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CONVERTING OF QUARRY TIPPER TRUCKS TO GAS UNDER THE NORTH CONDITIONS

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ПЕРЕВОД КАРЬЕРНЫХ САМОСВАЛОВ НА ГАЗ В УСЛОВИЯХ СЕВЕРА

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The use of alternative types of motor fuel contributes to the improvement of the economic and environmental situation in open-pit mining. An analysis of the development of opencast mining in Russia indicates constant shift to the remote northern territories. In the cost of mining, the share of transport works is 40–50 %, and as the mining operations go far for every 100 m, the cost of transporting the rock mass by dump trucks increases by 20–30 %. With an increase in the depth of the quarry, the natural ventilation of the working area deteriorates, which leads to the accumulation of exhaust gases of diesel engines in the quarry. This affects the health of miners and the economy of the enterprise, as it entails the need to stop the quarry. Currently, the global engine industry is considering the use of natural gas as a motor fuel instead of diesel fuel. The specificity of the northern regions is such that fuel must be delivered a year in advance during the navigation period, which increases its price, while gas fields are located directly in Yakutia. The cost of production of liquid natural gas (LNG) in the regions of its consumption as a motor fuel is much lower than the cost of delivery of diesel fuel.
Production can be organized directly at the gas fields in Western Yakutia. LNG plants are compact and highly reliable. Tests of Cat 789C, Komatsu 830 and 930 mining trucks in gas-diesel mode showed that the efficiency and performance of the gas engine were comparable to the efficiency of a diesel engine. Diesel fuel saving was 80 %, while exhaust emissions were reduced by 25 %, that improve the environmental situation. Converting dump trucks to LNG will reduce the gas pollution of quarries and noise by 2-3 times, increase the efficiency and competitiveness of the enterprise by reducing the costs of fuel, transporting rock mass and environmental fines.

Ключевые слова:
карьерные самосвалы, экология, открытые горные работы, дизельный двигатель, выхлопные газы, дизельное топливо, природный газ.

Улучшению экономической и экологической ситуации при открытых горных работах способствует использование альтернативных видов моторного топлива. Анализ развития открытых горных работ в России свидетельствует о постоянном их смещении на удаленные северные территории. В себестоимости добычи полезного ископаемого доля транспортных работ составляет 40–50 %, и при понижении горных работ на каждые 100 м себестоимость транспортирования горной массы самосвалами возрастает на 20–30 %. С увеличением глубины карьера естественная вентиляция рабочей зоны ухудшается, что приводит к накоплению отработанных газов дизельных двигателей в карьере. Это сказывается на здоровье горнорабочих и на экономике предприятия, так как влечет за собой необходимость остановки карьера. В настоящее время мировое двигателестроение рассматривает использование природного газа как моторного топлива вместо дизельного топлива. Специфика северных районов такова, что топливо надо завозить на год вперед в период навигации, что увеличивает его цену, тогда как газовые месторождения расположены непосредственно в Якутии. Себестоимость производства жидкого природного газа (СПГ) в регионах его потребления в качестве моторного топлива намного ниже, чем расходы на доставку дизельного топлива.
Производство может быть организовано непосредственно на месторождениях газа в Западной Якутии. Установки по производству СПГ компактны и высоконадежны. Испытания карьерных самосвалов Cat 789C, Komatsu 830 и 930 в газодизельном режиме показали, что эффективность и производительность газового двигателя были сопоставимы с эффективностью дизельного двигателя. Экономия дизельного топлива составила 80 %, а объем выбросов отработанных газов сократился на 25 %, обеспечивая при этом улучшение экологической ситуации. Перевод карьерных самосвалов на СПГ позволит в 2–3 раза уменьшить загазованность карьеров и шум, повысить эффективность и конкурентоспособность предприятия за счет снижения затрат на приобретение топлива, транспортировку горной массы и экологические штрафы.

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Introduction

Transport cost is one of the main component of the full cost of the minerals mining and processing. In the cost of mining, the share of transport work can be 40–50 %. The effectiveness of field development largely depends on the transport type used for the rock mass transportation (road, rail, conveyor, hydraulic, etc.), the choice of which is determined by the fields conditions. At present and in the near future, automobile is the main type of technological transport for open-pit mining.

An analysis of the open pit mining development at ore deposits in Russia shows their gradual shift to remote northern areas with an increase in the depth of the quarries to 500–600 m. At the same time, the depth of the quarries is continuously increasing, and with a high intensity of production capacity [1]. Practice shows that for every 100 m lowering of mining operations, the cost of transporting rock mass by tipper trucks increases by 20–30 %.

The movement of mining tipper trucks in deep pits (at a depth of more than 200 m) is carried out along serpentine on steep slopes. Due to the large roads elevation angle, the tipper truck engine is loaded at full capacity at low speed, which leads to an increase in toxic emissions and fuel consumption by 2–3 times. Increased production also contributes to increased energy consumption and diesel engine exhaust emissions from tipper trucks.

As the quarry is lowered, the natural ventilation conditions in the working area deteriorate and exhaust gases accumulate in the quarry. Such polluted air, entering into a working engine, leads to incomplete combustion of fuel and, consequently, to increased motor fuel consumption, and also further degrades the environment, creating a threat to the health of working personnel and having a significant impact on the performance of – due to the pits gas pollution [1–8].

To eliminate equipment and personnel downtime, numerous ways and means of reducing air pollution in the working area were developed and investigated: artificial ventilation of quarries (including the quarry forced ventilation by using end-of-life powerful aviation engines), air purification in stagnant zones by spraying water or generating snow, the use of various means and methods to reduce emissions of exhaust gases [9–11]. But they all do not provide an effective solution of the problem, and the environmental situation in the quarry continues to deteriorate [1, 2, 6–7, 12].

In Siberia and in the Far North, due to the engine starting problems at low temperatures, diesel engines often do not stop during the entire winter period. As a result, the engine resource is developed; there is a significant overconsumption of fuel and, accordingly, an increase in exhaust emissions. Despite the fact that the Russian north is characterized by a low concentration of the vehicle fleet, diesel vehicles produce 95.96 % of environmental pollution by harmful exhaust emissions. The nature of the north is very sensitive to such effects.

The long-term environmental problem of mining developed by the open method has also increased by the high cost of transportation costs, which is also determined by the continuing increase in motor fuels prices. The specificity of the northern regions, including Yakutia, is such that fuel can be brought only during the navigation period, which lasts only five months, so they are forced to deliver fuel a year in advance, which further increases its price.

One of the ways to improve the economic and environmental situation in open pit mining is the use of alternative motor fuels. Natural gas is currently recognized as the only economically viable alternative fuel, which can be used as motor fuel without any processing [13–22].

Gas engine fuel in the world

Currently, the global engine industry is considering expanding the use of natural gas as a motor fuel. The motor fuel used is liquefied petroleum gas (LPG), liquefied natural gas (LNG), and compressed natural gas (CNG), which is the cheapest of all motor fuel types (Table 1).

Table 1

Compressed natural gas prices in comparison with other types of gas engine fuel [23]

Country	Price, EUR/m^3	CNG price as a percentage of price	
		petrol	diesel
EU	0.83	58.4	60.2
USA	0.46	59.0	61.0
China	0.43	60.0	65.0
Russia	0.27	35.0	38.0

LNG is obtained from natural gas after purification from impurities. The liquefaction process proceeds in steps, at each of which the gas is compressed 5–12 times, then cooled and transferred to the next step. At a temperature of –161.5 °C, the gas turns into a liquid, and its volume decreases 600 times, which is one of the main advantages of this technology. Liquefied gas is transported in special cryogenic tanks – sea tankers or tanks for land transport. This allows LNG to be delivered to areas that are far from gas pipelines and exported to any part of the world [17, 19, 21, 22, 24, 25].

LPG is a mixture of propane and butane fractions produced at oil and gas processing plants as a separate heading. The advantage of liquefied petroleum gas is that it is easily liquefied at ordinary temperature and pressure of 10–15 atmospheres, and for its transportation it is sufficient to have a steel cylinder with a wall thickness of only 4–5 mm. To obtain compressed natural gas, it is necessary to compress methane to a pressure of 200–250 atmospheres. Therefore, when working with CNG, higher safety requirements are required. When it is transported and stored, much stronger cylinders and tanks are required. As a result, they prefer to use safer propane in road, rail and river transport.

For filling vehicles, two different types of gas filling stations are used: for CNG – these are gas filling compressor stations, for LPG and LNG – are automobile gas stations. According to the NGVA, there are now 1.433 LNG stations in the world, the vast majority of which are located in China. The United States ranks second with 46 LNG filling stations (Table 2). The US Energy Information Administration (EIA) predicts the mass usage of gas engine fuel in the country after 2025.

LNG filling stations do not connect to the gas pipeline and do not require compressors, but must have cryogenic storage facilities. Therefore, the construction of such stations is more expensive than for CNG [16].

Table 2

LNG gas stations in the world [23]

Country	Number of stations	Country	Number of stations
China	1330	Sweden	8
USA	46	Netherlands	7
Europe	43	Canada	2
Great Britain	13	Poland	1
Spain	12	Thailand	1
Estonia	12	Russia	1
Australia	10	Total in the world	1433

In recent years, a system of organizational, financial and technical measures to stimulate the use of gas engine fuel has been created in a number of countries around the world. The global market for liquefied natural gas as a motor fuel is currently actively developing (Fig. 1). The increase in the share of natural gas in the global energy balance is recorded statistically and, moreover, is forecasted by experts in the future.

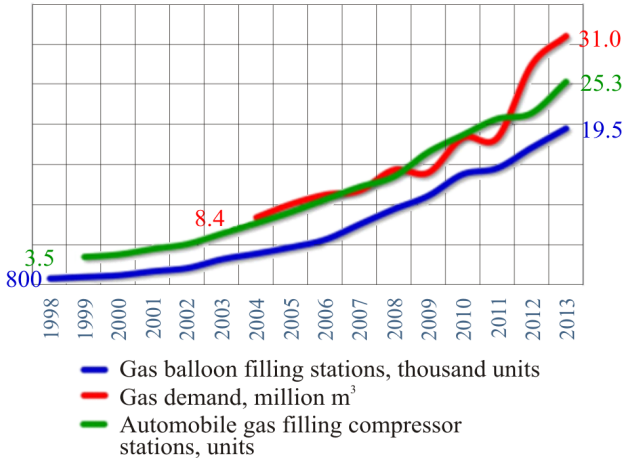

Fig. 1. The global gas fuel market [26]

According to the forecasts of the world energy development of International Energy Agency, IEA, British Petroleum, Institute of Energy Economics of Japan, IEEJ, natural gas consumption in the coming decades will grow at a faster rate than any other type of fuel, especially its fossil fuels. At the same time, the role of LNG in the future world energy balance will increase. Thus, according to the IEEJ forecast, the demand for LNG will increase by more than 2 times by 2040 (from 239 million tons in 2014 to 547 million tons). British Petroleum forecasts a similar development: by 2035, the share of LNG in consumption will increase from 10 % in 2014 to 15 % in 2035 [22].

Gas engine fuel in Russia

Today, Russia is ranked 20th in the world in the transport gasification, which mainly uses CNG and LPG. The number of gas engine cars in Russia is about 150 thousand; by 2020 it will increase more than 2 times and will reach 370 thousand units.

Almost all Russian market of gas engine fuel in the form of LPG accounts for oil producing companies, including PJSC Gazprom Neft, and the CNG market belongs to PJSC Gazprom [13, 15, 18, 20].

Systematic work, including the formation of the regulatory framework, the auto park renewal, the petrol stations and storages network construction and other infrastructure, is just beginning. More than 250 gas filling stations operate in Russia, and their number is steadily increasing (Tab. 3). The construction and commissioning of new gas engine infrastructure facilities for CNG and LNG provided by Gazprom Gas Engine Fuel, which has been granted the status of a single operator for the gas motor fuel market development from PJSC Gazprom.

Table 3

Gas transport and gas filling stations in Russia [23]

Name	Qty
Gas engine transport	
Total transport units	86 012
Percentage of gas engine transport in the world	0.53
Percentage of total vehicle fleet in the country	0.24
Gas stations	
Total pieces	253
Percentage of gas filling stations in the world	1.2

It should be noted that the cost of building gas stations with propane and methane is significantly different and in Russia is about 15 and 85 million rubles respectively.

To date, liquefied natural gas in Russia is most in demand in the trunk freight and rail transport [13, 15, 19, 20]. With the gradual development of the market, gas consumption by 2020 could reach 10.4 billion m^3.

Reducing the cost of motor fuel is possible due to lower gas prices compared with refined products. Russian experience has shown that gas engine fuel is the cheapest type of fuel (Table 4) [13, 15, 19, 20]. According to the National Gas Engine Association, the cost of 1 liter of gasoline is equivalent to 1 cubic meter of gas, which is more than 2 times cheaper than traditional fuel.

Table 4

The average retail price for LPG in Russia regions on 07.16.2018 [27]

Region	LPG average retail price, rub/l (including VAT)	Region	LPG average retail price, rub/l (including VAT)
Republic of Tatarstan	20.28	Volgograd region	22.76
Stavropol region	21.17	Astrakhan region	22.78
Bryansk region	21.87	Oryol Region	23.10
Belgorod region	22.00	Lipetsk region	23.15
Krasnodar region	22.00	Rostov region	23.80
Kursk region	22.00	Republic of Adygea	24.00
Tambov Region	22.47	Orenburg region	24.19

Note: The wholesale price for liquefied gas is 13.582 rub. per kilogram on 06/05/2018.

The savings will be the greater, the higher the cost of diesel fuel, i.e. in the north. For example, in Yakutia, the cost of diesel fuel is 1.2–1.3 times higher than in the central regions of Russia (Table 5).

Table 5

The price of diesel fuel in Russia regions on 18.02.18

Region	Price of diesel fuel, rub/l	Region	Price of diesel fuel, rub/l
The Republic of Ingushetia	30.8	The Republic of Buryatia	41.82
Republic of Tatarstan	37.83	Novosibirsk region	41.84
Stavropol region	38	Irkutsk region	42.62
Smolensk region	38.46	Transbaikal region	42.65
Vladimir region	39.24	Tyva Republic	43.97
Omsk region	40.36	Moscow	44.19
Altai region	40.53	Khabarovsk region	44.23
Altai Republic	40.60	Amur region	44.27
Yamalo-Nenets Autonomous District	41.61	Nenets Autonomous District	45.50
Tomsk region	41.63	The Republic of Sakha (Yakutia)	50.64
The Republic of Khakassia	42.30	Kamchatka Krai	51.04

Currently, Russia has embarked on the introduction of environmentally friendly fuels in the transport complex. It is predicted that by 2030, natural gas will become a key alternative fuel for passenger, cargo, sea and rail transport, in the use of agricultural and mining equipment.

The impetus for the natural gas vehicle (NGV) market development was the Russian Federation Government Decree № 767-r dated 13.05.2013, in accordance with which a comprehensive plan was developed to expand the use of natural gas as a motor fuel. Today, these documents are the backbone for the NGV industry. Their adoption has given impetus to NGV fuel market development in most of the Russian Federation [29].

Use of LNG on vehicles

When converting diesel cars to natural gas, two engine operating modes are used: gas-diesel and gas. A wider practical application has received the use of gas-diesel mode.

In this case, diesel fuel is not completely replaced by liquefied gas. With partial throttling, a mixture of 70 % of liquefied gas and 30 % of diesel fuel is used, and with full throttling, 25 % of liquefied gas and 75 % of diesel fuel [21, 30–34].

Gas diesel mode is advisable to use on trucks that are in operation, because this requires minimal changes of the engine fuel system and the creation of onboard gas reserves. After the modernization, the tipper truck can operate on both diesel and gas-diesel mode.

The converting of mining trucks to a purely gas mode is advisable to produce during the planned engine overhaul, as well as when installing new engines to replace the failed ones. Installing a modified gas engine on mining trucks is available and much cheaper than buying a new engine of the same power. When a mining truck operates on a purely gas

mode, there is no diesel fuel consumption, therefore, instead of a diesel tank, a cryogenic tank is installed, and the cylinder head is equipped with spark plugs [24, 30, 32–34].

Natural gas as a motor fuel has the following advantages. [1, 13, 15, 19, 21, 30–37]:

- the cost of gas is significantly lower than the equivalent in calorific value petroleum motor fuel;
- the engine converting to natural gas does not require a substantial constructive alteration of the engine itself, except for equipping the engine with gas fuel equipment;
- engine power is almost unchanged;
- 1.5 times longer engine life;
- reduced fuel consumption by 20–30 %;
- reduced transportation and maintenance costs;
- the amount of toxic emissions decreases by 2–3 times (emissions of nitrogen oxides are reduced by 2.5 times, carbon oxide – by 10 times, hydrocarbons – by 3 times, emissions of lead compounds, sulfur and soot are completely excluded);
- reduced by 3–5 dB (A) engine noise;
- methane self-ignition temperature is 550 °C, propane-butane – 450 °C, and diesel and gasoline – 250–300 ° C.

Abroad, there is a clear trend towards the use of LNG in motor vehicles. Liquefied natural gas is used in urban and intercity diesel vehicles in France, Great Britain, the Netherlands, Germany, Japan, and the USA. Recent studies conducted by Ford, MAN, Saviem, Toyo Menka, and others have shown the technical and economic feasibility of widespread use of LNG in motor vehicles [21, 24, 25, 36].

In Europe, Volvo Trucks represents gas trucks that comply with the Euro-6 standard. They are comparable to diesel trucks in terms of performance and fuel efficiency, but at the same time they have much less of a detrimental effect on the environment. The new Volvo FH LNG and Volvo FM LNG trucks are equipped with gas engines that run on LNG in a Diesel cycle. The Volvo gas engine with a power of 460 hp has a torque of 2300 N·m, and for a version with a capacity of 420 hp, the torque is 2100 N·m. Similar Volvo diesel engines have the same characteristics. Moreover, the fuel consumption of these engines is comparable with Volvo diesel engines and is 15–25 % lower than that of traditional gas, and the level of CO_2 emissions is 20 % less compared to diesel fuel [37].

In many countries, converting of off-road equipment to LNG is actively carried out. For example, 240 000 NGV travel across China, 5000 in the United States and 1500 in Europe [25, 36–42].

Mining tipper truck HOWO produced by the Chinese Sinotruk runs on LNG. The test results showed a twofold saving in fuel equivalent. A similar diesel tipper truck consumes about 200 liters of diesel fuel per shift, and a gas truck consumes about 280 liters of liquefied natural gas. Even with a single-shift mode of operation, the annual savings amount to more than a million rubles. LNG makes it possible to provide a large power reserve at one gas filling using containers of traditional shape and size, comparable to fuel tanks for diesel fuel. Due to the increase in the use of LNG as fuel for heavy-duty and mining trucks in China (approximately 4.6 billion cubic meters of natural gas in 2015), diesel fuel savings amounted to 16 million tons. As a result, this led to a reduction in exhaust gas emissions of 6 million tons of CO_2 equivalent [38, 39, 41, 42]. SHACMAN introduced the new F3000 series tractor and off-road mining truck on LNG. According to SHACMAN, mining trucks on LNG save about $ 16 per 100 km compared with the same diesel trucks [43].

In Russia, creating and converting powerful tipper trucks to LNG is also

underway. At the international industrial exhibition INNOPROM-2017 (Yekaterinburg), the gas engine mining tipper truck BelAZ-75476 with a lifting capacity of 45 tons was presented. The power unit has a gas turbine supercharging and a power of 550 hp. Liquefied natural gas is used as a fuel; its stock is located in a special cryoback on the frame on the left side (Fig. 2).

Fig. 2. Mining tipper truck BelAZ-75476 on LNG

The curb weight and load capacity of the BelAZ-75476 remained the same as that of the diesel prototype – BelAZ-7547. But the gas tipper truck is 10 % more powerful, more economical and provides low emissions, which is especially important when working in deep quarries.

Over the past few years, giant mining tipper trucks with an engines capacity of 1000–2500 kW and a carrying capacity of 100–350 tons have also been converted to LNG fuel.

The technology of liquefied natural gas using was tested on Caterpillar mining tipper trucks. Testing of the Cat 789C truck in gas-diesel mode in Queensland's Morayfield, USA, showed that the efficiency and performance of the gas engine is comparable to that of a diesel engine. Diesel fuel saving was 80 %, while exhaust emissions were reduced by 25 %, while improving the environmental situation. According to test results, only by reducing fuel costs, it is possible to save US $ 600 000 per year for a truck.

GFS Corp. offers LNG conversion systems for four truck models: Caterpillar 777 and 793, as well as Komatsu 830 and 930. Over tens of thousands of driving hours, Caterpillar and Komatsu tipper trucks at mining plants in the western United States also showed significant savings in fuel costs [40].

American company Arch Coal, Inc. placed an order for GFS Corp (GFS) to convert Komatsu 930E mining dump trucks to EVO-MT™ 9300 NG + D Systems™ gas diesel technology at Campbell, Wyoming, USA. As part of this program, GFS Corp will convert nearly a quarter of the Arch Coal mining equipment, namely Komatsu 930E, for operation on LNG using EVO-MT 9300 System technology. The company employs 148 mining trucks [40].

The American company Chart Industries launched a pilot LNG project in collaboration with the Canadian company Teck Resources. According to the resource LNG World News, the project plans to use liquefied gas as a motor fuel for six super-heavy dump trucks with powerful diesel engines operating in the Canadian province of British Columbia. Liquefied gas is supplied by Fortis BC.

Pilot projects of transport converting to compressed natural gas are being implemented in 20 regions of Russia, and in three regions active work has begun in the innovative direction – the introduction of liquefied natural gas in transport. Such a differentiation of the gas engine fuel market is primarily due to the peculiarities of the use of natural gas on various types of equipment.

In Kuzbass, six mining companies signed an agreement of intent to use LNG. Within the framework of the project, it is planned to transfer 2500 BelAZ-75139 dump trucks with Cummins KTA 50C engines to gas

engine fuel (LNG) by 2030. It is expected that the switch to liquefied gas will reduce the cost of the fuel component in the cost of coal by 30–40 % and significantly reduce the negative impact on the environment.

Since 2015, ALROSA has been actively introducing the system for converting machinery to gas fuel. The company spends 2 billion rubles annually on fuel and lubricants (gasoline, diesel fuel). The bulk of the costs are borne by the purchase, delivery and storage of diesel fuel for mining trucks. In 2018, the number of flights of road trains from the Verkhne-Munsky diamond deposit to Factory No. 12 of the Udachninsky mining will increase significantly. The volume of work of the mining and servicing equipment on the Upper Muna industrial site will increase, therefore, the need for fuel and lubricants grows. Under the conditions of the Mirny district, the compressed methane is used. Natural gas is present in this area, it is distinguished by low cost and environmental safety. This year, due to the use of fuel and lubricants as a motor fuel, savings of up to 100 million rubles are expected.

The cost of converting of mining trucks in operation for gas-diesel mode using LNG consists of the cost of the electronically controlled fuel system, the cryogenic fuel tank and the cost of their installation. The total cost of re-equipment of one BelAZ-75485 mining truck in the serial version will approximately amount to 10.0–12.0 thousand dollars.

When converting dump trucks to a purely gas mode, the cost of the dump truck re-equipment, taking into account the installation of spark plugs, high voltage equipment and electronic ignition system will be about 15.0 thousand dollars [30, 34, 36].

For example, on a mining dump truck BelAZ-75485 with a carrying capacity of 42 tons, having an average diesel fuel consumption of 320 liters per shift, when switching to gas-diesel mode, a cryogenic tank with a capacity of 560 liters and a mass of 130 kg should be installed. LNG is stored at a pressure of 4–10 bar at temperatures from –125 to –140 °C. With a capacity utilization factor of a cryogenic tank of 0.9, the amount of natural gas after LNG gasification will be 300 nm^3. The maximum gas pressure in the cryogenic fuel tank will not exceed 0.6 MPa, and to reduce the gas pressure before it is fed into the fuel system of the engine, a one-step reduction is performed. A tank with a volume of 560–680 liters contains enough LNG for 800–1000 km, and gas filling takes as much time as comparable tanks for diesel fuel [21, 24, 30, 34, 36].

The payback period for the re-equipment of a mining truck from diesel fuel to LNG mode will be 1.0–1.5 years [30, 34, 40]. Taking into account the increase in engine service life by 1.5 times and reduction of engine oil consumption by 30–40 %, the economic effect will be much longer, and the payback period for the cost of the dump truck re-equipment from the diesel mode to the gas-diesel mode is less.

North option

The cost of production of liquid natural gas in the northern regions as a motor fuel is much lower than the cost of delivering diesel fuel by rail from regions located at distances of 2000 km or more. In addition, the most important competitive advantage of natural gas over diesel and gasoline fuels is its resistance to low temperatures, allowing it to be used on all types of transport in the Arctic and northern territories.

Sources of gas engine fuel can be individual small gas fields that are not included in the regional gas distribution network, as well as fields that are at the final stage of operation directly in Western Yakutia [44].

Natural gas produced in the fields of Western Yakutia mainly consists of methane, the amount of which varies widely (Table 6). LNG production can be organized directly at the gas field. Equipment for its production is compact, well adapted to field conditions and highly reliable. In this case, transporting liquefied natural gas to a mining enterprise that uses gas fuel technology becomes more cost-effective than transporting petroleum fuel. This is due to the fact that for the production of oil fuel the production cycle includes transportation from the field to the refinery, oil refining and fuel fabrication, transportation of the finished fuel to the consumer. For natural gas there is no need for additional processing. To date, several low-tonnage complexes for the LNG production have been built and put into operation in various regions of Russia [45].

Table 6

The composition of the gas of some Western Yakutia fields

Field	Gas composition, %			
	Methane CH_4	Ethane C_2H_6	Propane C_3H_8 and heavier	Nitrogen N_2
Verkhnevilyuchanskoe	84.50	7.50	0.55	7.45
Irelyakh	87.71	2.45	2.82	7.02
Mirninskoe	82.40	9.60	6.80	1.20
Otradninskoe	83.15	4.16	3.19	9.50
Srednebutyuobinskoe	87.18	3.66	2.97	6.19
Srednevilyuyskoye	90.60	4.90	3.70	0.80
Ust-Vilyuisk	92.50	2.80	3.30	1.40
Khatago-Murbayskoe	90.77	4.78	3.13	1.32
Chayandinskoe	85.48	4.57	3.51	6.44

In the summer, at positive air temperatures, the consumption of gas fuel increases by 3 %, and in winter, at negative temperatures, the consumption of diesel fuel increases compared to natural gas by 9 %. When the ambient temperature drops to –38 ° C, the adaptability of the NGV in gas-diesel mode increases by 6–18 % compared to the diesel mode.

The decrease in air temperature reduces the soot and nitrous oxide emissions in the exhaust gases of the engine in both diesel and gas-diesel modes. The content of soot is reduced to 26 %, and nitrogen oxide – to 54 %. But regardless of the ambient temperature, the amount of emissions of the NGV when operating in the gas-diesel mode is 14–33 % less than that of diesel engine [46–47].

Consequently, on the territory of Western Yakutia there are all the necessary conditions and technical reserve for providing the production and housing sector with electricity and heat, as well as motor fuel for mining equipment, railway transport and small energy facilities through the use of LNG [44].

Despite the fact that the advantages of LNG as a motor fuel for diesel engines are obvious the conversion of the heavy industrial transport and equipment to LNG is extremely slow.

The volume of LNG in comparison with equivalent diesel fuel is larger than the volume of diesel fuel. In addition, gas fuel is more combustible. Even small fuel leaks can have serious consequences. The electric equipment of the dump trucks was not even checked for the possibility of an explosion in the event of gas leaks and accumulation in places where a spark from a running engine is possible. There is also the risk of the air pollution in the quarry with products that are heavier than air (butane, propane, ethane, pentane, etc.), although they are always present in small amounts in natural gas but tend to accumulate on the lower zones in the quarry. Deep cleaning of gas from these fractions can solve the problem, but increases the cost of fuel.

The use of gas fuel in open-pit mines requires solving many problems and can be possible with reliably tested equipment, established service with qualified personnel and safety recommendations. In particular, heating the engine with an open flame before starting the engine should be prohibited. Welding, cutting by fire and other open flame work should also be prohibited in open pits. All these additional precautions make the use of gas vehicles more expensive, so even tests can be carried out only after a full assessment of the safety measures.

LNG production in Russia is at the initial stage of development. All large-scale projects in Russia – Gazprom (Sakhalin, Vladivostok, Baltic), Novatek (Yamal), the oil company Rosneft (Far Eastern), the ALLTEK Group and the oil company Rosneft (Pechora) – are carried out with the participation of foreign companies in whose hands the key elements of the project – technology are remained. The absence in Russia of its own large-capacity liquefaction technologies, methods for calculating the main cryogenic equipment makes Russian projects dependent on foreign suppliers of technology, equipment and services.

In order to reduce this dependence and increase the technological level of LNG production in Russia, Gazprom VNIIGAZ is developing the domestic technology for liquefying natural gas from Gazprom MR through a new refrigeration cycle. According to this development, Gazprom filed an international application for the invention "Method of liquefying natural gas and installation for its implementation" [22].

In recent years, the liquefied natural gas market has been developing more active, and the demand for this type of fuel is constantly increasing, which leads to the construction of new plants for its production.

Russian companies have plans to build LNG plants in Yamal, northwest Russia, in Vladivostok, but the only real LNG project is the Yamal LNG with a capacity of 16.5 million tons. Its shareholders are Novatek (50.1 %), French Total (20 %), Chinese CNPC (20 %) and the Silk Road Fund (9.9 %).

Conclusions

Natural gas is a promising motor fuel for vehicles, including mining (dump trucks, bulldozers, excavators, crushers, etc.). Therefore, enterprises of this industry are beginning to convert their fleet to gas engine fuel, including developing the infrastructure for servicing this equipment.

The limiting factors for the widespread use of gas fuel in the Russian Federation are an undeveloped network of filling stations, which are usually built near gas pipelines. Mining enterprises are located in areas where the gas network is absent or underdeveloped. However, compact and highly reliable compressor stations to liquefy natural gas directly at the field have been developed.

Converting mining dump trucks to LNG will completely eliminate lead compounds, reduce the opacity of diesel engine exhaust gases by 8–10 times, reduce the quarry atmosphere and noise pollution by 2–3 times, increase the efficiency and competitiveness of the enterprise by reducing the cost of fuel purchasing, transportation of rock and environmental fines.

In addition, the conversion to LNG will ensure that remote regions of the Russian Federation will be guaranteed fuel, reduce the volume of petroleum products reservation in the spring-summer period and reduce federal budget expenditures.

Thus, the use of LNG as an engine fuel for mining and processing equipment in the northern quarries today has great prospects.

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