Structure of energy consumption and improving open-pit dump truck efficiency

V Yu Koptev and A V Kopteva

Saint-Petersburg Mining University, 21-st line, Saint-Petersburg, 199106, Russian Federation

E-mail: Alexandrakopteva@gmail.com

Abstract. This paper studies the dynamics of the improvement of wheel type transport vehicles environmental and energy performance in open-pit mines. The paper discloses characteristics of the gas turbine engine with capacity of 1250 hp, mounted on tanks, and technical-economic calculations, confirming reasonability of their use in open-pit dump trucks with the 120 … 130-ton loading capacity. The general layout scheme of mechanical transmission with the gas turbine engine is shown.

1. Introduction

The mining industry provides more than 80% of material and energy resources necessary for mankind. The total volume of mineral and fuel resources, together with stripping soils and construction materials, produced in Russia, makes tens of billions of tons per year. Tens of thousands units of diesel-powered equipment, consuming many millions of tons of diesel fuel per year, are required for its transportation. Diesel vehicles produce 95 … 96% of environmental contamination with harmful exhaust gases emissions. The nature of the North is the most sensitive to such impact. In the pits of the CIS countries, about 60% of the rock mass is transported by dump trucks with the 30 … 220-ton loading capacity.

In order to make accounting of the modern mining enterprise transport system efficiency more objective, it is necessary to take into account the environmental and energy performance, as a whole. To this end, innovative conceptual models are required to improve transport vehicles design and to reduce the level of contamination while their operating [1].

2. Materials and methods

The Mining University carried out complex studies to improve the environmental and energy performance of the open-pit motor-vehicle transport [2, 3], proposed and tested methods to reduce the gas concentration of pits, developed a methodology of forecasting the volume of harmful emissions depending on mining conditions and models of used dump trucks [4]. Figure 1 illustrates the transport system energy consumption structure.

The design factor is determined by the perfection of components and assemblies that convert fuel combustion thermal energy into a mechanical one. The coefficient of efficiency, the value that determines the transportation energy consumption, is used for the energy characteristics assessment.
This approach is acceptable during the expert evaluation of certain components and assemblies perfection of wheel type machines. In such case, the value of the transmission efficiency as a whole is not a constant value due to losses at pitch points. This phenomena is the result of the following:

• periodic teeth sliding, related to each other;
• losses in the bearings of shafts;
• losses from oil shaking in crankcase of gearboxes;
• hydraulic losses in the torque converter;
• losses in friction control elements (brakes or sleeves) depend on toothed wheels speed and on the transmitted torque.

Consequently, the efficiency value is different for each load mode.

Studies revealed that less than 32% of the total energy, obtained due to chemical reaction of diesel fuel oxidation in engine cylinders, is used for effective work performance (this is even without taking into account the vehicle's own weight with a coefficient within the range of 0.4 ÷ 0.5). The rest of the energy is spent on overcoming the dissipative forces, forming a huge potential for improving the energy performance. Increasing the efficiency of the diesel engine from 0.38 to 0.45 helps to improve the efficiency of the machine from 0.32 to 0.38 (depending on the type of transmission). Consequently, (and this is confirmed by numerous studies) improving fuel efficiency has huge potential.

![Figure 1. The transport system energy consumption structure](image)

According to experts, up to 20 ... 25% of fuel consumption is spent on tire rolling.

Calculations show, that taking into account the rest part of the energy losses on transportation, the rear axle tires of the truck take 60-65% of expenses, while the front axle tires take only 35 ÷ 40%. When moving a trailer by the truck, 60% falls on its wheels, 25% - on the rear axle tires of the truck, and only 15% falls on the front axle tires. Energy consumption for losses during tire rolling depends on the design and materials of tires, road conditions, the load and speed mode, qualification of drivers.

One of the ways to improve fuel-saving, which can be referred to a design factor, is a reduction of the vehicle's own weight without reducing the capacity of its diesel engine via the use of lighter materials and alloys, not worse in durability and resource parameters. Averagely, open-pit dump trucks self-weight ratio makes 0.6 ÷ 0.8.

The second important characteristics of the design factor are resource parameters of components and assemblies, as they directly determine the stability of the energy losses from working hours. Statistical data in this case gives a significant error, because the maintenance and repair of units takes place with departing from the requirements of the manufacturers due to lack of spare parts, needed repair and adjustment equipment, insufficient qualification of service personnel. Therefore, in order to assess the impact of working hours on the energy characteristics, an expert method, allowing detection of changes in efficiency depending on working hours (Table. 1) and applicable maintenance and repair system, was used. The results obtained confirm that working hours affect the energy parameters of the open-pit dump trucks power module (ICE, generator, traction engines).
Table 1. Reducing the power unit working hours efficiency

| Engine | Generator and traction engine |
|--------|-----------------------------|
| Working hours, thous. km | Efficiency reduction, % | Working hours, thous. km | Efficiency reduction |
| 0.0 -60.0 | 100 | 0.0-40.0 | 100 |
| 70.0-100.0 | 80 | 50.0-70.0 | 90 |

3. Results and discussion

The amount of diesel exhaust gases, with other conditions being equal, is proportional to the amount of fuel used. Consequently, optimizing the operating cycle on energy criterion, there is an impact on the amount of exhaust gases emissions. Improving environmental performance is a way to find a compromise due to the presence of a direct correlation between fuel-saving and harmful emissions: the better fuel-saving corresponds to a higher level of NO\textsubscript{x} emissions; any impact on diesel engine workflow, resulting in an increase of fuel-saving, as a rule, leads to an increase of NO\textsubscript{x} emissions, and vice versa.

But with the increase of NO\textsubscript{x} emissions, there is a decrease of soot emissions. To this end, when searching for the optimal design and technological solutions, one should evaluate the toxicity of diesel via the integral index, taking into account the whole range of emissions and their negative impact on humankind and the environment.

The main ways to create environmentally friendly diesel [5,6] are:

- providing low-toxic workflow by changing the geometry of the combustion chamber and other design solutions, the introduction of the multi-fuel process (water-fuel emulsions, gas-condensate mixture, etc.);
- exhaust gases purification using ceramic filters;
- changing the moment of fuel injection depending on the load mode by implementing the high-pressure fuel pump control via signals obtained from the appropriate sensors of the microprocessor;
- use of alternative fuels;
- providing exhaust gases recirculation, depending on the load mode.

One of the ways to implement modernization of diesel engines to reduce harmful NO\textsubscript{x} emissions is to convert them into low-toxicity modifications designed to operate on alternative fuels, the most promising of which is methane, liquefied natural gas (LNG). Creating a dual-fuel engines (gas diesel engines) or gas engines on a design basis of diesel engines is nowadays actively and successfully implemented by the industry.

In diesel engines, only partial replacement of diesel fuel to liquefied gas is possible. Generally, the following ratio is used in the mixture: while partial throttling - 70% of liquefied gas and 30% of diesel fuel, while fully throttling - 25% of LNG and 75% of diesel fuel. Installing a modified gas engine in large vehicles is available and much cheaper than buying a new engine of the same power capacity. When using LNG, technical efficiency of the engine decreases (due to less compression rate of the mixture), but mechanical efficiency increases due to reduced force of friction [7].

Even though LNG advantages [8], as diesel engines fuel, namely, a significant improvement of the ecological situation in the area of equipment maintenance and diesel fuel-saving (LNG almost twice cheaper than diesel fuel) are obvious and acknowledged by those skilled in the art, practical implementation of converting heavy transport equipment in industry to LNG goes extremely slow.

The main reason is that gas fuel becomes more combustible. Minor leaks of fuel in such machines may result in something serious. Therefore, open-pit dump trucks with electrical transmissions were
not even tested for this, as there would be a risk of explosion due to leaks and gas accumulations in cabinets and other places, where operating engine may spark the air. There is also a risk of polluting the ambient air in a pit with products that are heavier than the air (butane, propane, ethane, pentane etc.), which are always present in natural gas and tend to accumulate on lower layers in a pit. Deep cleaning of gas from those fractions may solve the problem, but the fuel would become more expensive. Another problem is how to place the tank with gas at a diesel vehicle. Also, a dump truck takes 20% less load with a smaller platform.

4. Conclusion
In general, using gas fuel in open-pit dump trucks requires solving many problems, and may be possible with reliably tested equipment, established service with qualified personnel and safety guidelines followed. In particular, open flame engine warm-up before starting the engine would be prohibited. There must be a stationary warm water or warm air warming system, which performs worse. Welding, cutting with fire, brazing and other open flame works would be banned on open-pit dump trucks with gas tanks installed. All those additional precautions in connection with using gas at open-pit dump trucks make the usage of such vehicles too costly, thus even testing might be carried out only after full evaluation of the need for such measures. Liquefied natural gas is economically reasonable.

At the moment, because military plants are no longer fully loaded with orders, but have hi-tech products ready, it is worth discussing whether it is a good idea to use tank gas turbine engines in open-pit dump trucks. For example, Kaluzhski Engine OSJC produces gas turbine engines GTE-1250, 1250 hp (920 kW) for the Ministry of Defense of the Russian Federation.

Using gas turbine engines GTE-1250 with the mechanical gearbox on BelAZ open-pit dump trucks with the 100…130-ton loading capacity would give substantial effect due to:

• a more than 4-time decrease in gas turbine engines GTE-1250 weight and the weight of its system (engine, air cleaning system, engine cooling system, starter, generator, prestart engine, compressor etc.);
• the possibility of fast startup under any temperature without preliminary warming up;
• improving the technical readiness factor due to improved startup features of gas turbine engines (preparation time below zero is 7…10 times shorter) resulting in better performance.

The open-pit pollution level with open-pit dump truck exhaust gases is lower, when gas turbine engines are used (table 2).

Table 2. Comparison of emissions in exhaust gases of diesel and gas turbine engines, g / kWh (g / hp h)

| Emission parameters | Diesel engine | The gas-turbine engine with a capacity of 1250 hp. |
|---------------------|---------------|-----------------------------------------------|
| Carbon monoxide (CO) | 9.5 (7.0)     | 0.101…0.826 (0.074…0.6)                       |
| Hydrocarbons (CH)    | 3.4 (2.5)     | 0.124…1.02 (0.091…0.75)                       |
| Nitric oxide (NOₓ)   | 18.35 (13.5)  | 1.59…4.24 (1.17…3.11)                         |

References
[1] Radkevich J M, Belyankina O V 2006 Mining informational and analytical bulletin (scientific
and technical J.) 2 262-268
[2] Koptev V Y and Kopteva A V 2016 Mining business transportation system structure optimization *International Journal of Applied Engineering Research* **11** 7402-7405
[3] Kuleshov A A 2003 Economic evaluation of the impact of environmental factors when choosing the best type of loading and transportation vehicle complex *Week of the miner* **12** 152-154
[4] Koptev V Yu 2017 *IOP Conf. Series: Mater. Sci. Eng.* **177** 012005
[5] Cheremushkina M S and Poddubniy D A 2017 *IOP Conf. Series: Earth and Environmental Science* **50** 012043
[6] Keerthika R and Jagadeeswari M 2015 Coal Conveyor Belt Fault Detection and Control in Thermal power plant using PLC and SCADA *Int. J. of Advanced Research in Computer Engineering & Technology* **4** 1649-1652
[7] Abramovich B N, Sychev Yu A, Medvedev A V 2010 *Oil Industry* **4** 112-114
[8] Abramovich B N, Ustinov D A, Sychev Y A and Shkljarcki A Ya 2014 *Oil Industry* **8** 110-112
[9] Cheremushkina M S and Baburin S V 2017 *IOP Conf. Series: Materials Science and Engineering* **177** 012060