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FUEL CONSUMPTION OF BELAZ DUMPERS AND CARBON DIOXIDE EMISSIONS USING THE EXAMPLE OF OPEN PIT 'TURIJA' OF THE BROWN COAL MINE BANOVIĆI

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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.

Key words: fuel, open pit mining, BelAz dump truck, maintenance, Coal Mine Banovići, carbon dioxide

1. INTRODUCTION

The main activity of the Brown Coal Mine "Banovići" Ltd. 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 underground mine 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 Mine "Underground Exploitation" (with one underground mine"Omazići"). After the period of delayed exploitation, reactivation was started at the Open Pit "Turija", while at the Open Pit "Grivice", a continuous exploitation is carried out from the day of opening 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 OP Turija, namely: 12 diesel-electric trucks BelAz 75131 with a capacity of 136 t and 2 dieselelectric trucks BelAz 75137 with a capacity of 136 t. The BelAz trucks are with dieselelectric DC traction. By a comprehensive research and collection of data on the parameters of truck transport at a specific location, it was necessary to conclude which parameters have the greatest impact on fuel consumption at constant load in driving of useful and useless minerals. In order to perform the subject analysis, it was necessary to deter-mine the average monthly fuel consumption for each considered transport unit (dump truck). For dump trucks in the conditions of work at the OP "Turija" of the Brown Coal Mine Banovići, taking into account all relevant influencing factors, the average fuel consumption can be defined as well as measures to reduce it.

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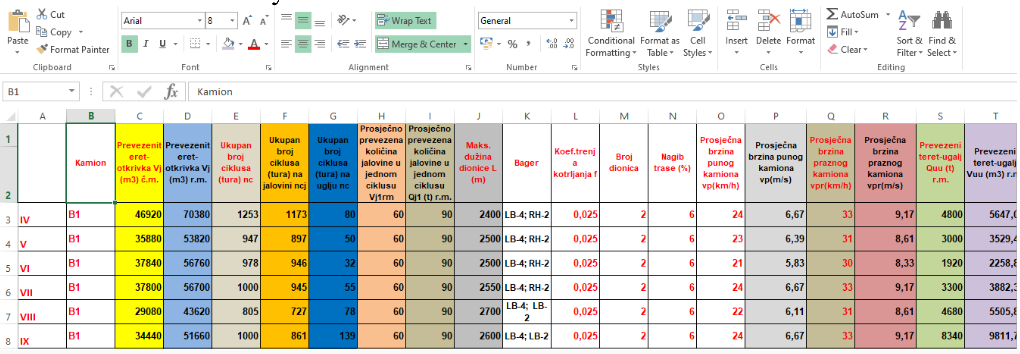
2. METHODS OF DATA COLLECTION AND PROCESSING

2.1 Methods of data collection

The data used in preparation of this work were taken from the database of the Department Mining Technical and Operational Preparation of the Mine "Open Pit Coal Exploitation". The data were processed using Microsoft Excel licensed by the BCM "Banovići".



	Kamion	Prevezenit eret-otkrivka Vj (m3) č.m.	Prevezenit eret-otkrivka Vj (m3) r.m.	Ukupan broj ciklusa (tura) nc	Ukupan broj ciklusa (tura) na jalovini ncj	Ukupan broj ciklusa (tura) na uglju nc	Prosječno prevezena količina jalovine u jednom ciklusu Vj1rm	Prosječno prevezena količina jalovine u jednom ciklusu Qj1 (t) r.m.	Maks. dužina dionice L (m)	Bager	Koef.trenja kotrljanja f	Broj dionica	Nagib trase (%)	Prosječna brzina punog kamiona vp(km/h)	Prosječna brzina punog kamiona vp(m/s)	Prosječna brzina praznog kamiona vpr(km/h)	Prosječna brzina praznog kamiona vpr(m/s)	Prevezeni teret-ugalj Quu (t) r.m.	Prevezeni teret-ugalj Vuu (m3) 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	5647,0
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	3529,4
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	2258,8
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	3882,3
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	5505,8
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	9811,7

Figure 1 The layout of a Microsoft Excel Sheet in which the data has been inserted for processing

2.2 Determining of fuel consumption

The most accurate method for determining the truck fuel consumption is to obtain data from 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. Hourly fuel consumption FC (l/h) can be determined from the following equation [1]: $FC = P \times 0.3 \times LF$
where P is the engine power (kW), 0.3 is the unit conversion factor (l/kW/h) and LF is the engine load factor (part of the full power required by the truck). Values for the truck engine load factors according to some authors in the relevant literature range from 0.18 to 0.50, while the others state values between 0.25 and 0.75, depending on the type of equipment and level of use. [1] For different engine load factors LF, the hourly fuel consumption FC (l/h) is shown in Figure 2, 3.

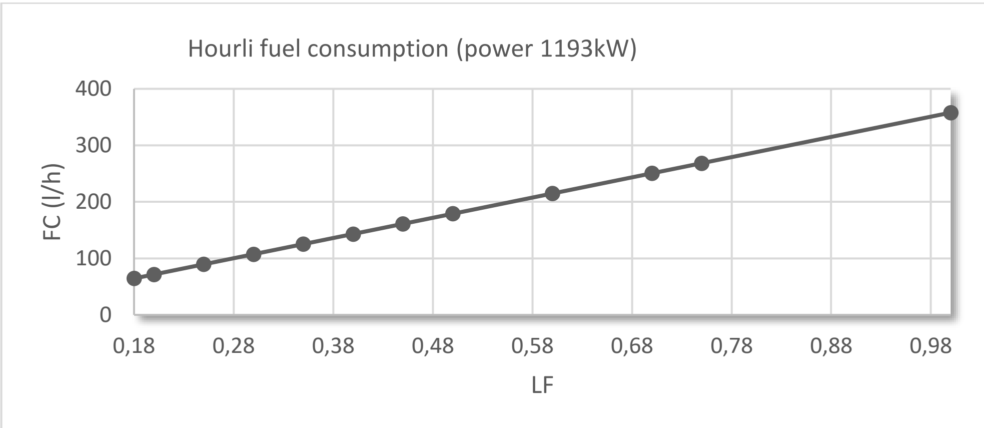


Figure 2 Fuel consumption FC (l/h) for engine load factor values (part of full power required by truck) LF = 0.18 to 1 for engine power P = 1193 (kW)

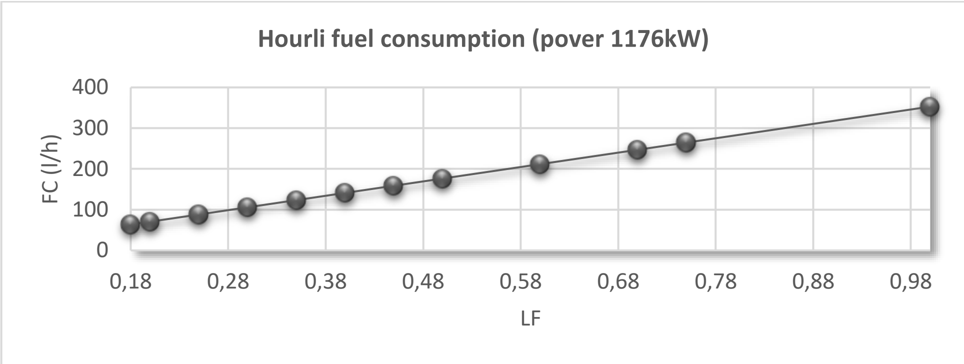


Figure 3 Fuel consumption FC (l/h) for engine load factor values (part of full power required by truck) LF = 0.18 to 1 for engine power P = 1176 (kW)

A similar equation for fuel consumption has been proposed in literature [1]: FC = (CSF × P × LF) / FD where CSF is the specific fuel consumption for the engine at full power (0.213 - 0.268 kg/kW/h) (0.35-0.44 lb/HP per hour), P is the power (kW), LF is the engine load factor, and FD is the fuel density (0.8318 kg/l for diesel purchased by the mine). The following values for engine load factors are ecommended in literature: 25% (light working conditions), 35% (average working conditions) and 50% (difficult working conditions) [1].

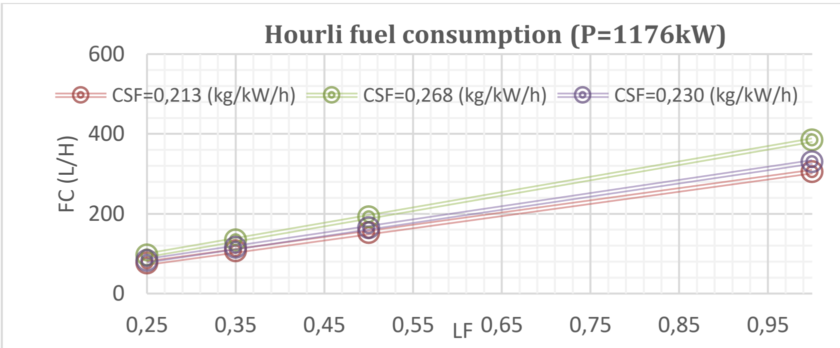


Figure 4 Fuel consumption FC (l/h) for engine load factor values (part of full power required by truck) LF = 0.25, 1.35, 0.5 and 1 for engine power P = 1176 (kW) and specific CSF fuel consumption for the engine at full power

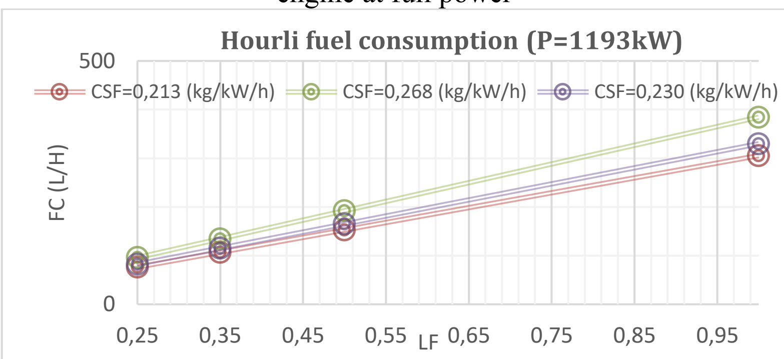


Figure 5 Fuel consumption FC (l/h) for engine load factor values (part of full power required by truck) LF = 0.25, 1.35, 0.5 and 1 for engine power P = 1193 (kW) and specific CSF fuel consumption for the engine at full power

Based on the collected and processed data, it was found out that the dump truck at the OP "Turija" worked in difficult working conditions, and the load factor of the LF engine had value of 45 to 50%. Liebherr developed a method for determiningnthe truck fuel consumption per hour. According to this method, the rate of fuel consumption is directly proportional to the delivered power [1]. Assuming that LF = 100%, the obtained fuel consumption would be 352.8 (l/h) for 1176 kW engine and 357.9 (l/h) for 1193 kW engine.

CO2 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 CO2 emission using the mathematical equations [1].

CO2 emission from diesel fuel in (t/h) can be written as [1]: CO2 = FC × CF
where FC is diesel consumption (l /h) and CF is the conversion factor. CO2 emission conversion factors for diesel fuel can be calculated as: CF = CC × 10^{-6} × 0.99 × (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 AMOUNT OF CARBON DIOXIDE EMISSIONS

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 at the OP "Turija" transport both overburden and coal during their work. The average volume mass of the overburden in the solid state is ρ_{rmj}=2.25 (t/m3), the average bulk density of the overburden in the loose state is ρ_{rmj}=1.5 (t/m3), and the average looseness coefficient for overburden krj=1.5.

As an illustration of the calculated operating parameters of all dump truck individually, Table 4 and Figure 6 are highlighted for BelAz of internal code B-1.

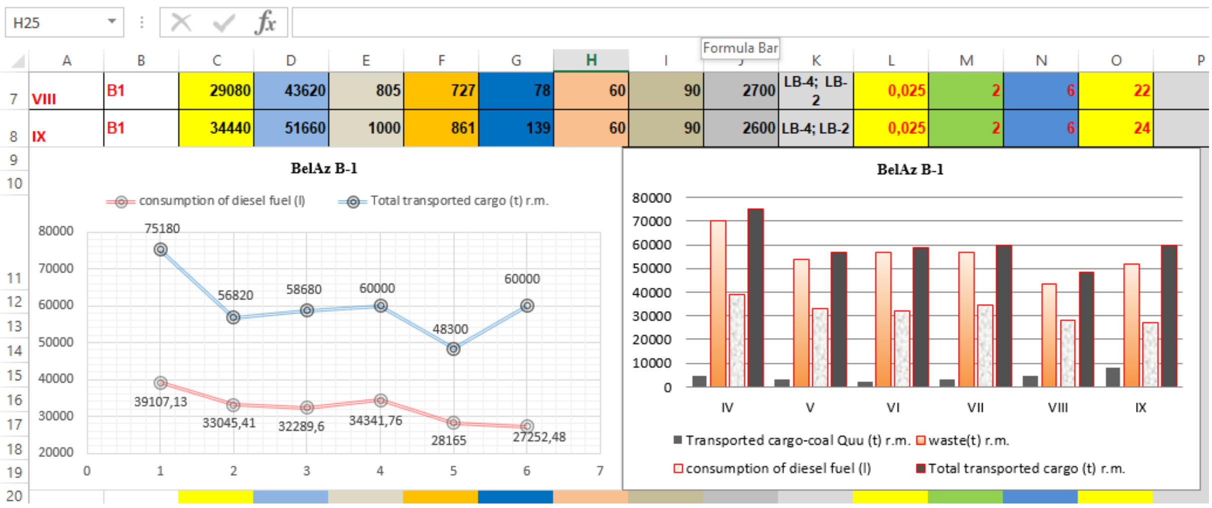


Figure 6 Transported cargo-coal (t) r.m., waste(t) r.m., total transported cargo (t) r.m. and consumption of diesel fuel (l) in IV, V, VI, VII, VIII and X months of BelAz internal code B-1

Figures 7 show the diesel fuel consumption (l) in IV, V, VI, VII, VIII and IX months of all BelAz at the open pit "Turija".

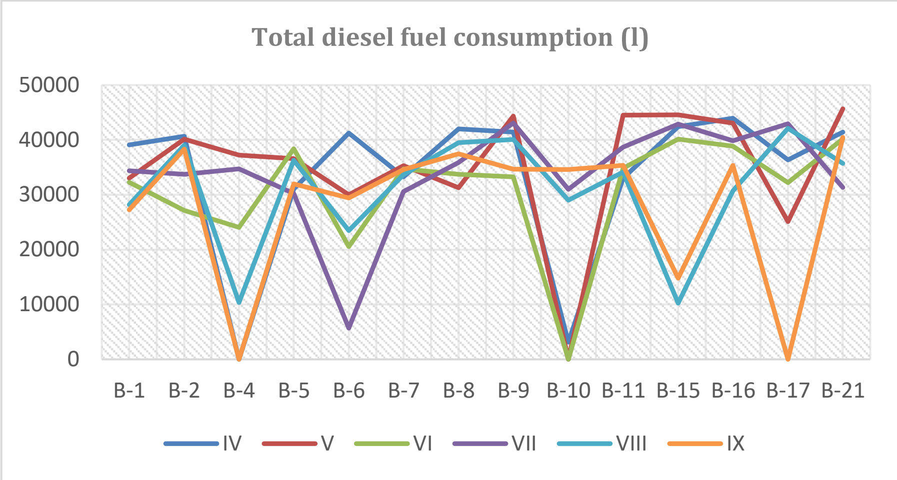


Figure 7 Total diesel fuel consumption (l) in IV, V, VI, VII, VIII and IX months

During six months of monitoring, the dump trucks traveled a total of 443692 (km). Analyzing the relationship between the amount of transported cargo and consumption of diesel fuel, it was found that in the same working conditions, the transport of a larger amount of cargo requires higher consumption of diesel fuel and vice versa. For the same amount of transported cargo, changes in working conditions affect the fuel consumption. Lack of auxiliary equipment and climatic conditions (precipitation, storm) cause the production to be difficult, so that even in the case of increasing the number of effective hours for transporting the same amount of cargo, leads to more fuel consumption, and it happens that more fuel is used for transport smaller amounts of cargo. In some cases, due to bad weather (heavy rain), it is necessary to move the dump truck to the other sites. Based on the collected data, the average consumption of diesel fuel was calculated per hour traveled (l/h), per kilometer traveled (l/km) and transported ton of loose tar (l/t r.m.), and shown in Figures 8 and 9.

BelAz B-1

month	Kilometers traveled	Diesel fuel consumption (l)	Total transported cargo (t) r.m.	Average monthly working hours Tm (h)	Diesel fuel consumption (l/km)	Diesel fuel consumption (l/t r.m.)	Diesel fuel consumption (l/h)
IV	6014,4	39107,13	75180	230,01	6,5	0,52	170,02
V	4645	33045,41	56820	178,245	7,11	0,58	185,39
VI	4890	32289,6	58680	188,7	6,6	0,55	171,12
VII	5100	34341,76	60000	192,78	6,73	0,57	178,14
VIII	4347	28165	48300	155,295	6,48	0,58	181,36
IX	5200	27252,48	60000	176,46	5,24	0,45	154,44
prosjek	5032,73	32366,9	59830	186,915	6,45	0,54	173,41

BelAz B-2

month	Kilometers traveled	Diesel fuel consumption (l)	Total transported cargo (t) r.m.	Average monthly working hours Tm (h)	Diesel fuel consumption (l/km)	Diesel fuel consumption (l/t r.m.)	Diesel fuel consumption (l/h)
IV	6888	40666,03	86100	249,135	5,9	0,47	163,23
V	5457,6	40153,74	68220	212,16	7,36	0,59	189,26
VI	4085	27135,08	49020	157,335	6,64	0,55	172,47
VII	5457	33722,5	64200	182,58	6,18	0,53	184,7
VIII	6215,4	39029,41	69060	223,635	6,28	0,57	174,52
IX	6687,2	38324,9	77160	230,52	5,73	0,5	166,25

Figure 8 Consumption of diesel fuel (l/h), (l/ km), (l/t r.m.) in the IV, V, VI, VII, VIII and IX months

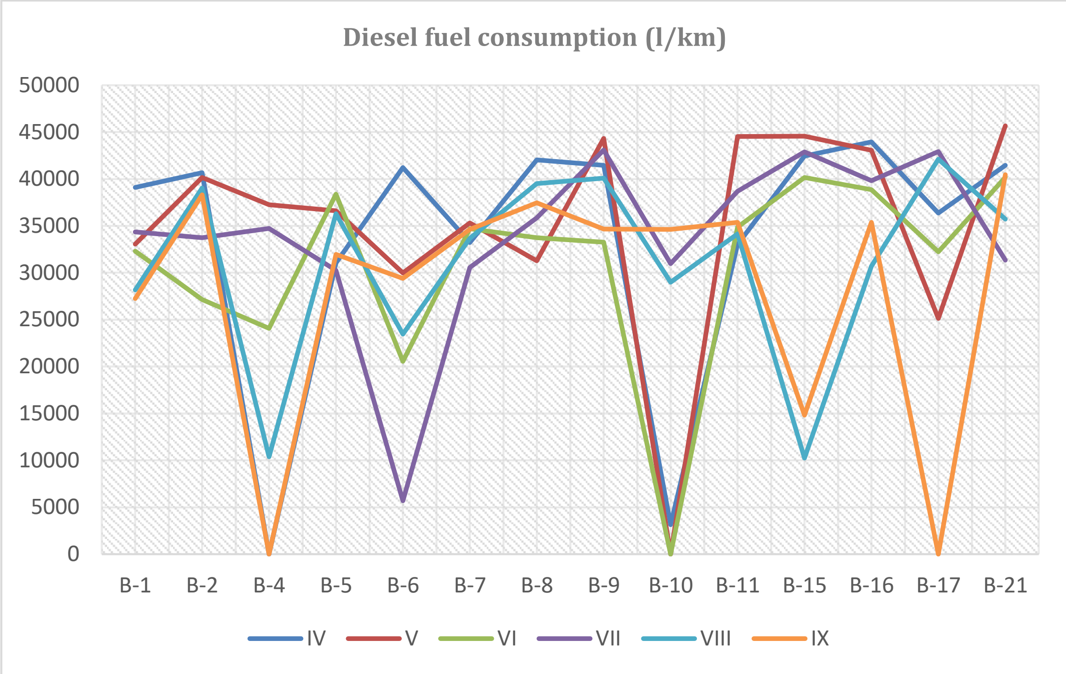


Figure 9 Consumption of diesel fuel per kilometer (l/ km) in the IV, V, VI, VII, VIII and IX months of the BelAz dump truck at the open pit "Turija"

Table 1 The average values of diesel fuel consumption per kilometer (l/km) for the IV, V, VI, VII, VIII and IX months of all BelAz dump trucks that were in operation

Month	Average diesel fuel consumption per kilometer traveled (l/km)
IV	6,065385
V	6,7125
VI	6,668333
VII	6,331538
VIII	6,126923
IX	5,118333

In the VII and VIII months, all dump trucks were working and the average monthly consumption of a BelAz dump truck ranged from 6.13 to 6.67 (l/km). Older BelAz trucks, driven by drivers with less experience, had the highest consumption in cargo transport, while relatively newer BelAz trucks used less fuel. With the BelAz B-8, the replacement of t engine showed a reduction in diesel fuel consumption, which was to be expected. The greatest impact on fuel consumption has the quality of road surface, weather conditions, and operation of auxiliary machinery. The transport of overburden took place to the inner western landfill with an average route length of 2500 m. Coal was loaded occasionally, and the average length of the route was 2500 m.

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 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*
EmissionCO2 (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

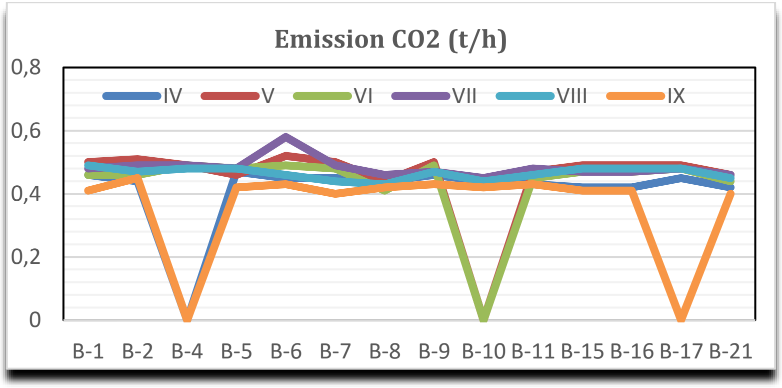


Figure 10 Emission of CO_2 (t/h) in the IV, V, VI, VII, VIII and IX month

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 CO2 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 CO2 (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 CO2 (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 CO2 (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 CO2 (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 CO2 (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.

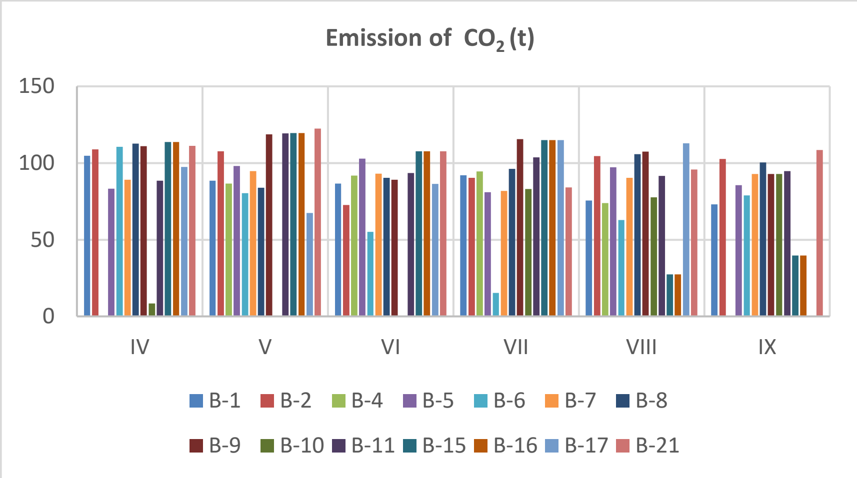


Figure 11 Total amount of emitted CO2 (t) in the IV, V, VI, VII, VIII and IX month

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 CO2 (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 CO2 (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 CO2 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 CO2 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 CO2 emissions in irregular months, except for the winter period when diesel fuel consumption increases by 20%, and thus CO2 emissions. Also, the consumption and emission of CO2 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.
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 CO2 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 CO2 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 CO2. With the BelAz B-8, the replacement of engine showed a reduction in diesel fuel consumption, which was expected..

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 CO2 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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