other karst fields, the general direction of movement of both surface and groundwater is from the north and northeast to the south and southwest.

The current state of hydrology is somewhat different. The river Mušnica was moved by a new canal through the Gacko field and introduced into its bed near the village of Bašić. The current open pit "Gacko" is well secured from water of the river Musnica, both surface and underground, considering that it is the main recipient of all the waterof the Gacko field. Previously, the river Mušnica flowed directly along the final slope of the mine, on its southern and southwestern side, so that the water penetrations into the mine, whether surface or underground, were very present and unpredictable, especially during the periods of heavy rainfall.

The river Gračanica was moved to a new regulatory riverbed with impermeable foils, directed to the west and introduced into the abandoned riverbed of the river Mušnica, and through the Srdjevski klanac near the village of Bašić it was reintroduced into the river Mušnica. With this relocation, the current open pit is quite well secured, both from the surface and groundwater of the river Gračanica. The mine has uninterrupted production of coal and waste, unlike the previous period, when the surface mine existed in the western exploitation field and had to have a defense system on its northern and northeastern side the PERIPHERAL CHANNEL - PS1-PS2-PS3-DIAPHRAGM - INJECTION CURTAIN to protect against surface and groundwater from the north and northeast [6]. Such a defense system was very complex, economically unfavorable and, regardless of the complexity of maintenance, it was necessary.

The current situation of the mine in terms of surface and groundwater is far more favorable regardless of its depth (120 m) and the development of open pit towards the central parts of the Gacko field, due to this reason such a complicated hydrological defense system is not needed. Evacuation of water from the mine is being done successfully using a system of submersible pumps in water reservoirs and pipelines from water reservoirs in the riverbeds of the rivers Mušnica and Gračanica.

Surface and groundwater are collected in water reservoirs and from that aspect the open pit has solved the problem of drainage, but the negative impact of flooding of coal and waste remains. Since the Mušnica River has been relocated to a new surface bed, the groundwater flowing through the alluvium of the Musnica River remains present in the waste excavation zone. The final southern slope reached the designed excavation elevation, which almost coincides with the route of the old bed of the river Musnica [5]. Groundwater problems are constantly present in both rainy and dry periods. All the water that gravitates from the south are directed towards the reservoir, but they also pass through the coal floors, so there is a frequent occurrence of flooding the energy fuel that is transported to the landfill of the thermal power plant.

Coal flooding is a frequent occurrence of exploited coal from the local "coal zone", especially in the period of increased rainfall, when clay as an insulator captures all groundwater and surface water, which passes through the permeable parts of the coal seam. Clay interlayers, which appear in the coal seams of the roof series, represent a balance both as inorganic matter and raw material that carries moisture and which, due to its small thickness in the layer, is delivered together with pure coal substance to thermal power plant landfills.

3 IMPACT OF HUMIDITY ON QUALITATIVE CHARACTERISTICS OF ENERGY FUEL

The essence of technological problems related to the water content (moisture) is in a difficult control of this parameter, and thus all other quality parameters.

Difficult control is due to the high variability of the content of (coarse) mine moisture, which represents the largest part of the total moisture. The change in the content of water (moisture) in the deposit is conditioned by changes in the hydrological and hydrogeological situation. Thus, the humidity is highest at the time of melting snow and heavy rains. The excavated coal quickly moistens in case of precipitation, especially if there are clay-marl impurities [1].

Parameter that is directly related to the water absorption in coal is porosity, which is expressed through the effective porosity. Effective porosity is the ratio of volume of interconnected pores to the total volume [2]. The properties of coal as a collector of groundwater and surface water depend on the effective porosity. Effective porosity in terms of water absorption refers primarily to brown coal and lignite (the Gacko coal).

In the case of tests with a low percentage of moisture (below the usual norms), the thermal value was corrected via an appropriate diagram (diagram 5) constructed according to the laboratory tests.

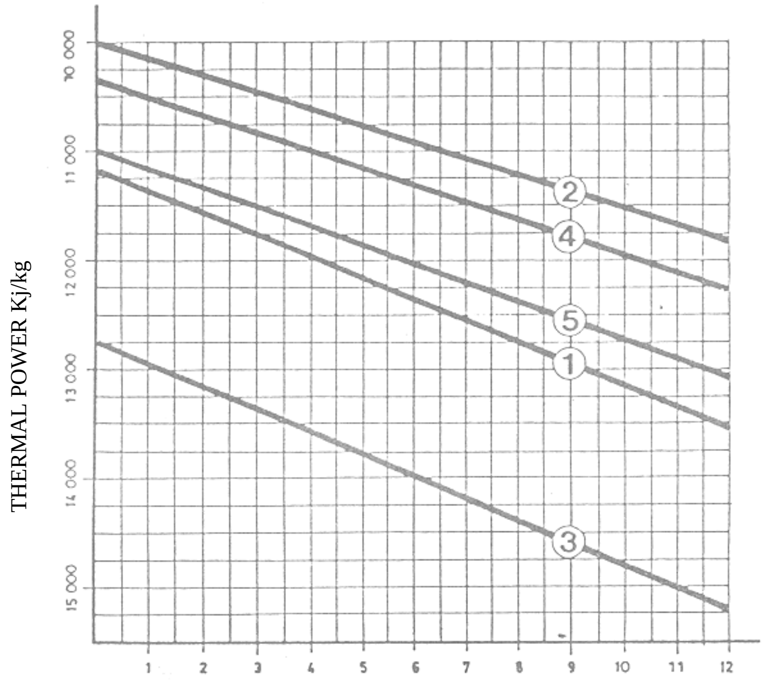

Diagram 5 *Diagram of the effect of coarse moisture reduction on the calorific value of coal in samples from drillhole 292*

Laboratory tests have shown that by reducing the coarse humidity by 1%, the calorific value of coal increases by about 200-250 kJ/kg [4].

FINAL CONSIDERATIONS

The qualitative characteristics of energy fuel that is burned in the boiler of the Gacko Thermal Power Plant largely depend on the climatological and hydrological conditions in which the coal is mined at the OP “Gacko“. The complexity of climatological conditions and their impact on the quality of combustible coal is reflected in the large number of days with precipitation (rain and snow) during the year, which leads to the increased humidity and thus reduced the lower calorific value of coal. Moisture is a parameter that, in addition to the participation of waste layer with the presence of the carbonate component, mostly reduces the calorific value of coal, and thus the negative effects, in the energy production power of the Gacko Thermal Power Plant block.

In the period of increased precipitation, the water content of coal increases, which creates problems in reaching the required granulation in the mills of the thermal power plant, as the initial phase in the preparation of energy fuel for combustion in the boiler of the thermal power plant. By reducing the production capacity of the thermal power plant block, lower economic profit is achieved, which means that increased moisture in coal in the entire economic system of mines and thermal power plants, significantly affects the negative economic effects. Also, the complex hydrological conditions, which are manifested in the appearance of a large number of springs, which gravitate towards the coal floors to a certain extent (slightly less than climatic conditions), affect the coal flooding and increase moisture content in the period without precipitation. In the coming period, a special attention should be paid to the problems of reducing the negative impact of moisture caused by the unfavorable climatological and hydrological conditions through study analyzes and research, in order to reduce the negative economic effects caused by this parameter of energy fuel quality.

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Original Scientific Paper
Energetics

Boško Vuković[*]

PROCUREMENT AND CONSTRUCTION OF THE COAL REFINING PLANT IN A FUNCTION OF INCREASING THE ENERGY EFFICIENCY AND LONG-TERM PRODUCTION AND ECONOMIC EFFECTS OF THE MINE AND THERMAL POWER PLANT GACKO

Abstract

Conquering the new technologies for coal purification in the world has enabled the exploitation of coal deposits with similar characteristics as the subject locality, which until a few years ago were not profitable or even "forgotten". In order to exploit such deposits, more systematic research and testing of useful raw material base as a thermal energy fuel is needed [1].

Considering all that, the Gacko Mine and Thermal Power Plant, as the research holder, started drafting the Project of Detailed Geological Explorations on the return coal zone with a clear goal to define the quantities and quality of coal, i.e. obtaining the clear parameters on thermotechnical properties of combustible coal. On the basis of the Exploration Project, the detailed geological explorations of the "return coal zone" were performed and the exploration results served as a basis for the analysis of coal refining possibilities and possible reconstruction projects on the boiler system of the Gacko Thermal Power Plant.

Keywords: *coal, return zone, waste, calorific value, coal refining, X-Ray*

INTRODUCTION

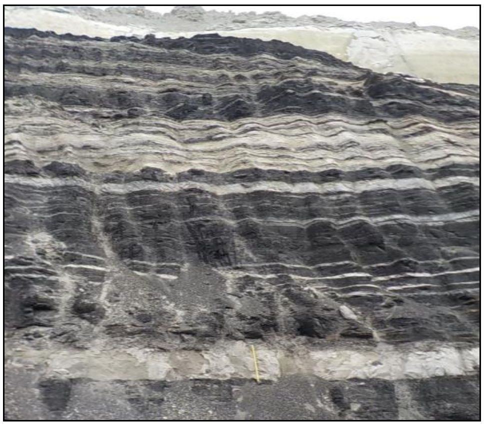
Fossil fuel from the Gacko deposit is primarily used exclusively as the thermal energy fuel for the needs of the thermal power plant in Gacko, and a small share in the total annual production, for commercial placement, and then as an energy raw material. Fossil fuel from this deposit is represented by coal of lignite to brown lignite type of the primary economic and strategic importance for the Republika Srpska. In order to ensure regular supply of TPP with coal of the appropriate and uniform quality, i.e. appropriate calorific value, it is necessary, methodologically, on a concrete example, to perform the coal refining, Combustion of coal without waste, leads to a large number of economically and technologically positive effects in the production process of coal and electricity and at the same time, to reduce and eliminate the negative impact on the environment.

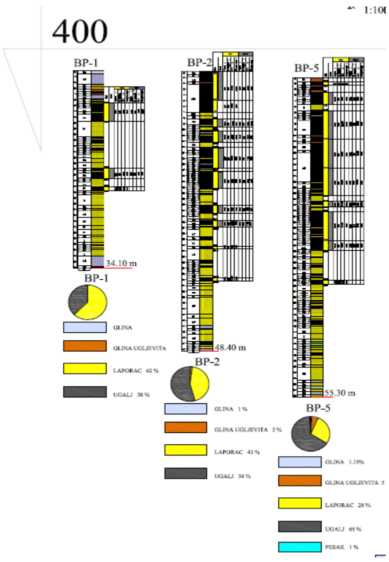
GEOLOGICAL CHARACTERISTICS OF THE COAL DEPOSIT GACKO

Geological research, on the site of the "surface zone - roof coal seams", on the coal deposit Gacko, conducted in the period from 2015 until 2020 have shown that the coal seams are about 15 m thick, with the geological coal columnwith about

[*] *Mine and TPP Gacko*

65% pure coal with an average calorific value of 9.5 MJ/kg, 9% coal clay with an average calorific value of 5 MJ/kg and about 26% stratified waste. The typical appearance of a stratified coal deposit is shown in Figure 1, while the results of exploratory geological drilling are shown in Figure 2.





Figures 1 and 2 *Roof part of the main coal seam in the field "C" (1-left) and geological column of the exploration drillhole at the site "surface zone - roof coal seams (2-right)"*

The appearance of waste layers (marl, coal clay and clay) directly affects the calorific value of coal, which is its most important characteristic and determines its application and price. The calorific value of coal depends on the type of coal defined by the method of its formation, moisture content and ash content. The ash in coal comes partly from coal itself and mostly from waste [4].

In general, it was found that the LCV - Lower Calorific Value of the analyzed coal - lignite (brown-lignite) decreases by the ΔLCV = 0.4-0.5 MJ/kg for each percentage increase in ash content in coal [6]. The LCV can be increased either by reducing the ash content in coal or its moisture content.

Reduction of moisture in coal can be achieved by its drying, where it is necessary to consume more energy than it will be returned through increases in the LCV of coal, so this method is justified if the waste heat is available. Reduction of ash content in coal can be achieved, inter alia, by dry methods of an X-Ray sensor sorting, i.e, by removal the inorganic materials (marl, clay, coal clay) as inclusions in the coal seam.

TECHNOLOGICAL PROCEDURE OF THE DRY METHOD OF X-RAY SENSORY SORTING/REFINING OF COAL FROM THE COAL OPEN PIT "GACKO"

In the following text, the technological process of coal refining by commissioning of coal refining plant using the method of dry X-Ray sensor sorting/refining of coal is presented. Coal production at the OP "Gacko" takes place at the open pit - Central field - field "C" and "return coal zone". The excavated coal with the admixture of layered waste is transported by trucks to the primary crushers, where it is crushed into pieces up to -400 mm. Then, it is transported to the coal refining plant by a system of 5 belt conveyors, 1200 mm wide. Here, the coal is subjected to the secondary crushing, sieving and separation, whereby 3 fractions are obtained: -60 mm + 25 mm, -25 mm + 8 mm, -8 mm (fineness).

Coal refining is done for the first two fractions, the X-Ray sensor sorter and fineness falls on the belt, with the on-line LCV meter. If the lower calorific value (LCV) of coal is satisfactory (9 MJ/kg), the coal falls on the coal conveyor belt, and if it is not satisfactory, it is directed to the waste belt. The quality of coal from the Central Exploitation Zone is such that about 30% of coal can go directly to the TPP landfill and about 70% must go to the additional treatment. Coal from the return zone is of poorer quality, so it must be completely subjected to the additional treatment [8]. The basic operating parameters of the Coal preparation and refining plant for the working hours fund of 5000 h/year are given in Table 1.

Table 1 *The basic operating parameters of the coal preparation and refining plant for the working hours fund of 5000 h/year.*

Products	Unit measure	Scenarion I: Tg = 5,000 h/year	
		According to sample S1	According to sample S2
Total run-of-mine coal (t/year)	(t/year)	3,262,306	3,262,306
Plant input capacity (t/h)	(t/h)	653	653
Discarded fineness (-8 + 0 mm)	(t/h)	196	196
	(t/year)	979,592	979,592
Discarded waste (-60 + 8 mm)	(t/h)	137	137
	(t/year)	685,714	685,714
Total discarded material	(t/h)	333	333
	(t/year)	1,665,306	1,665,306
Refined coal	(t/h)	320	320
	(t/year)	1,600,000	1,600,000
	(MJ/kg)	10.3	10.0
	(TJ/year)	16,522,449	16,032,654

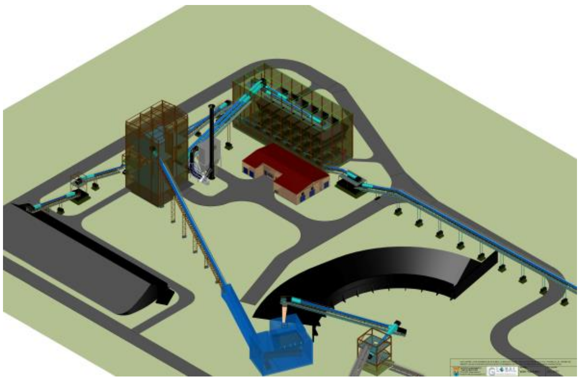


Figure 3 *3D drawing of the coal preparation and refining plant*

ECONOMIC AND TECHNOLOGICAL EFFECTS

Direct profits from the realization of the project for construction the Coal Purification/Refining Plant from the OP "Gacko" are reflected in the effects of the thermal power plant operation, as follows:

- increasing the degree of efficiency of the thermal power plant,
- reduction of the production costs of MWh of electricity.

According to the available literature, for each increase in LCV by 0.5 MJ/kg of coal, the production costs of 1 MWh is reduced by 1 EUR, with data relating to the lignite-like thermal power plants of similar quality, mining and thermal power complexes in Greece [5].

In our case, the coal purification/refining process is planned to increase the LCV from 7 MJ/kg to 10 MJ/kg (at humidity of 35%), which would correspond to a reduction in the electricity production costs by about 6 EUR/MWh.

Indirect profit - benefit from this project for the Mine and TPP Gacko and company as a whole is reflected in:

- Ensuring a continuous and quality supply of the thermal power plant with coal of the required quality (required minimum LCV)
- Prevention of possible negative consequences for the company reputation, if it does not comply with the environmental regulations, which is the basis of business and quality policy and maintaining a positive image through the implementation of an integrated environmental management system, according to ISO standards.

Introduction of such plant into operation leads to a uniform quality of refined coal at the landfill, which will be characterized by [3]:

- uniform ash content up to 15%,
- uniform lower calorific value: LCV = 9.5-10.5 MJ/kg.

Using the refined coal for boiler operation, the following will be achieved:

- increased efficiency of boiler, increase in boiler power, increase in generator power and amount of electricity produced at the same or lower consumption of run-of-mine coal,
- reduction the amount of ash and slag after coal combustion by at least 50%, as follows:
  - reduction the fine ash particles at the outlet of electrostatic precipitator, i.e. at the outlet of a stack below the upper emission limit prescribed by the Law,
  - reduction the amount of ash and slag at the landfill,
  - reduction of gas emissions (CO_2, SO_2, NO_x …).
- elimination of the need to enter the missing energy and maintain the temperature in the furnace with the additional burners on fuel oil,
- elimination of slagging the pipe screens and frequent cleaning interventions.

SOCIAL ASSESSMENT/NATIONAL FEASIBILITY OF THE PROJECT

There is a high degree of interdependence between investment and economic growth since investment strengthens the material basis of society and provides the accelerated economic and social development. When drafting and evaluating an investment project, the macroeconomic effects should be taken into account, i.e. effects from the aspect of society [2]. This valuation of the investment project aims to review the economic effectiveness of the project from the point of view of society and its contribution to the socio-economic development.

The assessment of the project is based on the socio-economic flow, which has the elements of economic flow, but differs in that it excludes the so-called transfer payments. In the revenue part, recourses, subsidies, donations and export premiums are excluded, and in the expenditure part, taxes, contributions, customs duties, taxes, etc. are excluded. The amount of net income represents the project contribution to the creation of social accumulation. In this case, there are no corrections on the income side, the only correction is the exclusion of income tax, on the expenditure side. The parameters for assessment the socio-economic effectiveness of the project are [3]:

- Social net present value, and
- Social internal rate of return.

Contribution of the project to the socio-economic development is not always quantitatively measurable, so the qualitative assessments are used:

- Meeting the needs of society – implementation of the project directly helps the production of electricity, which is necessary for both the economy and the population,
- Increase in employment - although the project does not envisage employment of the new workers, redistribution of jobs has been provided, for 21 workers,
- Faster regional development - increasing the material base of the region and increasing the living standards of employees,
- Protection and preservation of the environment - refined coal will produce less ash and harmful gases during combustion, which go into the atmosphere, and therefore less ash will be deposited on the internal landfill.

SUMMARY WITH THE FINAL EVALUATION OF THE PROJECT

Further exploitation of coal in the Gacko coal deposit, after the end of exploitation at the open pit Gračanica, in the fields "A", "B" and part of field "C", is directed to the Central and Eastern fields. Coal exploitation is currently taking place within the boundaries of the new open pit Gacko – Central field (field "C" and "roof coal seams - return zone"). In the next period of coal exploitation, a lower quality coal is expected, which was determined by the exploratory drilling. The expected lower quality of coal will be reflected in:

- lower LCV values (up to 6 MJ/kg),
- increased waste content, up to 40%, which also entails the increased moisture content.

Due to all the above, it is necessary to build an X-Ray sensor sorting/purification plant for coal [9].

The X-Ray sensor sorting plant will be located on a free flat surface on the northwest side of the existing coal dump.

Optimization of providing a continuous coal capacity should enable the Coal Mine Gacko to be stable, rational and economical production with all economic parameters to the TPP Gacko landfill, as a product for the TPP supply and product with its selling price including all costs to the TPP Gacko landfill.

Analyzing the financial cash flow has determined the permanent liquidity of the project, the total accumulated amount, net financial flow, i.e. cash at the end of the project life is **79,175,701 KM.**

Economic cash flow provides the basic indicators of profitability of the planned investment and the success of the project as a whole [9]:

- Internal rate of return is **16.98%,**
- Net present value (6%) is **37,881,597 KM,**
- The payback period is **7 years** (including an investment period of 2 years).

The internal rate of return is satisfactory, since that it is an investment in the field of mining where, due to large capital investments, the high rates of return are not expected (on average about 13%).

The net present value is satisfactory, as it is discounted at a rate of 6%, which is higher than the projected interest rate on loans, if the interest rate on loans is higher than projected, the project will continue to be positive.

A payback period of 7 years or 5 production years is also acceptable, as the invested funds will be returned after 1/3 of the production life of project [7].

The final conclusion is that the construction of a coal processing plant by the method of dry X-Ray sensor separation, at the OP Gacko – Central field, is economically completely justified.

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Original Scientific Paper
Management in Mining

Slavica Miletić, *Dejan Bogdanović*, *Ana Kostov*

BUILDING A STRATEGY FOR THE MINING AND METALLURGY COMPANIES DURING THE COVID-19 PANDEMIC***

Abstract

This work proposes a methodology for adopting a strategy in mining and metallurgical companies during the Covid - 19 pandemic. For this purpose, the AHP analysis is recommended as an instrument for formulating the optimal business models. Selected business models are the most desirable for solving the preventive strategy of mining and metallurgical companies. The methodology of the work shows the applicability of the proposed model for solving the real problems caused by the Covid - 19 pandemic.

Keywords: *preventive strategy, mining and metallurgical companies, Covid-19*

1 INTRODUCTION

The Covid-19 pandemic has not bypassed any country; it has caused a significant damage to the economies all over the world. Using the literature, the research shows that many companies are either closed or are in a big business trouble. The economic crisis has not bypassed the mining and metallurgical companies either. They have undergone a major transformation in business.

Since December 2019, a new disease of the Koran virus has spread rapidly, starting in China, which has led to a global epidemic causing a great concern for the business of companies. Everyone in the world is aware that there is no exact cure for the Covid-19 to date, so it is very important to create such business models so that the companies can carry out their activities. At the beginning of pandemic, the companies managed, but the long-lasting pandemic requires difficult transformations. For a successful change, before any investment, it is necessary to start from a business strategy [1]. Preventive measures are the adoption of current strategy by the managers in order to solve the real problems. Preventive strategies are aimed at the optimal business models that bring the new values, new products and services and new markets.

* *Mining and Metallurgy Institute Bor, Zeleni Bulevar 35, Bor, slavica.miletic@irmbor.co.rs, ana.kostov@irmbor.co.rs*

** *Technical Faculty Bor, University in Belgrade, V. Jugoslavije 12, 19210 Bor; e-mail: dbogdanovic@tfbor.bg.ac.rs*

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To solve the real problems for the mining and metallurgical companies, the authors chose the AHP method, which belongs to the methods of multi-criteria decision-making (MCDM). The AHP method evaluates the given business models. The calculation of the AHP method is flexible because it allows solving a complex problem with many criteria and alternatives. The calculation evaluates the criteria and alternatives giving the best criteria and best alternative in relation to the given target.

2 LITERATURE REVIEW

Previous literature shows that the economic impact of the coronavirus crisis is significant in all countries of the world. Almost 50% of companies are forced to suspend the operations such as the tourism organizations and airlines. Companies that remained open had a drastic drop in profits due to the reduced demand caused by the pandemic. Many non-manufacturing companies organized work from home while manufacturing reduced their activities. According to research, some companies have reduced the number of employees, which leads to concerns. Although there were layoffs, the research shows that fewer jobs were lost than expected [2].

During the pandemic, as everywhere in the world, the Government of the Republic of Serbia passed a decree on the implementation of employee safety measures. The conducted analysis of implementation the security measures in the mining and metallurgical companies shows the efficiency of achieving the business success. Using the protective measures, provided for the protection of employees, reduces the possibility of infection with Covid-19.

The mining and metallurgical companies are necessary for the functioning of the entire economy in Serbia, but this industry was also affected by the Covid-19 pandemic. A review of the literature shows that the most severe impact of the Covid-19 pandemic in the use of non-renewable resources is a decline in business volume and profitability, rising gold prices and high energy uncertainty [3]. The results obtained by surveying the employees in a mining and metallurgical company show that the pandemic caused by the Covid-19 caused severe consequences for employees. The consequences are: reduced working capacity, constant fear of spreading the pandemic, reduced concentration and fear of infection. Such consequences for employees lead to a reduction in the volume of business. Reduced business activity reduces the demand for products and services and thus reduces the company profit [4].

The most serious problem facing companies during a pandemic is declining demand for products and services. This type of problem for the mining and metallurgical companies has changed the current strategy. The situation caused by the Covid-19 pandemic has led to the reduced demand and sales of many products, leading to the reduced economic activity and a slowdown, including the mining and non-renewable natural resources sector [5]. Reduced demand for some products leads to oversupply, so that the price of metals has fallen, which has increased the world stocks, while gold prices are rising [6].

Research shows that the Covid-19 pandemic has affected the supply chains and their environmental performance, as well as an economically sustainable growth [7-12]. The Covid-19 pandemic had a strong impact on small and medium-sized enterprises in the United States. The consequences of the Covid-19 pandemic have affected many companies and changed the course of consumer behavior [14]. The food and beverage industry has also experienced enormous consequences caused by the Corona virus [15].

Some research shows the positive results according to which over 80% of sur veyed companies believe that the crisis caused by the Covid-19 pandemic will disappear in three months. In order to survive the current economic crisis, the mining and metallurgical companies have been offered the new business models, namely:

1. Implementation of the security measures prescribed by the Republic of Serbia;
2. Digital business in order to provide services more efficiently,
3. Finding the best solutions to conquer the market.

Business models are the ways in which employees think about which technique to use to best perform the business activities and create the expected value. The choice of business models provides guidance to the managers on: service delivery, product, profit, market, positioning and many other useful information to overcome the current crisis.

This work analyzes the new and existing business models. They represent the criteria used to find the optimal business model for the mining companies. The AHP (Analytical Hierarchical Process) calculation has come to a realistic solution to the problem caused by the Covid-19 pandemic. The AHP is the most suitable method of multi-criteria decision making (MCDM) for evaluating criteria.

Recent works using the AHP method: Modeling procedure for the selection of steel pipe suppliers using the FUZZY and AHP methods (Modeling Procedure for the Selection of Steel Pipe Suppliers by Applying the FUZZY AHP method), [16]; Multi-Criteria Assessment of Manufacturing Cell Performance Using the AHP Method (AHP Method), [17]; Selection of Sustainable Business Model During the Covid-19 pandemic in Serbia (Selection of Sustainable Business Model During the Covid-19 Pandemic in Serbia), [18] etc.

3 WORK METHODOLOGY

The strength of each criterion that defines the new optimal way of doing business for the mining and metallurgical companies is calculated by the AHP method. The AHP method is one of the most applicable multicriteria decision making (MCDM) methods. The feature of AHP in relation to the other methods is that the weight coefficients of criteria are determined in the most realistic way on the basis of the Satie scale (Table 1). Each element has its own value. If the criterion K_1 dominates over the criterion K_2, a value greater than 1 is entered in the comparison matrix, and if it is the opposite, the reciprocal value of the given value is entered. The sum of the weighting coefficients is one (1).

Table 1 *Satie's scale for evaluating the two elements j and k in relation to the target*

$$S=\left\{\frac{1}{9},\frac{1}{8},\frac{1}{7},\frac{1}{6},\frac{1}{5},\frac{1}{4},\frac{1}{3},\frac{1}{2},1,2,3,4,5,6,7,8,9\right\}$$

Value a_{jk}	Interpretation of results
1	Elements j and k are equally important
3	Element j is somewhat more important than k
5	Element j is more important than k
7	Element j is much more important than k
9	Element j is absolutely more important than k
2,4,6,8	Inter-values between two elements

The criteria are compared with each other depending on the given problem. Each criterion is compared to each other.

The degree of consistency is checked and should have a value less than 0.1. In case the degree of consistency does not have an appropriate value, the values entered in the comparison matrix are reconsidered.

To determine the degree of consistency, the consistency index is first calculated according to the formula:

$$CI = {(\lambda_{max} - n)}/{(n-1)} \qquad (1)$$

λ_{max} is a significant parameter used as a reference index to display the information in consistency degree (*CR*) calculations.

The rule is that the closer λ_{max} is to the number n, the lower the consistency will be.

CR is calculated according to the form:

$$CI = \frac{CI}{RI} \qquad (2)$$

RI - random consistency index taken from Table 2

In Table 2, the first row represents the matrix row and the second the random indices.

Table 2 *Random indexes [19]*

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.0	0.0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

The criteria that determine the optimal business model for the mining and metallurgical companies are:

1. Implementation of security measures prescribed by the Republic of Serbia;
2. Digital business in order to provide services more efficiently;
3. Finding the best solutions for conquering the market;
4. Existing business models;
5. Business models with the minimum production process.

The matrix of pair comparisons (Table 3) gives the value of significance the criteria in relation to the others by observing the defined goal and using the Satie scale (Table 1).

Table 3 *Pair comparison matrix for criterion weight coefficients*

Criteria	C_1	C_2	C_3	C_4	C_5
C_1	1	3	5	1/2	1/2
C_2		1	1	3	5
C_3			1	3	3
C_4				1	1/2
C_5					1

With the help of Super Decisions software, the result of assessment the business models was obtained. Before the weighting coefficients of business models are determined, the multidimensional hierarchical structure of the optimal business models is finally defined - Figure 1.

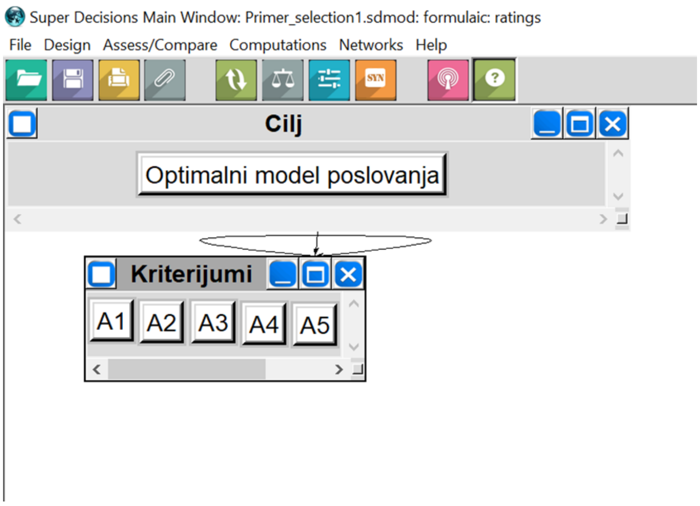

Figure 1 *Multidimensional hierarchical structures of business models*

The results of the AHP method calculation are shown in Figure 2. The consistency degree is less than 10% (0.1) and is 0.47829, which means that the results are adequate.

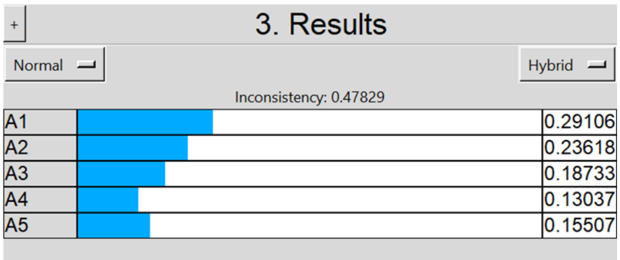

Figure 2 *Ranking results*

4 ANALYSIS OF RESULTS

By evaluating the business models from A_1 to A_5 by the AHP calculation, with the help of Super Decisions software, it was found that A_1 has the highest weighting coefficient. The value of its weighting coefficient is 0.29106. Analyzing the results, it was established that during the Covid-19 pandemic, the best solution for the mining and metallurgical companies is the implementation of the A_1 business model (Implementation of security measures prescribed by the Republic of Serbia). By applying the A_1 model, the employees in the mining and metallurgical companies are safer, the infection rate is reduced and the prevention strategy is sustainable. The analysis of the implementation of security measures prescribed by the Republic of Serbia, performed in a mining and metallurgical company as a case study, shows that 90% was successfully implemented [20].

The A_2, business model, digital business in order to provide more efficient services is in the second place as an option to overcome the crisis. The weighting coefficient of the business model A2 is 0.23. Digital business gained prominence during the Covid-19 pandemic. Many jobs in the mining and metallurgical companies have been digitized. Due to the development of digital technologies, the companies are going through radical changes. Thus, the digital age is one of the most important trends that are changing the current business [21].

In third place is the A_3 business model for finding the best solutions to conquer the market. The weighting coefficient of the A_3 business model is 0.18733. In a period of pandemic where markets are relentless, conquering new markets is a major business trend. The corona virus has brought the golden age of online commerce, digital e-commerce and e-shopping.

Comparing the existing business models (A_4) and business models with a minimum production process (A_5), the A_5 models rank the fourth place. The value of the weighting coefficient A_5 is 0.15507. The business model A_4 has a lower value of the weighting coefficient 0.13037.

The A_4 business models are not ready to meet the prevention strategies as well as markets and are threatened by the changes in technology and current market factors. They are simply not profitable. Due to the epidemiological situation in which they currently find themselves, the current A_4 business models may disappear or gain a new form of business.

The A_5 business models are models that survive by creating a new prevention strategy. By creating a new strategy, they move to a more profitable form of business.

For business models to be a good basis for business, they must monitor the external and internal environment.

CONCLUSION

The goal of all business models is to accelerate the growth of companies, make profits, conquer the new markets and create the value for customers. The strategy listens to the business environment and together with the business models participates in the decision-making process and approach to the business.

The task of this work is to establish a preventive strategy by selection the optimal business models for overcoming the economic crisis that followed the Covid-19 pandemic.

The order of business models for building a prevention strategy is:

1. Implementation of security measures prescribed by the Republic of Serbia with a weighting coefficient of 0.29106;
2. Digital business for the purpose of more efficient provision of services with a weighting coefficient of 0.23618;
3. Finding the best solutions for conquering the market with a weighting coefficient of 0.18733;
4. Business models with a minimum production process with a weighting coefficient of 0.15507;
5. The existing business models with a weighting coefficient of 0.13037.

The chosen AHP method made the appropriate decisions on selection the optimal business models for building a strategy that ensures the efficient operation of the mining and metallurgical companies.

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Telephone: +381 (0) 30/435-164; +381 (0) 30/454-110

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