REDUCTION OF EMISSIONS IMPACT ON THE ENVIRONMENT AND HEALTH OF COAL MINE WORKERS

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ABSTRACT. The maximum permissible concentrations of poisonous and harmful gases in the mine atmosphere in existing underground mines during the operation of self-propelled mining equipment with diesel drive used for the transport of people and mined minerals, repair and other types of work were considered. The qualitative composition of pollutants during the operation of a diesel engine has been studied, namely, the main emissions that cause dangerous diseases in workers, such as carbon oxides, oxides and nitrogen dioxide, hydrocarbons, fine particulate matter, sulphur compounds and others, and their concentrations have been determined. The main characteristics of the ZETOR 1404 turbo diesel engine were obtained and studied, and the amount of harmful emissions generated from the use of diesel fuel in this engine was determined. The main methods of reducing emissions of pollutants from diesel vehicles into the atmosphere were also considered, and a method was proposed for reducing harmful substances in exhaust gases by changing the composition of diesel fuel, namely, introducing an environmentally friendly bio-additive into oil fuel, which, when burned, does not form harmful compounds.

Keywords*:* coal mines, diesel engine, MPC, harmful gases

НАМАЛЯВАНЕ НА ВЪЗДЕЙСТВИЕТО НА ЕМИСИИТЕ ВЪРХУ ОКОЛНАТА СРЕДА И ЗДРАВЕТО НА РАБОТНИЦИТЕ В МИНИ ЗА ДОБИВ НА ВЪГЛИЩА

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РЕЗЮМЕ. Разгледани са максимално допустимите концентрации на отровни и вредни газове в атмосферата на рудника в съществуващи подземни мини при експлоатацията на самоходно минно оборудване с дизелово задвижване, използвано за транспортиране на хора и добивани минерали, ремонт и други видове работа. Изследван е качественият състав на замърсителите по време на експлоатацията на дизелов двигател, а именно основните емисии, които причиняват опасни заболявания на работниците, като въглеродни оксиди, оксиди и азотен диоксид, въглеводороди, фини прахови частици, серни съединения и др., като техните концентрации са определени. Получени са и изследвани основните характеристики на турбодизеловия двигател ZETOR 1404 и е определено количеството вредни емисии, генерирани от използването на дизелово гориво в този двигател. Разгледани са и основните методи за намаляване на емисиите на замърсители от дизеловите превозни средства в атмосферата и е предложен метод за намаляване на вредните вещества в отработените газове чрез промяна на състава на дизеловото гориво, а именно въвеждане на екологосъобразна биологична добавка. в мазута, който при изгаряне не образува вредни съединения.

Ключови думи: въглищни мини, дизелови двигатели, максимално допустима концентрация, вредни газове

Introduction

The use of self-propelled mining equipment with a diesel drive in coal mines significantly increases labour productivity during such auxiliary work as the transportation of technical fuel and lubricants, repair and rigging works, construction and repair of underground roads, transportation of people, etc. However, the advantages achieved when using self-propelled mining machines and mechanisms with diesel drive in underground conditions can be achieved only under the condition of ensuring safe conditions for their operation (Davies, 2004).

At enterprises using self-propelled mining equipment with a diesel drive, the air of working zones is intensively polluted not only with dust, but also with components of exhaust gases. In addition to increased concentrations of nitrogen oxides, carbon monoxide in the workplace, acrolein and formaldehyde are present in the air (Bagley et al., 2002; Air-Met, 2003). It should be emphasised that in mine air the concentrations of these gases often exceed the permissible values. It should be borne in mind that the gaseous exhaust products are sorbed on dust and soot particles, increasing the fibrogenicity of dust (Cohen et al., 2002; Davies, 2000). Therefore, the determination of the nature of the combined action of the main components of exhaust gases, the identification of risk factors at these enterprises is of particular importance, as well as the improvement of methodological approaches for the reduction of harmful substances in the specific conditions of mining workings.

One way to improve working conditions in mines is to reduce the harmful effects of emissions on workers' health by changing the composition of the fuel used in self-propelled diesel equipment.

Analysis of the state of gas pollution in coal mines

Table 1 shows the number of diesel locomotives used in the coal mines of JSC SUEK-Kuzbass.

Table 1. *The number of used diesel locomotives in the mines of JSC "SUEK-Kuzbass"*

№	Name of mine	Number of diesel locomotives
1	Komsomolets	6
2	Polysaevskaya	6
3	them. S.M.Kirov	12
4	them. A.D.Ruban	3
5	Trunk	8
6	November 7th - new	2
7	im.V.D. Yalevsky "pl. 50	5
8	im.V.D. Yalevsky "pl. 52	7
9	T -West 1	4
10	T -West 2	7
Total:		60

The analysis of the routes of diesel locomotives showed that most of them pass through capital workings with the main incoming and outgoing air jets intended for airing several “consumers”, including cleaning and tunnel faces. Due to the high methane content at excavation sites and dead-end preparatory workings in most of the mines of SUEK-Kuzbass, the main criterion determining the amount of air in the ventilation jets is dilution of methane to the maximum allowable concentrations. Thus, the calculated air flow rate required for diluting exhaust gases of diesel engines is almost universally a multiple of the accepted air flow rate for airing the workings. However, in some cases, routes of movement of diesel locomotives pass outside the routes of movement of the main air flow (for example, the ventilation drift of the adjacent prepared or already prepared extraction column, the disassembly chamber, etc.) 5, the Yalevsky mine), which necessitates the conduct of mine research to determine the degree of gas pollution of these mine workings by exhaust gases and the potential for its reduction.

The average quantitative and qualitative characteristics of the pollutants from the work of diesel locomotives in the mine air at the mines of SUEK-Kuzbass, are given in Table 2.

Table 2. *The composition of the mine air in the main positions*

Sampling point	Gas concentration, %				
	CO_2	O_2	CO	CH_4	NOx
In workplace driver	0.04	20.92	0.0005	0.00	0.00004
Baseline	0.03	20.92	0.0006	0.00	0.00002
At the exhaust (min. Load)	2.02	16.06	0.0017	0.00	0.0008
At the exhaust (max. Load)	2.04	16.05	0.0034	0.00	0.0014
20 meters from the diesel locomotive	0.12	20.62	0.0001	0.00	0.00001

As can be seen from the data in Table 2, the largest amount of emissions comes from carbon dioxide and carbon monoxide. Carbon monoxide is tasteless and odourless, but at high concentrations causes dizziness, headache, nausea, and can lead to fainting. A slight increase in the concentration of carbon dioxide, up to 2-4%, in the premises leads to the development of drowsiness and weakness in people.

The current regulatory and technical document for the regulation of exhaust gases when diesel engines operate in coal mines is the Order of the Federal Service for Ecological, Technological and Nuclear Supervision dated January 12, 2016 N7 "On approval of Safety Guidelines" Recommendations for use in coal mines transport vehicles with diesel drive", according to which the maximum permissible concentrations (MPC) of exhaust gases are summarised in Table 3.

Table 3. *Recommendations for use in coal mines transport vehicles with a diesel engine*

Harmful gases	Maximum permissible concentration of gas in operating mountain conditions	
	%	mg/m3
CO	0.00170	20
NO_x	0.00025	5
Sulphurous anhydride	0.00038	10
H_2S	0.00070	10

Analysing the data from Tables 2 and 3, we can conclude that the values of emissions of nitrogen oxides and carbon oxides exceed the norm at the exhaust (at maximum and minimum load), but the concentration of carbon dioxide exceeds the norm in all measurement sites.

According to GOST 12.1.005-88 Occupational Safety Standards System (OSS) the general sanitary and hygienic requirements for the air of the working area (with a change in N 1) MACs of harmful gases are listed in Table 4.

Table 4. *General sanitary and hygienic requirements for working area air*

Harmful gases	MPC mg/m3	Hazard Class	human influence
NO_x	7	III	O
CO	20	IV	O
Sulfurous anhydride	10	III	
H_2S	10	II	O

Note: O - substances with a highly directional mechanism of action requiring automatic control of their content in the air.

Based on the MPC values in GOST 12.1.005-88, it can be concluded that the concentration of nitrogen oxides and carbon oxides exceed the norm on the exhaust (at maximum and minimum load).

The way to reduce the concentration of harmful substances in the air of the working area of coal mines

Significant reduction of aerotechnogenic load during the work of diesel locomotives can be achieved through an integrated approach, involving the implementation of several tools in practice. Particular attention should be paid to the development of diesel fuel additives to reduce harmful

emissions. The use of biodiesel in traditional diesel engines significantly reduces the amount of hydrocarbons emitted into the atmosphere, carbon monoxide, sulphates and particulate matter, toxic and carcinogenic substances (Anchita, 2017). Due to the fact that biodiesel does not contain sulphur, sulphur dioxide does not enter the atmosphere when it is burned. The high content of oxygen in biodiesel contributes to a more complete burning of CO_2 (Bezergianni, Dimitriadis, 2013).

In the last decade, the esterification process of fatty acids contained in vegetable oils (for example, sunflower, corn, flax, etc.) and animal fats has become very popular. This technology is based on the interaction of organic acids with alcohols, leading to the formation of esters (Fig. 1), (Bezergianni, Dimitriadis, 2013).

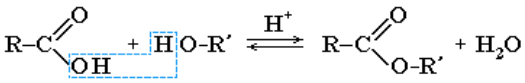

Fig. 1. Scheme of the esterification reaction

For the synthesis of biodiesel according to the esterification method, the authors selected acids contained in sunflower oil and dihydric alcohol (ethylene glycol) as raw materials. After this process, the separation of the phases (organic and aqueous) in the product mixture was carried out by sedimentation, drying and distillation. Table 5 shows the main indicators of the quality of biodiesel fuel obtained by esterifying fatty acids of sunflower oil (FASO) with a dihydric alcohol in comparison with the physicochemical properties of a mixture of fatty acids isolated from sunflower oil (Kondrasheva et al., 2018; Kondrasheva et al., 2019).

Table 5. *Physical and chemical properties of a mixture of FASO and biodiesel fuel obtained by the esterification of FASO with ethylene glycol*

Indicator	FASO	Biodiesel fuel
Density at 20 ° C, kg/m3	0.90978	0.91400
Viscosity at 40 ° C, mm2/s	27.995	23.250
Flash point in closed crucible, ° C	115	>110
Sulphur content, mg / kg	13	71
Lubricity (CWSD) * at 60 °C, microns	157	202

*Note: * CWSD - corrected wear spot diameter.*

Calculation of harmful emissions from fuel combustion

At the mining enterprises, the most common is the Zetor 1404 engine in the underground monorail transport. The engine operating parameters are presented in Table 6.

Table 6. *The parameters of the diesel engine Zetor 1404*

Engine's type	ZETOR 1404 turbo (for mine conditions)
Engine type	with compression ignition, direct fuel injection
Max. power	81 kw – 5 %
Nominal speed	2300 min^{-1}
Number of cylinders	4
Fuel consumption	255 g/ kWh
fuel	diesel fuel

The amount of pollutants emitted into the atmosphere during the operation of this engine was determined through the material balance (Fig. 2).

$$S_S / S_C = 0,3746S/C;$$

$$S_C / S_H = 0,0839C/H;$$

$$\alpha S_C / S_O = 0,1678C/(0,3356C + H);$$

$$S_O / S_N = 1,1082(0,21 + O);$$

Fig. 2. Material balance of substances in the exhaust gases

The calculated amount of harmful substances when using petroleum diesel fuel and improved diesel fuel (NPDF) are presented in Table 7.

Table 7. *The amount of harmful substances when using petroleum diesel and improved diesel fuel*

Harmful gases	NPDF, g/min	DF, g/min
NO_2	1.976	3.19
NO	0.321	0.518
C	0.41	0.662
Sulfurous anhydride	0.23	0.39
CO	1.57	3.108
Kerosene	0.51	0.9

As can be seen from Table 8, the amount of harmful substances when using diesel fuel with a bio-additive decreases by almost 2 times.

Conclusion

The most effective way to reduce harmful substances is to improve the quality of the fuel used, the use of additives or alternative fuels. All these methods can be combined using the introduction of bio-additives based on animal and vegetable fats and oils into the composition of the fuel and including the composition of esters (Kondrasheva et al., 2018). Simultaneously with the reduction of harmful emissions when using these additives, the engine life increases by 2-3 times, the diameter of the fuel wear spot decreases, and the calorific value decreases.

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