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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

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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".

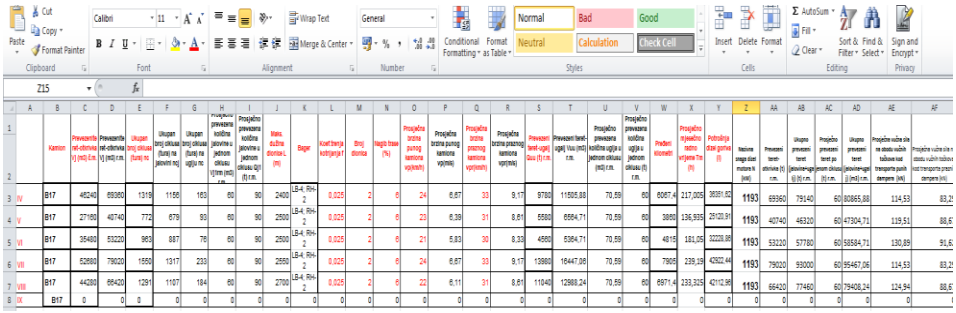

Figure 1 *Layout of a Microsoft Excel Sheet with inserted data for processing*

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 (m³) t.m.	Transported cargo-overburden Vj (m³) 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 Vjlrm (m³) r.m.	Average amount of transport. waste in one cycle Qjl (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 Qnu (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 (m³) r.m.	Average transport. amount of coal in one cycle (m³) 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) (m³) 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 (m³) 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 (m³) 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	32089.6	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

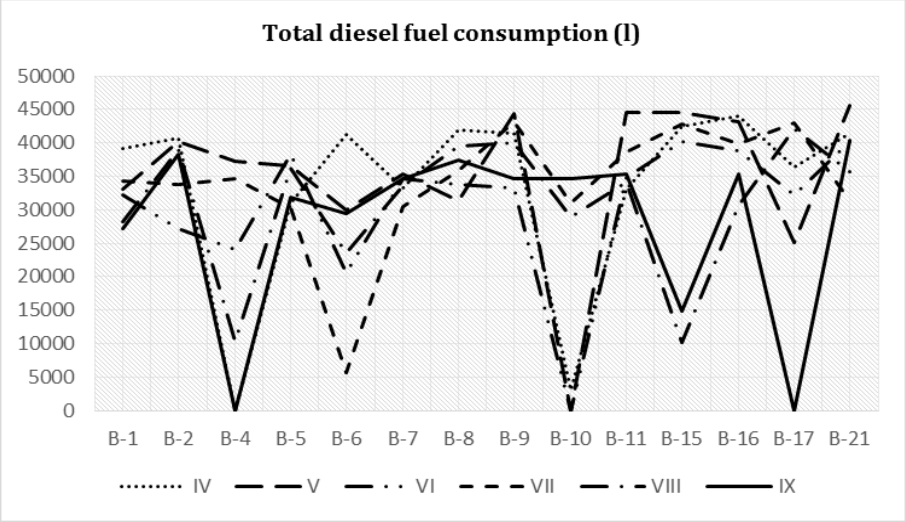

Figure 2 *Total diesel fuel consumption (l) in the IV, V, VI, VII, VIII and IX month*

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

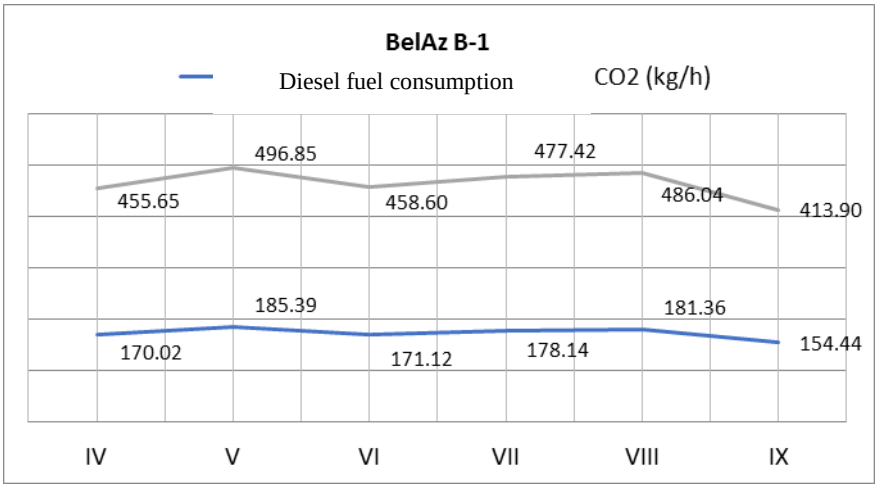

Figure 3 *Diesel fuel consumption (l/h) and CO_2 emission (t/h) of he BelAz dump truck internal code B-1*

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

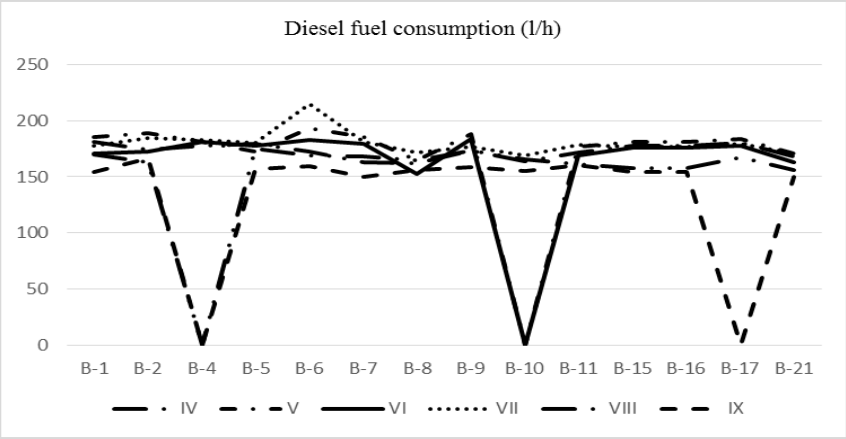

Figure 4 *Diesel fuel consumption (l/h) in the IV, V, VI, VII, VIII and IX month*

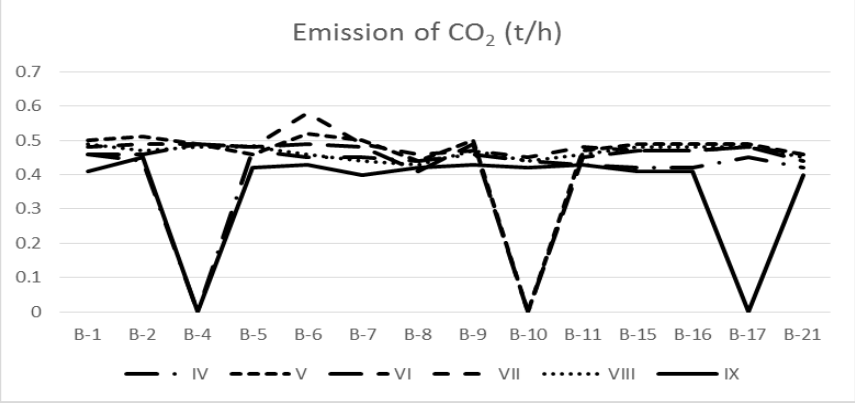

Figure 5 *Emission of CO_2 (l/h) in the IV, V, VI, VII, VIII and IX month*

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.

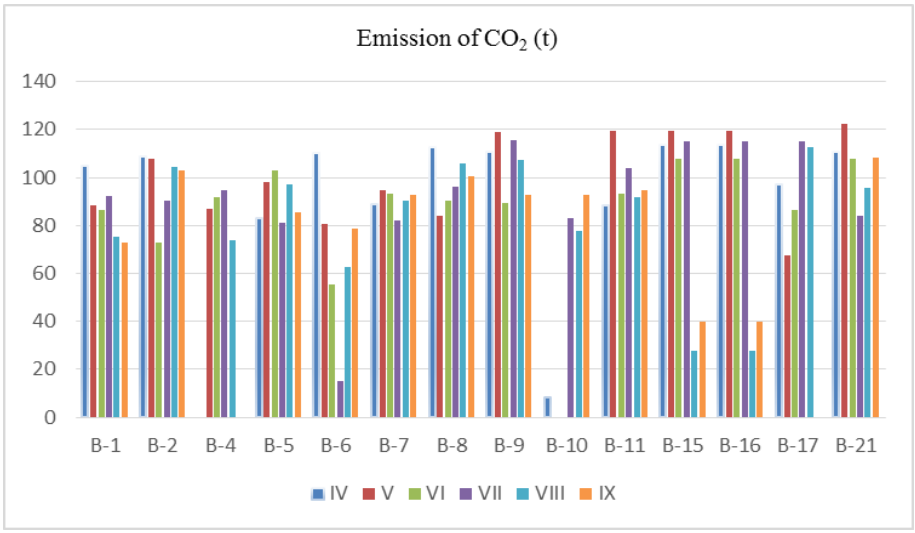

Figure 6 *Total amount of emitted CO_2 (t) in the IV, V, VI, VII, VIII and IX month*

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 ave-

rage 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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