Energy Assessment of BelAZ-75131 Gas-diesel Mining Dump Trucks Operation at Kuzbass Open Casts

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Abstract. The parameters of the BelAZ-75131 heavy dump truck improved model using gas-diesel mixture are given in the paper. The monitoring analysis of the conditions and operation indicators of BelAZ-75131 heavy dump truck using diesel and gaseous fuels is done. Numerical and percentage values of the replacement of diesel fuel with liquefied natural gas when transporting exploded rock mass are determined; the volume of diesel fuel and liquefied natural gas consumption has been established. The analytical dependence to calculate the cost per unit of energy during transportation by mining dump trucks with gas equipment is determined. The energy estimation of diesel and gas-diesel mining dump trucks operation is given.

1 Introduction

Kuzbass and Russia coal industry is developing annually both technologically and technically. Renovation of the mining equipment occupies about 60% of all costs of an enterprise. Constantly developing and increasingly complicated mining conditions give rise to competitive enterprises producing mining machines for various purposes [1-7].

In the sphere of open cast mining, the most famous and demanded supplier of mining heavy dump trucks is the company «BelAZ». The range of trucks varies in carrying capacity from 55 to 450 tons. Open casts are mainly equipped with BelAZ-75131 dump truck models and their modifications. Today, the BelAZ-75131 modification project has received support for development; BelAZ-75131 operates on a combined type of fuel (liquefied gas and diesel fuel) [8-15].

The purpose of this article is to analyse and give energy assessment of BelAZ-75131 mining dump trucks operation, using diesel and gas-diesel fuel at Kuzbass open casts.

2 Results and Discussion

2.1 Description of BelAZ-75131 modification using gas-diesel mixture

The main difference between the upgraded BelAZ-75131 mining dump truck and series produced prototypes is that it is additionally equipped with gas-cylinder equipment (GCE), which allows partially replace diesel fuel with natural gas and, thereby, ensure the engine operation in dual-fuel (diesel/gas) mode. Cryogenic tanks are located on the deck of a mining truck (Fig. 1). The safety of the main GC equipment arrangement is confirmed by strength and deformation calculations.

Fig. 1. The upgraded BelAZ-75131 dump truck using gas-diesel cycle.

2.2 Operation monitoring of BelAZ-75131 mining dump trucks using gas-diesel mixture and diesel fuel

Observations for gas-diesel and diesel mining trucks operation indicators were carried out in the period from January to June in 2018 at open cast «Razrez Yuzhnyi». Figure 2 shows a report example of data received via GPS navigation systems.

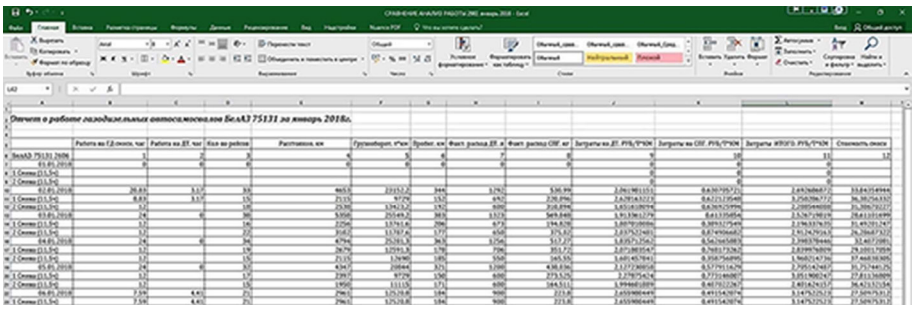

Fig. 2. A report example of BelAZ-75131 mining dump truck operation indicators.

Figure 2 shows that during gas-diesel and diesel mining dump trucks operation monitoring, the main trucks operation indicators were established: operational kilometres, cargo turnover, using gas-diesel mixture and diesel fuel, consumption of gas-diesel mixture and diesel fuel, cost and expenditures. Loading, unloading, rock mass transportation time and the mining trucks speed are recorded in other reports.

When exploded rock mass is transported by gas-diesel mining trucks in certain areas, diesel fuel is replaced by natural gas. Figure 3 shows the calculation results of natural gas (NG) amount per 1 km of operational kilometres to 1 litre of diesel fuel (DF).

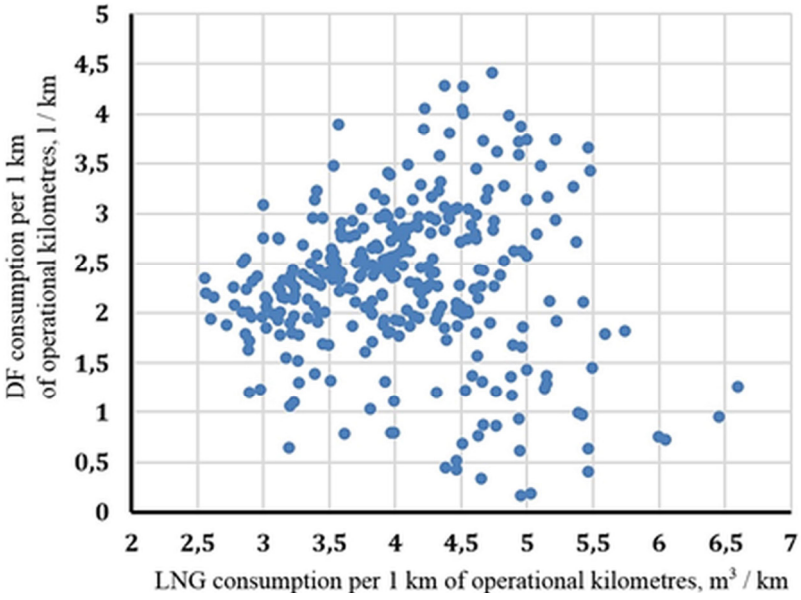

Fig. 3. The consumption of natural gas per 1 km of operational kilometres to one litre of diesel fuel.

Figure 3 shows that the consumption of natural gas does not depend on the consumption of diesel fuel. However, when diesel consumption is within 3-4.5 litres per 1 km of operational kilometres, it is highly likely that natural gas will be consumed within 2-3 m^3 per 1 km of the route, as there is the densest concentration of points in this area (see Fig. 3).

To analyse the efficiency of gas-diesel mining dump trucks in comparison with diesel vehicles, the BelAZ-75131 was monitored under identical conditions. The following parameters were taken into account: the location of the excavator in the face, the transportation distance, speed, operation period and cargo turnover. It has been established that under the same operation conditions, the diesel fuel consumption of mining dump trucks with and without gas cylinder equipment varies significantly (Fig. 4).

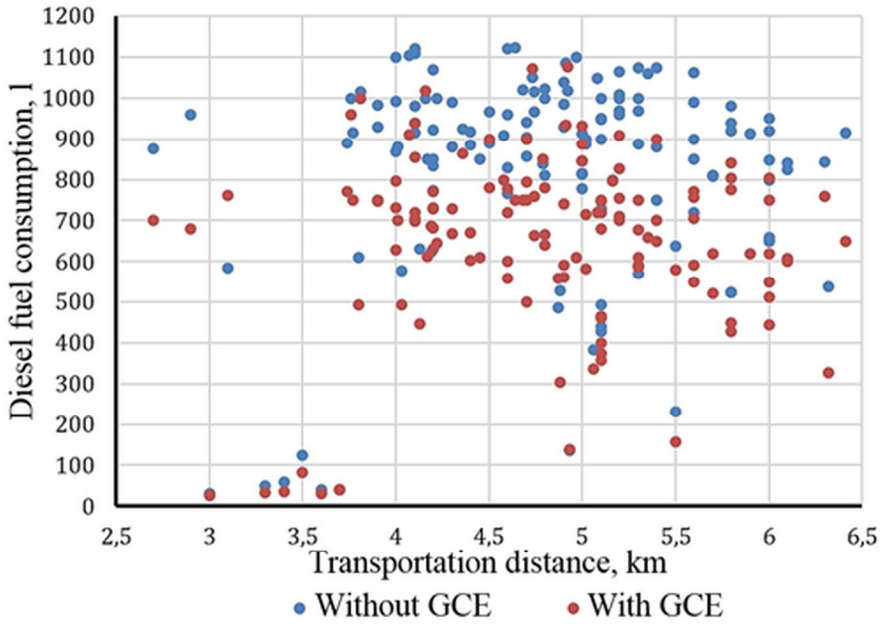

Fig. 4. Diesel fuel consumption by quarry dump trucks with and without gas cylinder equipment translation.

Figure 4 takes into account the fact that one of the main factors affecting diesel consumption and productivity is the transportation distance. For each value of distance in kilometres, a selection of diesel fuel consumption values for gas-diesel and diesel mining trucks was made.

To get more accurate analysis of the obtained results, a graphics of the ratio of diesel fuel consumption of mining trucks per 1 km of transportation distance was constructed (Fig. 5).

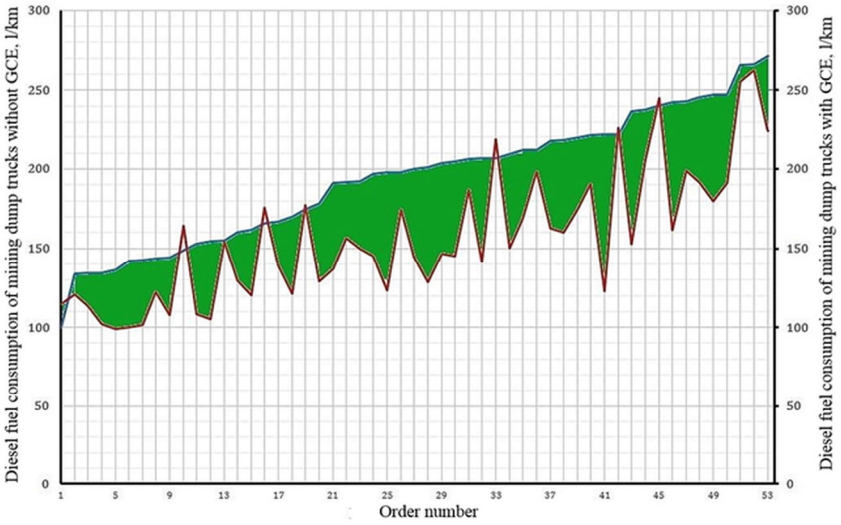

Fig. 5. The ratio of diesel fuel consumption of mining dump trucks with gas cylinder equipment and without it for 1 km of operational kilometres.

The values of diesel fuel consumption by mining dump trucks without gas cylinder equipment were ranked in increasing order. They corresponded to data for vehicles with gas cylinder equipment according to the results of operational monitoring.

The upper blue line is constructed according to data for mining dump trucks without gas cylinder equipment, the lower red abrupt line is constructed according to data for mining dump trucks with gas cylinder equipment. The green area represents the percentage of diesel fuel replacing with natural gas. According to calculations, 20-40% of diesel fuel is replaced by natural gas.

2.3 Energy intensity of the transportation process by mining dump trucks with gas cylinder equipment

A universal indicator of the heavy mining dump trucks operation is the energy intensity of exploded rock mass transportation. In previous studies, the unit of energy intensity measurement was cost per unit of energy (CUE). Taking into account the fact that BelAZ-75131 unified mining dump trucks use both natural gas and diesel fuel, CUE will be calculated as follows:

$$P_f = R\left(P_f^{DF} + P_f^{NG}\right), \tag{1}$$

где P_f^{DF} – is cost per unit of energy for transportation of 1 ton of rock mass per 1 m with diesel fuel, g.s.f./t·m (gram of standard fuel/t·m); P_f^{NG} – is cost per unit of energy for transportation of 1 ton of rock mass per 1 m with natural gas, g.c.e./t·m (gram of standard fuel /t·m); R – is the distances ratio that a mining truck drove using gaseous and diesel fuels.

In this case, the cost per unit of energy for diesel fuel is calculated by the formula

$$P_f^{DF} = \frac{g}{i} k_{proc} k_{ex} k_{sf}, \tag{2}$$

где g – is the specific diesel fuel consumption of a mining truck, g / t·m; i – average weighted slope of the route, ‰; k_{proc} – is the processing coefficient, taking into account the energy costs of obtaining diesel fuel from oil (k_{proc} = 1.18 ÷ 1.20); k_{ex} – is the coefficient taking into account energy costs for the extraction and transportation of fuel (k_{ex} = 1.04 ÷ 1.10); k_{sf} – is the coefficient taking into account the difference in the specific heat of combustion of diesel and standard fuel (k_{sf} = 1.5).

The specific diesel fuel consumption of a mining truck was calculated from the formula:

$$g = \frac{Q}{ml}, \tag{3}$$

where Q – is diesel fuel consumption, g; m – is cargo mass, t; l – is transportation distance, m.

In the case of mining truck using natural gas, cost per unit of energy is calculated as:

$$P_f^{NG} = \frac{g'}{i} k'_{proc} k'_{ex} k'_{sf}, \tag{4}$$

где g' – is NG specific consumption of a dump truck, g/t·m; k'_{proc} – is processing factor taking into account the energy costs of obtaining and liquefying natural gas (k'_{proc} = 1,2÷1,4); k'_{ex} – is the coefficient taking into account energy costs for the extraction

and transportation of NG (k'_{ex} = 1÷1,3); k'_{sf} – is the coefficient taking into account the difference in the specific heat of combustion of gaseous and standard fuel (k'_{sf} = 1,2).

The specific consumption of natural gas is calculated similarly by the formula (3).

The coefficients are substituted in the formula (1)

$$P_f = R\left(\frac{Q}{iml}\times 1.2\times 1.1\times 1.5 + \frac{Q'}{iml}\times 1.4\times 1.3\times 1.2\right);$$

$$P_f = \frac{1.98R}{iml}\left(Q + 1.1Q'\right). \quad (5)$$

Formula (5) is obtained under the condition that the transportation distances when using diesel and gaseous fuels will be the same, which is almost impossible to do in a production environment. In this regard, the costs per unit of energy of dump trucks with gas equipment will be calculated:

$$P_f = \frac{1.98R}{im}\left(\frac{Q}{l} + \frac{1.1Q'}{l'}\right), \quad (6)$$

where l – is the distance the mining truck drove using diesel fuel; l' - is the distance the mining truck drove using natural gas.

2.4 Results analysis

Using the methods and means of statistics, the data processing obtained during the monitoring of the operation of diesel and gas-diesel mining dump trucks of the BelAZ-75131 model was carried out. Processing results examples are presented in Table 1.

Table 1. The result examples of statistical processing of monitoring data.

No	Distance, km	Cargo weight, t	Average weighted slope, ‰	CUE without gas cylinder equipment, g.s.f./t·m	CUE with gas cylinder equipment, g.s.f./t·m
1	3.74	132	75	48.326	41.889
2	3.76	132	75	54.00	51.948
3	3.77	132	75	49.29	40.476
4	3.8	130	77	32.557	26.342
5	3.81	130	77	54.1	53.402
6	3.9	130	78	49.832	39.049
7	4	134	82	45.867	33.424

According to obtained results, the radar chart which displays the energy efficiency of gas-diesel mining trucks was constructed (Fig. 6).

The radius of the radar chart is the axis of the cost per unit of energy values for BelAZ-75131 mining dump trucks: the blue area is diesel dump trucks (without gas equipment); the red area is the diesel mining trucks (with natural gas equipment). The axis corresponding to the ordinal values of the cost per unit of energy is located over the length of the cir-

cle. The operation of mining trucks in identical conditions was taken into account for calculations and construction.

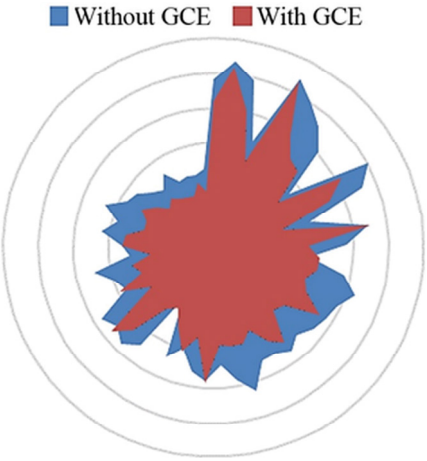

Fig. 6. Distribution of cost per unit of energy by BelAZ-75131 mining dump trucks during operation.

Figure 6 shows that the distribution area of cost per unit of energy during transportation of rock mass by dump trucks with GCE is much smaller than for dump trucks without GCE. Therefore, according to the energy criterion for operation evaluation, it is more efficient to use mining dump trucks using gas-diesel mixture.

3 Conclusion

The operation of mining trucks at great depths is a laborious and costly process. The usage of gas-diesel mixture as a combined alternative fuel for the operation of mining trucks seems to be a promising solution, both from energy and economic point of view. At the same time, the specific energy consumption for transportation of exploded rock mass by BelAZ-75131 mining dump trucks with gas cylinder equipment is 15–25% lower than with classic diesel engines.

The installation of gas-cylinder equipment for the partial replacement of diesel fuel will allow both reducing fuel and economic costs during the operation of mining trucks and resolving issues related to a significant reduction of harmful emissions into the environment, that will ultimately have a positive impact on the environment.

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