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FUEL CONSUMPTION OF THE BELAZ DUMP TRUCKS ON AN EXAMPLE OF THE OPEN PIT "TURIJA" OF THE BROWN COAL MINE BANOVIĆI

Abstract

This work sets out the methodology and presents the calculation results of fuel consumption of the BelAz dump trucks at the Open Pit "Turija" of the Brown Coal Mine Banovići itd. based on monitoring data. Properly determined fuel consumption allows the preventive measures and selection of strategy to reduce it. Data collection took six months, the data were analyzed, and thus the results by month of all dump trucks were presented.

Keywords: *dump truck, BelAz, fuel, open pit, coal, overburden, maintenance, Brown Coal Mine Banovići*

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 diesel-electric trucks BelAz 75137 with a capacity of 136 t. The BelAz trucks are with diesel-electric 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 consump-

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tion 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.

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 is established. The mode of operation in the production facilities of the BMC Banovići is a three-shift eight-hour system. The data used in preparation of this work 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 Microsoft Excel licensed by the BCM "Banovići".

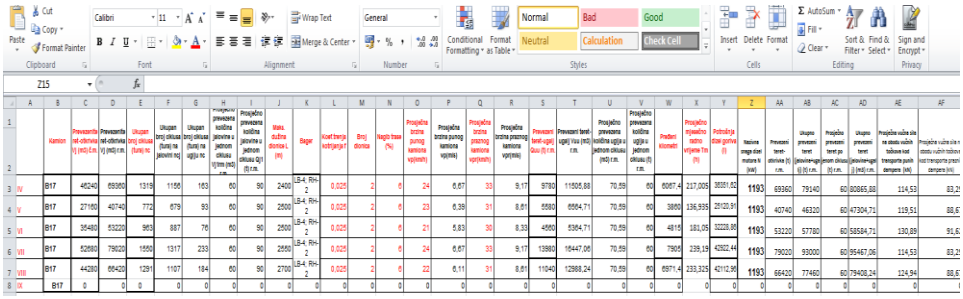


Figure 1 *Layout of a Microsoft Excel Sheet with inserted data for processing*

2.2 Methods of data processing

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]:

$$FC = P \times 0.3 \times LF \qquad (1.1)$$

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 Table 1.

Table 1 *Hourly fuel consumption FC for engine power of 1193 (kW) and 1176 (kW) and various load factors LF*

Engine power 1176 (kW)		Engine power 1193 (kW)	
LF	**FC (l/h)**	**LF**	**FC (l/h)**
0.18	63.504	0.18	64.422
0.2	70.56	0.2	71.58
0.25	88.2	0.25	89.475
0.3	105.84	0.3	107.37
0.35	123.48	0.35	125.265
0.4	141.12	0.4	143.16
0.45	158.76	0.45	161.055
0.5	176.4	0.5	178.95
0.6	211.68	0.6	214.74
0.7	246.96	0.7	250.53
0.75	264.6	0.75	268.425
1	352.8	1	357.9

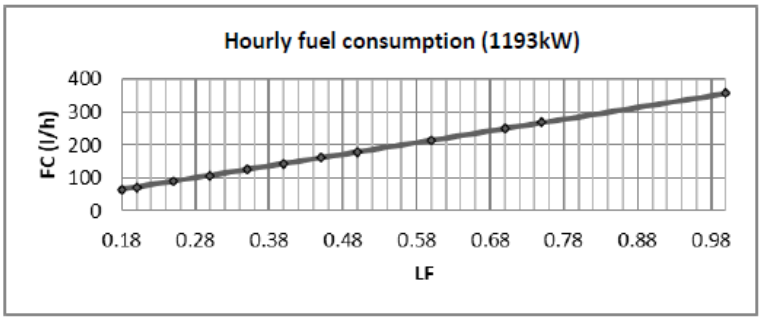


Figure 2 *Fuel consumption FC (l/h) for engine load factor values (part of full power required by truck) LF = 0.18 to 1 for engine power P = 1193 (kW)*

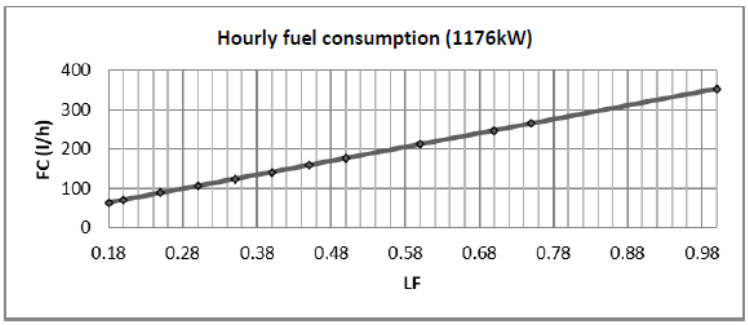


Figure 3 *Fuel consumption FC (l/h) for engine load factor values (part of full power required by truck) LF = 0.18 to 1 for engine power P = 1176 (kW)*

A similar equation for fuel consumption has been proposed in literature [1]:

$$FC = (CSF \times P \times LF) / FD \quad (1.1)$$

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].

Table 2 *Fuel consumption FC (l/h) for different SCF and LF (P = 1176kW)*

LF	FC (l/h) CSF=0.213 (kg/kW/h)	FC (l/h) CSF=0.268 (kg/kW/h)	FC (l/h) CSF=0.230 (kg/kW/h)
0.25	75.28492	94.72469	81.29358
0.35	105.3989	132.6146	113.811
0.5	150.5698	189.4494	162.5872
1	301.1397	378.8988	325.1743

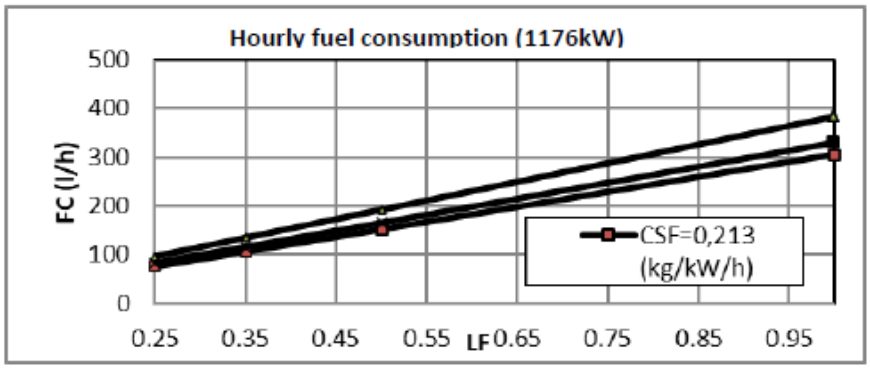


Figure 4 *Fuel consumption FC (l/h) for engine load factor values (part of full power required by truck) LF = 0.25, 1.35, 0.5 and 1 for engine power P = 1176 (kW) and specific CSF fuel consumption for the engine at full power*

Table 3 *Fuel consumption FC (l/h) for different SCF and LF (P = 1193kW)*

LF	FC (l/h) CSF=0.213 (kg/kW/h)	FC (l/h) CSF=0.268 (kg/kW/h)	FC (l/h) CSF=0.230 (kg/kW/h)
0.25	76.37323	96.09401	82.46874
0.35	106.9225	134.5316	115.4562
0.5	152.7465	192.188	164.9375
1	305.4929	384.3761	329.875

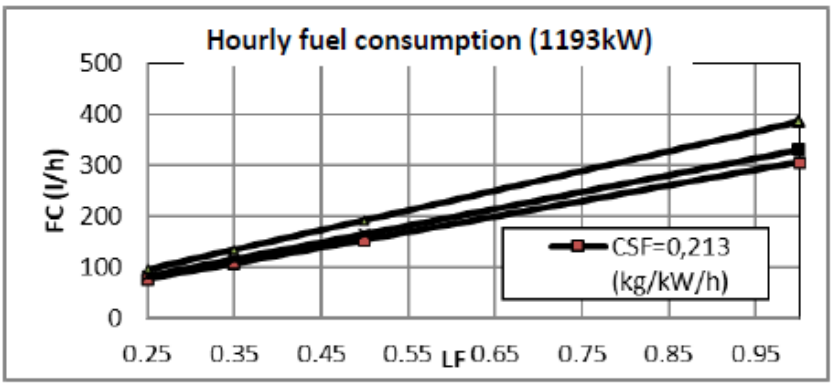


Figure 5 *Fuel consumption FC (l/h) for engine load factor values (part of full power required by truck) LF = 0.25, 1.35, 0.5 and 1 for engine power P = 1193 (kW) and specific CSF fuel consumption for the engine at full power*

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 determining the 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.

3 FUEL CONSUMPTION OF THE BELAZ DUMP TRUCK AT THE OPEN PIT "TURIJA"

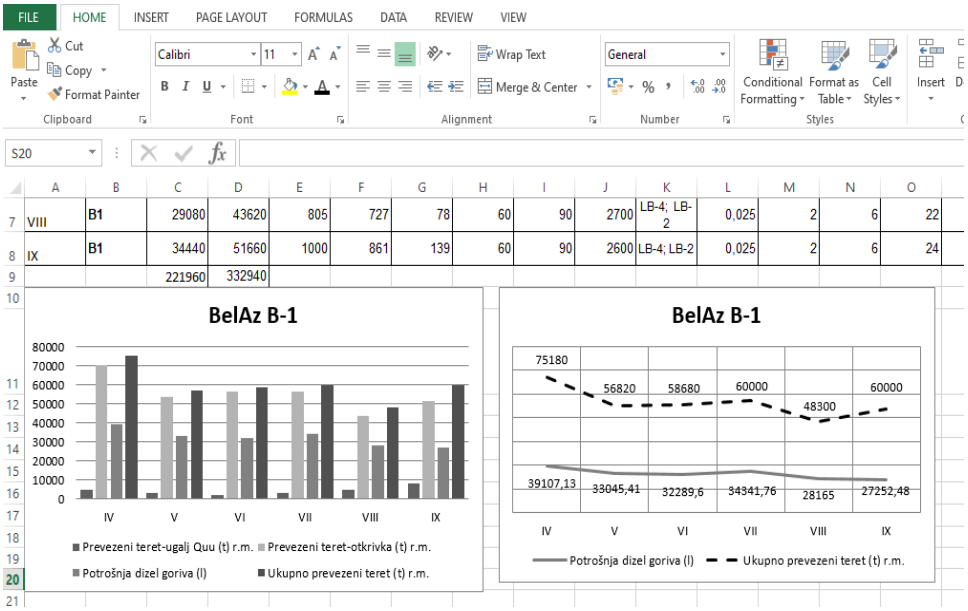
Based on the data of the Operational Technical Preparation Service, the operating parameters of the BelAz dump truck with internal markings B-1 were calculated; B-2; B-4; B-5; B-6; B-7; B-8; B-9; B-10; B-11; B-15; B-16; B-17 and B-21. The BelAz dump trucks at the OP "Turija" transport both overburden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

Table 4 *Operating parameters of BelAz internal code B-1*

Month	Truck	Transported load- waste Vj (m^3) č.m.	Transported load- waste Vj (m^3) r.m.	Total number of cycles (tour), n_c	Total number of cycles (tour) on waste, n_{cj}	Total number of cycles (tour) on coal, n_c	Average amount of waste transported in one cycle, Vj1rm (m^3) r.m.	Average amount of waste transported in one cycle, Qj1 (t) r.m.	Maximum length of a section, L (m)	Excavator	Rolling friction coefficient f	Number of route sections	Slope of route (%)	Average speed of a full truck, v_p (km/h)	Average speed of a full truck, v_p (m/s)	Average speed of an empty truck, vpr (km/h)	Average speed of an empty truck vpr(m/s)	Cargo-coal transported 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

Transported cargo-coal Vuu (m^3) r.m.	Average transported amount of coal in one cycle (m^3) r.m.	Average transported amount of coal in one cycle (t) r.m.	Traveled km	Average monthly working time Tm (h)	Diesel fuel consumption (l)	Rated power of diesel engine N (kW)	Transported cargo-discovery (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 in transport of full dump trucks(kN)	Average traction force at circumference of traction wheels in transport of empty dump trucks (kN)	Average cycle time (h)	Average cycle time (s)	Average transported cargo per cycle (m3) r.m.	Average distance traveled for one cycle Lu = 2L (km)	Average driving time of a full truck tp (s)	Average driving time of an empty truck tpr (s)	Average transported cargo 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



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
7	VIII	B1	29080	43620	805	727	78	60	90	2700	LB-4; LB-2	0,025	2	6	22
8	IX	B1	34440	51660	1000	861	139	60	90	2600	LB-4; LB-2	0,025	2	6	24
9			221960	332940											

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 and 8 show the total transported cargo (t) r.m. and diesel fuel consumption (l) in IV, V, VI, VII, VIII and IX months of all BelAz at the OP "Turija".

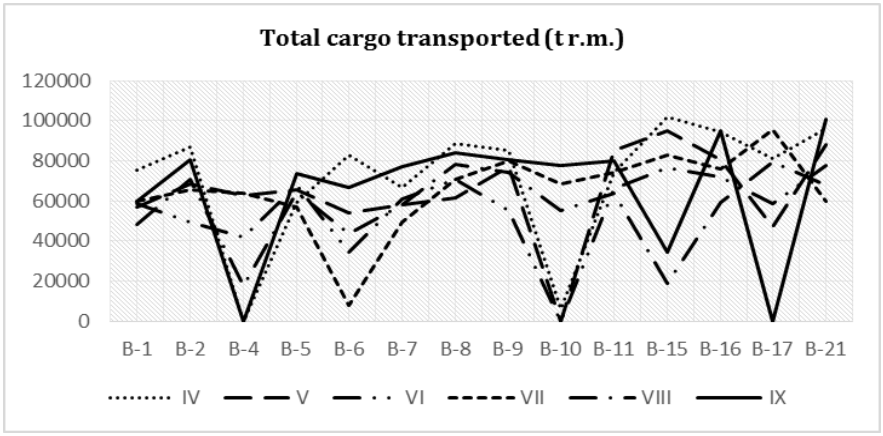


Figure 7 *Total transported cargo (t r.m.) in IV, V, VI, VII, VIII and IX months*

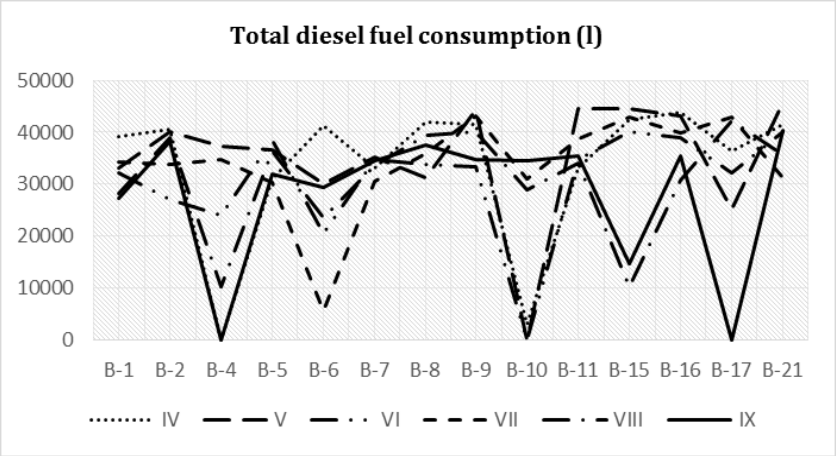


Figure 8 *Total diesel fuel consumption (l) in IV, V, VI, VII, VIII and IX months*

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. By transferring the Liebher and Terex RH 120E excavators from the lower floors of the E – 252 base terrain E - 360 base, i.e. on the first floor, the length of waste transport to the landfill has decreased, as well as the slopes (ascents) of the route.

In case of excavator failure, the dump trucks are transferred to the other excavator sites, and in case of lack of excavator capacity at the existing open pits, the dump trucks are transferred to open pits, and this procedure reduces the productivity of the dumper. The organizational part in the production process is very important due to the productivity of the open pit. Poor work organization leads to a decline in coal production and overburden, and production costs rise. Poor passability of transport units due to narrowing of transport routes, poorly demined floors, maintenance problems, lack of spare parts, as well as failure to fulfill orders for the purchase of parts for dump trucks are just some of the elements that affect the diesel fuel consumption.

Based on the collected data, the average diesel fuel consumptions per hour traveled (l/h), per kilometer traveled (l/km) and the transported ton of loose cargo (l/t r.m.) were calculated, and shown in Figures 9 and 10.

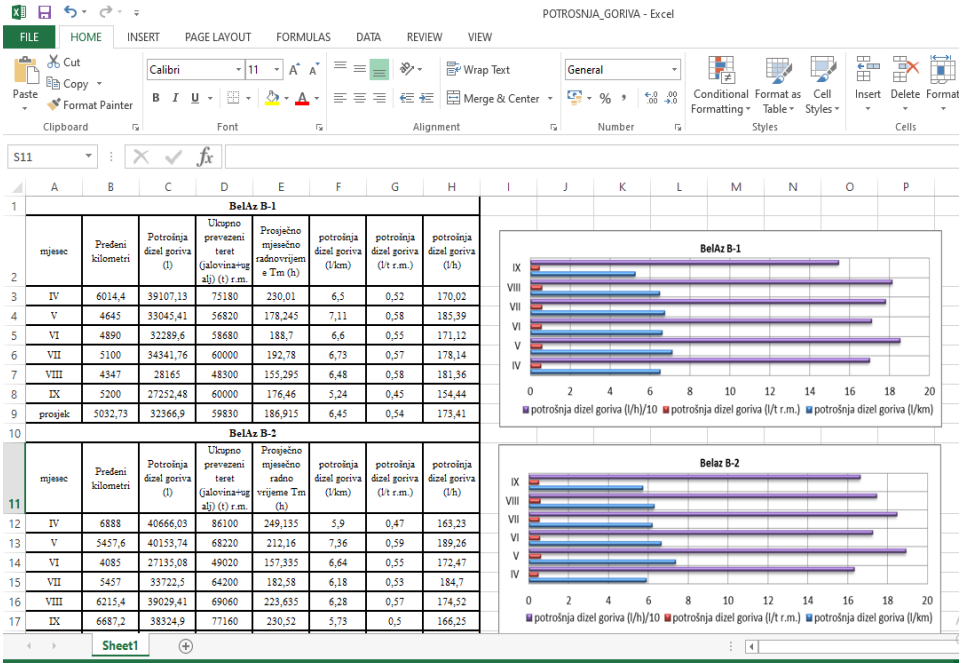


Figure 9 *Consumption of diesel fuel per kilometer (l/ km) in the IV, V, VI, VII, VIII and IX months*

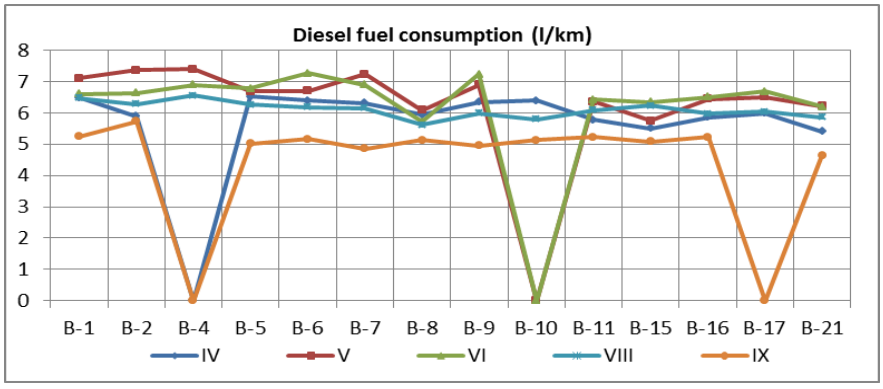


Figure 10 *Consumption of diesel fuel per kilometer (l/ km) in the IV, V, VI, VII, VIII and IX months of the BelAz dump truck at the OP "Turija"*

The first dump trucks of the type BelAz B-1, B-2, B-3, B-4, B-5, arrived at the BCM Banovići on March 15, 2006 and as such are among the dumpers of older production, and they have made over 70,000 engine hours. The average values of diesel fuel consumption per kilometer (l/km) of a dump truck in operation at the OP "Turija" are shown in Table 5.

Table 5 *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.

The analysis can generally conclude that the ratio of the amount of transported waste 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 rm) of the BelAz dump truck at the OP "Turija". The reason is in the fact that there were the same length of sections for waste and coal transport, and approximately road surfaces of the same quality.

In the dry period, the minimum fuel consumption for similar operating conditions can be expected from 6.13 to 6.67 (l/km), while in winter it increases by 12%. As the dump truck ages, a higher consumption can be expected than the obtained one.

4 PREVENTIVE MEASURES AND SELECTION OF MAINTENANCE STRATEGY

Based on the knowledge after research, suggestions can be made to improve and reduce the fuel consumption. Fuel consumption is affected by adequate maintenance and servicing of BelAz dump trucks, and it is necessary to do it on time. Simplify access to the regular service points, because it simplifies service and reduces the amount of time spent on regular maintenance procedures. It is still necessary to check the tire pressure regularly. Too little tire pressure worsens the lateral guidance of tires, prolongs the braking distance and thus reduces the 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. The tire is the only contact surface between the vehicle and ground, and has the task of withstanding carrying, movement, shock absorption, braking and acceleration, while

the rolling resistance has a direct impact on fuel consumption. Maintenance and improvement of the road surface can signifycantly 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 enables a shorter cycle of dump trucks and transport of larger quantities of cargo with lower fuel consumption. Apply adequate organization of the technological process, because it has a significant impact on the fuel consumption.

CONCLUSION

Many parameters, such as age and maintenance of the vehicle, load, speed, cycle time, layout at the open pit, work schedule, idle time, tire wear, rolling resistance, engine operating parameters and gear change patterns can affect the fuel consumption at the open pit excavation. The fuel consumption of the BelAz dump truck during the six months was discussed at the OP "Turija". Analyzing the results of processed data, it was found out which parameters and circumstances affect the amount of fuel consumed.

Analyzing the relationship between the amount of transported cargo and diesel fuel consumption, it can be concluded that in the same working conditions, the transport of larger quantities of cargo requires higher diesel fuel consumption and vice versa. Lack of auxiliary equipment and climatic conditions (precipitation, storm) cause that the production is difficult. In the months when the technological process was difficult, the fuel consumption was increased compared to the consumption in stable working conditions. In such conditions, and in the case of increasing the number of effective hours for transporting the same amount of cargo, the fuel consumption was higher for transporting smaller amounts of cargo. Changes in route length as a result of moving the excavator to a new location and changes in route slope due to the increased length of transport route and inadequate organization of technological process, poor working conditions, some dump trucks recorded higher fuel consumption when transporting smaller quantities of cargo. It can be concluded that the dump truck at the OP "Turija" worked in difficult working conditions. Older manufactured BelAz had the highest consumption in transport, served by drivers with less experience, while relatively newer BelAz used less fuel. With BelAz B-8, the replacement of engine showed a decrease in diesel fuel consumption, which was to be expected. The greatest impact on the fuel consumption has the quality of road surface, weather conditions, and operation of auxiliary machinery.

The presented method of processing, analysis and extraction of important information on the parameters of operation and consumption of diesel fuel in this way in our area was done for the first time, and it can be repeated at the other open pits that use dump trucks to transport cargo. The contribution of this work to the professional literature is that for the first time the fuel consumption at one open pit was determined on the basis of collected data and the method used. Determining fuel consumption is used to determine the preventive measures and maintenance strategies for the transport system in order to reduce it, as well as the emission of exhaust gases into the atmosphere.

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