ГИАБ. Горный информационно-аналитический бюллетень /
MIAB. Mining Informational and Analytical Bulletin, 2022;(10-1):39—49
ОРИГИНАЛЬНАЯ СТАТЬЯ / ORIGINAL PAPER

УДК 622 DOI: 10.25018/0236_1493_2022_101_0_39

ВОЗМОЖНОСТЬ ПРИМЕНЕНИЯ БИОДОБАВОК К ТОПЛИВУ НА ГОРНОДОБЫВАЮЩИХ ПРЕДПРИЯТИЯХ

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Аннотация: Темпы добычи в горнодобывающей отрасли увеличиваются с каждым годом, одновременно с этим, возрастает количество специальной техники и автотранспорта, используемого при подземных и открытых работах. Большинство данной техники и автотранспорта оборудовано дизельными двигателями. При неполном сгорании дизельного топлива в двигателе образуется дополнительное количество выбросов токсичных газов, таких как угарный газ, оксиды азоты, летучие углеводороды и другие, а также в больших количествах появляются частицы сажи. Все эти компоненты наносят вред и здоровью работников и окружающей природе. Известные и применяемые на данный момент методы борьбы с выхлопными выбросами влекут за собой большие энергетические потери и затраты на электроэнергию. Одним из способов одновременного решения двух проблем является использование более экологичного топлива, а именно применение биодобавок, которые увеличивают полноту сгорания топлива и сами по себе при сгорании образуют меньшее количество нежелательных выбросов. Проведенные исследования доказали снижение концентрации угарного газа и оксидов азота при работе шахтных дизель-гидравлических локомотивов, а также наблюдалось снижение количество образующихся сажевых частиц при работе самосвалов на открытых работах.

Ключевые слова: горнодобывающая отрасль, угольные шахты, разрез, дизельные двигатели, токсичные газы, сажевые частицы.

Для цитирования: *Еремеева А. М., Ильяшенко И. С., Коршунов Г. И.* Возможность применения биодобавок к топливу на горнодобывающих предприятиях // Горный информационно-аналитический бюллетень. — 2022. — № 10-1. — С. 39—49. DOI: 10.25018/0236_1493_2022_101_0_39.

The possibility of application of bioadditives to diesel fuel at mining enterprises

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Abstract: The rate of production in the mining industry is increasing every year, and consequently the number of special equipment and vehicles used in underground and open pit mines grows. Most of these vehicles are equipped with diesel engines. Due to the inefficient combustion of diesel fuel in the engine, an additional amount of emissions of toxic gases, such as carbon monoxide, nitrogen oxides, volatile hydrocarbons and others, is formed, and soot particles are generated in large quantities. All these components are harmful to both the health of workers and the environment. Known and currently used methods of reduction of the exhaust emissions entail large energy losses and high electricity costs. One of the ways to simultaneously solve these two issues is the application of more environmentally friendly fuel, namely the use of bioadditives that increase the effectiveness of fuel combustion and form fewer undesirable emissions as a result of fuel combustion. The studies carried out shown a decrease in the concentration of carbon monoxide and nitrogen oxides during the operation of mine diesel-hydraulic locomotives, and there was also a decrease observed in the amount of soot particles formed during the operation of dump trucks at the open pit mine.

Key words: mining industry, underground coal mines, coal open pit, diesel engines, toxic gases, soot particles.

For citation: Eremeeva A. M., Ilyashenko I. S., Korshunov G. I. The possibility of application of bioadditives to diesel fuel at mining enterprises. *MIAB. Mining Inf. Anal. Bull.* 2022;(10-1):39—49. [In Russ]. DOI: 10.25018/0236_1493_2022_101_0_39.

1. Introduction

Mining industry statistics over the past few years show that there are about 190 coal mining enterprises (underground and open pit mines) in Russia nowadays [1, 2, 3]. Over the past 10 years, more than 3.5 billion tons of raw materials have been extracted [4, 5]. More than ten companies are engaged in mining of coal deposits in Russia, and one of the most productive ones is JSC SUEK.

All mining industrial facilities use a huge range of vehicles and equipment. Commonly, the open pit mine equipment (excavators, drilling rigs, dump trucks, etc.) is equipped with diesel engines [6, 7]. Transport is used to increase the productivity of workers [8], to ease the severity of labor, namely, for the transportation of materials and people, installation of mine workings supports, delivery and repair of equipment, which in turn leads to an increase in the pace of road-heading works. Diesel fuel has a number of advantages over gasoline, such as a longer engine life, lower fuel consumption, fewer components, thus leading to lower fuel expenditures [9]. But at the same time, diesel engines have increased smokiness, significant emissions of toxic gases into the atmosphere. The gas contamination and smoke content of the air in working area necessitates stopping the operation in the open pit to reduce the content of harmful elements in the air back to the normal values. The content and amount of exhaust gas emissions are affected by geotechnical conditions and engine operating mode.

The scientific literature proposes several ways to solve the problem of air contamination by toxic components of exhaust gases [10, 11, 12]. For instance, the transfer of equipment and vehicles from diesel engine to electric drive improves working conditions and reduces ventilation costs by almost 50% [13, 14].

The main way to reduce the concentration of toxic emissions is ventilation with a fresh stream of air [15]. The specifics of the ventilation of underground workings during joint mining operations (mining operations involving underground and open pit mining at the same space and time), are due to the fact that these workings are mined from the sides and bottom of the quarry. The air in such working areas contains a lot of dust and exhaust gases in concentrations exceeding the maximum permissible concentrations (MPC). Ventilation causes mixing of air flows and is complicated by the bowl shape of the quarry [18]. The function of underground ventilation in the combined mining method is to take fresh air from the windward side of the open pit with the help of auxiliary fans or stationary fan installations and to remove the return air to the mined area of the quarry, where air pollution by gas is very high [17, 19].

Another way to reduce the concentration of harmful gases in the exhaust is to use oxidizing gas purification systems. The principle of operation of oxidative exhaust gas purification systems is based on the combination of two methods: catalytic and thermal neutralizers. To provide additional air, these systems use pulsators, pumps or ejectors. Pulsators have a limited service life and low throughput, ejectors, in turn, can partially emit exhaust gases, pumps require a certain drive for operation, which makes the design of the engine more complicated.

Simultaneous reduction of energy costs needed for the ventilation to dilute the concentration of toxic gases, and direct reduction of harmful emissions can be achieved through the use of more environmentally friendly fuel.

In order to reduce environmentally harmful emissions into the atmosphere, the requirements for the content of sulfur in fuel have been significantly tightened. However, along with the reduction of harmful emissions in exhaust gases, the use of low-sulfur diesel fuels leads to a number of technical problems [20, 21]. The most significant issue could be, for example, the failure of high-pressure fuel pumps due to a decrease in the lubricity of diesel fuels and due to an increase in corrosion aggressiveness, which in turn is associated with the removal of surfactants during hydrotreating, since these substances are capable of forming a protective film on the metal surface. Many sulfur compounds potentially included in the diesel fraction, such as sulfides and benzothiophenes, are characterized by high anti–wear properties and their removal during hydrotreating leads to a sharp decrease in lubricating properties, which is an important performance indicator of diesel fuels. A scientific work has been published indicating that the failure of car fuel pumps is observed after 5–50 thousand km in cars running on fuel with a sulfur content of 50 ppm (0.005%), and the failure of car fuel pumps, running on fuel with a sulfur content of 10 ppm (0.001%) occurs after 3–13 thousand km. Herewith, the estimated service life of car fuel pumps is around 250 thousand km.

To carry out a comprehensive analysis of the existing problem, a number of modern researches, concerning the assessment of air dustiness at open pit mines, as well as aimed at assessing the cumulative impact of harmful factors of the production environment on personnel and ecosystems, have been studied [22]. Some studies indicate that industrial aerosols formed at all production stages of underground and open pit mining enterprises are capable of sorbing harmful gases with varying sufficiency when the clouds of dust and volatile substances are mixed. Consequently, after penetrating the upper respiratory tract and lungs of an employee the smallest particles of respiratory dust will be able to have, for example, not only a fibrous effect, but also a poisoning, irritating, sensitizing or other because of the gas inclusions. At the same time, the respirable dust is able to detain in a person’s lungs for a long time, thereby having a prolonged harmful effect on the employee both in terms of the properties of the dust itself and the properties of the sorbed gases. Therefore, the reduction of the concentration of harmful gases in the air of the working area is important both to reduce the direct harmful effects on personnel and the environment, and to mitigate the indirect impact, associated with the penetration with industrial aerosol particles inhaled.

The solution to this problem may be the use of bioadditives, biocomponents and biodiesel in traditional diesel engines [23, 24, 25], which will significantly reduce emissions of hydrocarbons, carbon monoxide, sulfates, aromatic hydrocarbons and solid particles into the atmosphere.

2. Experimental

2.1 Development of additives to diesel fuel

Biofuels or bioadditives are produced by hydrotreating vegetable oils in the presence of a catalyst, depending on the degree of required purification of the product.

The necessary characteristics of the developed bioadditives are given in Table 1.

There are many methods for testing additives (or biodiesel). In our opinion, the most complete and closest to the requirements of the Russian standard GOST R 53605–2009 is the standard EN14214, developed by the European Standards Organization, the core properties of the composition are presented in table 2.

The quantitative and qualitative composition of biofuels was obtained using the GCMS-QP2010 SE Shimadzu gas chromato-mass spectrometer. The biofuel sample contains a total of 88 compounds, the main of which are shown in Fig. 1.

Biofuel consists of paraffins of normal and isometric structure, which makes it as close in properties to petroleum diesel fuel as possible and provides sufficient mixing

Table 1

The core properties of bioadditive

№	Indicator	Bioadditive
1	Density in 15 °C, kg/ m^3	0,785
2	Content of sulfur, mg/kg	28
3	Flash point in a closed cup, °C	96
4	Lubricity: Wear Scar Diameter at 60 °C, μm	582
5	Kinematic coefficient of viscosity at 40 °C, mm^2/s	3,52
6	Fraction composition: – at temperature 250 °C, % (by volume) – at temperature 350 °C, % (by volume), – 95% (by volume) distilled at temperature, °C	6 93 295
7	Cetane number (CN)	65
8	Pour point, °C	–8
9	Content of methyl esters of fatty acids, % (by volume)	–
10	Ash content, % by weight	0,006

Table 2

The main methods of testing of biodiesel (additives) according to the EN14214 statute

Property	Units	Minimum	Maximum	Testing method
Density at 15°C	kg/m^3	860	900	EN ISO 3675, EN ISO 12185
Viscosity at 40°C	mm^2/s	3.5	5	EN ISO 3104
Flash point	°C	120		ISO / CD 3679
Content of sulfure	mg/kg		10	EN ISO 20846, EN ISO 20884
Cetane number (CN)		51		EN ISO 5165

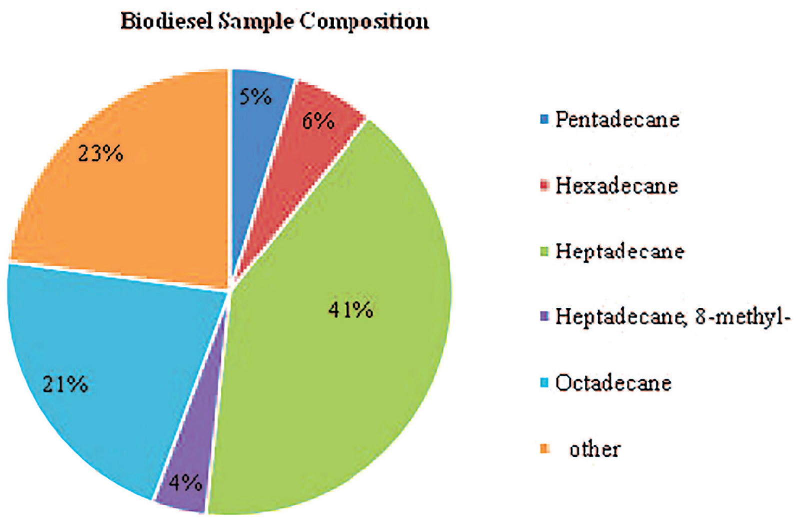

Fig. 1. Qualitative and quantitative composition of a sample of biodiesel fuel

when making the mixed compositions. Therefore, further tests were carried out in comparison with the test of basic petroleum fuel by application of mixed diesel fuel, namely 90% of petroleum fuel and 10% of bioadditive (biodiesel).

2.2. Tests in underground coal mine

At the coal mines of the SUEK-Kuzbass enterprise, such diesel engine companies as ZETOR, Ferrit and others are common in diesel-hydraulic locomotives, which we consider as the main source of toxic emissions into the mine atmosphere [26, 27].

Before the test, the air compositions from 3 different coal mines were analyzed: there were 4 set routes for diesel-hydraulic locomotives in mine No. 1, two routes in mine No. 2, and 1 route in mine No. 3. The concentrations of toxic gases were measured directly in the working area and at a distance of 30 meters from the source of emissions. The results of the measurements are presented in Table 3.

The analysis of the composition of the mine air showed that there are exceedances of the maximum permissible concentrations for gases such as carbon monoxide and nitrogen oxides in the working area and at the workplace of the diesel-hydraulic locomotive operator.

2.3 Tests at coal open pit mines

Regarding the mining equipment working in quarries and coal open pit mines, the transport mostly is represented by dump trucks running on diesel fuel. When fuel is burned by the working dump trucks, 2 significant issues are observed at once: emissions of toxic gases and the formation of a large amount of soot and industrial aerosols (dust) [28] that penetrate the human lungs and are no longer removed from them.

The haul equipment of two companies prevails at the open pit mines in Russia: BELAZ and Caterpillar.

Moreover, it is important to take into account the factor of dustiness of the air at mining enterprises. The problem of increased air dustiness at open pit mines is significant. Concentrations of aerosols formed at different stages of production can reach hundreds and thousands of milligrams per cubic meter, which, in turn, characterizes a significant harmful effect of this factor on the environment

Table 3
Composition of mine air

No.	Sampling location	Gas concentration, vol. %					
		CO_2	O_2	CO	H_2	CH_4	nitrogen oxides
Mine No. 1							
1	Workplace of the operator of a diesel-hydraulic locomotive	3,1563	16,0756	0,00186	–	0,0015	0,0025
2	30 meters from the emission source	0,11	20,73	0,0001	–	0,0000	0,00001
Mine No. 2							
1	Workplace of the operator of a diesel-hydraulic locomotive	2,3679	20,9164	0,00089	–	0,0009	0,0008
2	30 meters from the emission source	0,09	20,55	0,0001	–	0,0000	0,00001
Mine No. 3							
1	Workplace of the operator of a diesel-hydraulic locomotive	2,0212	22,3896	0,00055	–	0,0004	0,0002
2	30 meters from the emission source	0,05	20,46	0,0001	–	0,0000	0,00001

and personnel. However, the greatest hazard to personnel and ecosystems is the cumulative impact of factors of the production environment. The combined effect of industrial aerosols and harmful exhaust gases generated as a result of the operation of diesel equipment can lead to an aggravation of the harmful effects of these factors, thereby leading to the development of more severe occupational diseases and deterioration of ecosystems. At the same time, much less attention is paid to the problem of increased air dustiness in open-air mining sites than in underground mining enterprises, since the actual level of harmful effects of this factor in the open air is not as obvious as in underground workings. In this regard, reducing emissions of harmful gases from diesel exhaust using the proposed biodiesel fuel is of great importance. This solution can lead not only to an improvement in the technical properties of the equipment and an increase of its working life, but also to a comprehensive improvement of working conditions at the facility by reducing the direct and indirect harmful effects of the production factors.

3. Results and discussions

3.1 The effectiveness of the use of additives for coal mines

The calculation method [29–33] was used to determine the amount of harmful substances in the exhaust gases when using hydrotreated diesel fuel and diesel fuel mixed with bioadditive (Table 4).

One of the important indicators in addition to gas pollution is the smoke of exhaust gases. The opacity of gases was determined at different engine speeds and different operating modes (at maximum engine load, partial and minimum — 25%).

Thus, it can be concluded that at maximum and partial load at any number

Table 4

Amount of harmful substances when using petroleum diesel fuel and improved diesel fuel

Pollutant	Hydrotreated diesel fuel with bioadditive, g/min	Hydrotreated diesel fuel, g/min
Nitrogen dioxide NO_2	1,517	3,220
Nitrogen oxide NO	0,110	0,489
Carbon (Soot)	0,353	0,785
Sulfur dioxide SO_2 (Sulphurous anhydride)	0,093	0,287
Carbon oxide CO	1,251	2,859
Kerosene	0,403	0,951

Table 5

Measurement results by the smoke meter when using hydrotreated diesel fuel and a mixture of bioadditive with fuel

Test No.	n, min^{-1}	Diesel fuel		Diesel fuel with bioadditive	
		K, m^{-1}	N, %	K, m^{-1}	N, %
Load – 100%					
1	2135	0,09	4,02	0,06	2,55
2	2130	0,13	5,49	0,05	2,35
3	2118	0,16	6,17	0,06	2,55
4	2103	0,29	12,05	0,08	3,23
5	2809	1,83	35,57	0,19	7,84
6	2076	2,70	69,48	0,50	19,89
7	1780	9,42	96,82	1,18	34,89
Load – 75%					
1	1773	0,28	12,15	0,15	4,12
2	1743	0,31	12,84	0,16	5,49
3	1714	0,38	15,19	0,18	6,76
4	1706	0,51	19,99	0,30	7,25
5	1690	1,20	41,94	0,84	11,86
6	1672	3,38	87,71	2,06	31,65
Load – 50%					
1	1773	0,28	12,15	0,15	4,12
2	1743	0,31	12,84	0,16	5,49
3	1714	0,38	15,19	0,18	6,76
4	1706	0,51	19,99	0,30	7,25
5	1690	1,20	41,94	0,84	11,86
6	1672	3,38	87,71	2,06	31,65
Load – 25%					
1	1773	0,28	12,15	0,15	4,12
2	1743	0,31	12,84	0,16	5,49
3	1714	0,38	15,19	0,18	6,76
4	1706	0,51	19,99	0,30	7,25
5	1690	1,20	41,94	0,84	11,86
6	1672	3,38	87,71	2,06	31,65

of revolutions per minute n, the smokiness is reduced when burning environmentally friendly diesel fuel compared to the smokiness when burning hydrotreated diesel fuel without bioadditives.

Industrial tests were carried out directly in a coal mine. Petroleum diesel fuel and diesel fuel with an additive were used. The operating conditions of the engine were as identical as possible during the experiment.

The results of the experiment show that when using bioadditives in fuel, the concentration of harmful gases is reduced by more than 2 times.

3.2. Efficiency of application of bioadditives at coal open pit mines

The results of the calculation of soot particles due to the combustion of diesel fuel in dump truck engines at open pit mining are shown in Table 7. Exhaust emissions were determined for two types of dump trucks and two modes of operation of dump trucks: empty and loaded with raw materials.

Initially, an experiment was carried out using basic petroleum hydrotreated fuel, then the same tests were made using environmentally friendly diesel fuel with a bioadditive. The conditions of the experiment were as identical as possible.

The results of the experiment show that the dump truck No. 1 (with a more modern type of engine) forms fewer soot particles during operation than the dump truck No. 2. Also, according to the analysis of Table 5, it can be concluded that the amount of emissions of soot particles from an empty operating dump truck is significantly less (by %) than from a fully loaded operating dump truck.

The concentration of generated particulate matter is reduced by 7–13% when using eco-friendly fuel with bio-components (biodiesel) compared to the use of petroleum diesel fuel. This is primarily due to an increase in the sufficiency of diesel fuel combustion in the engine.

Table 6

Test results of diesel fuel with an additive in a diesel engine at the JSC SUEK-Kuzbass enterprise, % vol.

	Sampling location	**CO_2**	**CO**	**nitrogen oxides**	**O_2**
HT DF	diesel engine	2,52	0,0411	0,02358	18,52
HT DF with bioadditive		1,71	0,0084	0,00156	21,64

Table 7

Determination of soot carbon emissions during the operation of dump trucks in various engines

№	**Indicator**	**1st type dump truck**		**2nd type dump truck**	
		Diesel fuel	**Diesel fuel with bioadditive**	**Diesel fuel**	**Diesel fuel with bioadditive**
1	Emissions of soot particles for operation of an empty dump truck, g/h	66,32	59,69	34,58	30,09
2	Emissions of soot particles for operation of a loaded dump truck, g/ h	180,06	163,85	96,75	88,84

4. Conclusions

The biofuel sample can be used as a component of environmentally friendly diesel fuel mixed with hydrotreated diesel fuel in an amount of 5–10% by weight, while the fuel characteristics met the requirements of the European statute EN 590 and Russian standard GOST R 52368.

Laboratory, stand and full-scale tests of diesel fuel with the developed biodiesel showed that its use in an amount of 10% by weight reduces CO emissions due to combustion by 13–48% with a minimum load on the engine and by 25–41% with a maximum load on the engine. The concentration of nitrogen oxides also decreases by 65–71%. The test results are compared to the use of conventional diesel fuel.

The amount of soot particles decreased by 7–13% for the working dump truck with the application of mixed diesel fuel (90% petroleum diesel fuel and 10% bioadditives) in comparison with the use of basic petroleum diesel fuel. The decrease in soot emission was determined depending on the working conditions of the dump truck (load) and on the type of dump truck itself.

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Получена редакцией 20.03.2022; получена после рецензии 27.06.2022; принята к печати 10.09.2022.
Received by the editors 20.03.2022; received after the review 27.06.2022; accepted for printing 10.09.2022.