The Use of Alternative Fuel for Heavy-Duty Dump Trucks as a Way to Reduce the Anthropogenic Impact on the Environment

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Abstract. The state-of-the-art of relevance and prospects of using alternative fuels for heavy-duty dump trucks as an effective way to reduce the anthropologic impact on the environment is considered. The analysis of the combination of factors (economic, technological, engineering, safety) determining the possibility and prospects of using alternative fuels in the operation of heavy-duty dump trucks in mining industry is carried out. The data are presented on the available experience of using environmentally friendly (alternative) fuels for heavy-duty dump trucks: electric energy, liquefied petroleum gas (LPG), compressed natural gas (CNG), liquefied natural gas (LNG). The studies conducted show that liquefied natural gas (LNG), for a number of objective reasons, seems to be the most promising alternative to diesel of all possible fuels in the segment of heavy-duty haulage vehicles. It is said that in Russia, in the Kemerovo region, for the first time, within the framework of one group of companies, an integrated project for the production of liquefied natural gas and its consumption by BelAZ heavy-duty dump trucks was successfully implemented.

1. Introduction

The global demand for solid minerals is increasing annually. For example, only the program for the development of Russian coal industry envisages an increase in coal production up to 500 million tons per year by 2030. This will lead to a significant increase in the number of mining equipment used by mining companies [1].

Heavy-duty dump trucks with diesel internal combustion engines are used for rock mass hauling. Thus, billions of liters of diesel fuel are consumed annually; 70-80% of the total fuel being consumed by loaded dump trucks uphill at a relatively low speed. This leads to a significant emission of harmful (toxic) substances into the atmosphere: carbon oxides, nitrogen, hydrocarbon, aldehydes, lead, soot, sulfur oxides. According to Parker Bay, the number of mining dump trucks in use in the world in 2014 increased from 38.5 to 43.0 thousand units. Only the Belarusian Automobile Plant (OJSC BELAZ) annually produces an average of about 800 dump trucks. In January and February of 2018, 40 units of dump trucks were supplied to the Russian market more than in 2017 over the same period [2-4].

When operating heavy-duty dump trucks, the main way to reduce the amount of harmful emissions into the atmosphere, and, as a result, to reduce the anthropogenic impact on the environment, is to use alternative (more environmentally friendly) fuels. Based on the available world experience in the use
of alternative fuels for transport, the use of the following energy sources can be considered the most rational [5-16]:

- electrical energy (power supply);
- liquefied petroleum gas (LPG);
- compressed natural gas (CNG);
- liquefied natural gas (LNG).

The purpose of this study is to analyze the prospects for the use of alternative fuels in the operation of heavy-duty dump trucks, as a way to the anthropogenic impact on the environment.

2. Results and discussion
As noted earlier, alternative energy sources have a significant advantage - a higher level of environmental safety over diesel fuel. Also, the factors determining the feasibility and expediency of using this or that alternative fuel in mining vehicles include the following ones: economic, technological, engineering, as well as safety of use [17].

The main advantage of alternative energy sources over diesel fuel and gasoline is its higher level of environmental safety. Electric energy can be considered as the energy source that has a minimal anthropogenic impact on the environment and has found its application in heavy-duty dump trucks. However, the aggregate consideration of the factors of using alternative energy sources, as applied to mining dump trucks, does not allow perceiving electric energy as the only solution.

At present, in the world practice there is experience in the use of trolley and diesel-trolley (to a greater extent) dump trucks (Fig. 1, a), as well as commercial prototypes of dump trucks with combined power plants (Fig. 1, b), electric vehicles (powered by batteries) (Fig. 1, c) [18].

![Figure 1](attachment:image.png)

**Figure 1.** Dump trucks using electric energy as fuel:

a - Caterpillar 795F diesel-trolley truck; b - GE dump truck with a hybrid diesel-battery electromechanical power plant; c - BYD V60 electric dump truck (China).

Despite all the advantages, electrified dump trucks have not been widely used in mining industry. The main reasons hindering the widespread introduction of diesel-trolley trucks are engineering and technological difficulties associated with the need to create and maintain an extensive contact network that requires capital investments; with ensuring reliable communication between a dump truck and the supply network; with limited maneuverability of dump trucks; with the remoteness of the wires of the contact network from the place of loading and unloading of a trolley truck; with the distance of 300-
600 m between the contact network and the place of explosions; with the availability of a stationary dumping point in the technological cycle of rock mass haulage, etc. [19].

To date, gas is most widely used in operation of vehicles. When it is used as a motor fuel, the volume of toxic emissions into the atmosphere is reduced by 2-3 times (emissions of nitrogen oxides are reduced by 2.5 times, carbon monoxide by 10 times, hydrocarbons by 3 times, emissions of lead, sulfur and soot compounds are minimized, engine noise is reduced by 3-5 dB (A) [3, 20].

One of the gaseous motor fuels is liquefied petroleum gases (LPG). The high antiknock properties of LPG compared to diesel fuel reduce specific fuel consumption, which reduces the amount of harmful emissions into the environment. The advantages of using LPG are its low cost in comparison with diesel fuel, as well as the most complete combustion, which has a positive effect on reducing the amount of harmful emissions. The main components of LPG are propane, butane, or a mixture thereof. These components are explosive and fire hazard. They are heavier than air, can accumulate in natural and artificial depressions and create an explosion hazard. For this reason, the use of LPG as a motor fuel in heavy-duty dump trucks is problematic and dangerous.

Compressed natural gas (CNG) is of more considerable current use as motor fuel than LPG. The bulk of CNG is methane (CH\textsubscript{4}) - from 70 to 98%. Methane is lighter than air, so the use of CNG in open pits is safe, because in the event of an accidental release it quickly evaporates. Methane is the safest of all motor fuels, the temperature of spontaneous combustion of diesel fuel and gasoline is 250-300°C, propane-butane - 450°C, and methane - 550°C [20]. The greenhouse effect caused by its combustion products is less compared to petroleum fuels. CNG does not contain harmful impurities (lead, sulfur), is not toxic in low concentrations and does not leave soot that worsens the environment.

Despite all the advantages of CNG, there are a number of often insurmountable technical difficulties in its use. These difficulties are associated with the difficulty, and sometimes even the impossibility, of placing a sufficient number of gas cylinders to provide the necessary fuel supply for dump trucks for their operation during one shift. In addition, at low ambient temperatures, hydrates can form on the structures of gas distribution columns of gas stations, causing a decrease in CNG pressure [21].

The attempts to equip dump trucks with gas cylinder equipment and their operation on CNG are known. So, in 2013, at one of the motor transport enterprises of the Kemerovo region (Russia), five BelAZ 7555 light-duty dump trucks (Fig. 2) were converted to gas-diesel operation using CNG. However, they worked for about a year and the implementation of this project did not bring a positive result.

![Figure 2. CNG gas-diesel fuelled BelAZ 7555 dump truck: a - BelAZ 7555 dump truck appearance; b - gas cylinders placed on the body of BelAZ 7555 dump truck.](image)

Due to the development of technology in recent years, liquefied natural gas (LNG) has become increasingly popular as a motor fuel. LNG is a non-toxic odorless and colorless liquid. LNG, used as a motor fuel, consists of 90-92% methane, and the remaining 8-10% includes ethane, propane, butane,
and nitrogen. During LNG production, it is purified from sulfur dioxide, carbon dioxide. In open space, at normal temperature, LNG vapors and mixes quickly with air, which has a positive effect on safety when used in open pits.

One of the main advantages of using LNG as a motor fuel for heavy-duty dump trucks is its low cost. LNG does not burn, does not ignite or explode. When it is liquefied, it decreases in volume up to 600 times, which makes it possible to use it as motor fuel in heavy-duty dump trucks more efficiently compared to other types of gas fuel (the necessary fuel supply is provided on board, which allows its operation during one shift without refueling).

Today, the key problem in large-scale use of LNG in transport is the poor development of the infrastructure of its production, transportation and gas stations in Russia. However, it should be noted that at present, the group of companies “Sibir-Energy” LLC and “Tekhno-Eco” LLC (Russia) have implemented the first successful integrated project to create the infrastructure for the LNG production and consumption in relation to coal mining industry (Fig. 3).

During the implementation of the project, the natural gas liquefaction plant was commissioned in 2017 (Fig. 3, a). The fuelling infrastructure has been created, including mobile cryogenic refueling trucks (Fig. 3, b) and refueling areas (Fig. 3, c). With scientific and engineering support of scientists of T.F. Gorbachev Kuzbass State Technical University, the technical project was developed to convert BelAZ 75131 dump trucks (with a lifting capacity of 130 tons) to gas-diesel operation. This technical project has been approved by the BelAZ dump truck manufacturer. As part of the project, several modifications of onboard cryogenic fuel systems for BelAZ 75131 heavy-duty dump trucks were developed and carried out. As of August 2019, 58 BelAZ 75131 dump trucks were equipped with onboard cryogenic fuel systems and were successfully operated (Fig. 3, d) [22, 23].

Figure 3. LNG production and consumption infrastructure:
a - natural gas liquefaction plant; b - mobile cryogenic refueling trucks; c - refueling areas; d - BelAZ 75131 heavy-duty dump truck equipped with an onboard cryogenic fuel system.
3. Conclusion
Given the scale of the use of heavy-duty dump trucks in the mining industry of Russia, there is an urgent need for the use of alternative fuels as one of the ways to reduce the industrial impact on the environment. The analysis showed that, according to the assessment of the aggregate number of factors, LNG represents the greatest prospect of all possible alternative fuels for heavy-duty dump trucks. The project implemented in the Kemerovo region and including a full cycle from LNG production to its consumption within the same group of companies can be considered as the only project of the use of LNG as a motor fuel in heavy-duty dump trucks successfully implemented in Russia. Today, the lack of sufficient technically and scientifically substantiated solutions, as well as methodologies for assessing technical and economic indicators when using alternative fuels for heavy-duty dump trucks, hinder the development and implementation of such projects. Therefore, studies aimed at substantiating the use of alternative fuels for heavy-duty dump trucks, as a way to reduce the environmental impacts, in conjunction with economic, technological and engineering factors, are relevant.

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