Ensuring Occupational Safety and Health through Ventilation in Underground Mines with Internal Combustion Engine Vehicles on Duty

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Обеспечение безопасных условий деятельности сотрудников по фактору вентиляция в подземных рудниках при работе техники, оснащенной двигателями внутреннего сгорания

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Увеличение производственных мощностей и развитие вентиляционных сетей подземных рудников ставят перед горными предприятиями задачи повышения мощности применяемого горного и вентиляционного оборудования. Большинство горного оборудования для подводки и транспортировки горной породы на рудных месторождениях работает на базе техники с дизельными двигателями внутреннего сгорания. Недостаточная вентиляция или неправильный подход к расчету необходимого количества воздуха для разбавления основных компонентов выхлопных газов от двигателей внутреннего сгорания, таких как угарный газ и окись азота, могут привести к отравлению или даже гибели горных рабочих. Однако на большинстве современных предприятий вентиляционное оборудование работает на пределах технической возможности – без вероятности увеличения технологического резерва. Этот факт, в свою очередь, напрямую влияет на безопасность ведения горных работ. Предложенные методы и зависимости для расчета требуемого воздуха для рабочих зон машин, оснащенных двигателями внутреннего сгорания, подземных рудников при их проектировании и эксплуатации.

На анализ нормативной литературы показывает, что в настоящее время отсутствует требуемая норма расхода воздуха на единицу мощности двигателя внутреннего сгорания. Поэтому предлагается подход, соответствующий современным требованиям промышленной безопасности, основанный на фактических выбросах вредных компонентов, параметрах работы двигателей внутреннего сгорания и нормах выбросов, гарантироваемых производителем пути подтверждения соответствия двигателя экологическому классу. Предлагаемые методы позволят повысить безопасность на рабочих местах при работе техники с двигателями внутреннего сгорания на подземных рудниках, а также увеличить эффективность проектирования новых блоков, горизонтов и рудников за счет исключения необоснованного резерва при подборе горного и вентиляционного оборудования.

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Introduction

Currently, mining industry is facing a range of issues in the development of mineral deposits. The increasing demand for mineral resources, stringent enforcement of regulatory and environmental laws, complexity of mining conditions and many other factors pose challenges to mining enterprises, which influence profitability of companies and safety of personnel.

Increasing production capacities aimed at meeting demands for more mineral resources entail the development of new mining sites located at great depths or at significant distances from main openings, as well as the increase in the inventory or capacities of mining machinery. Most mining mobile equipment for loading and transporting rocks at ore deposits is powered by diesel internal combustion engines (ICE). Insufficient ventilation or wrong determination of the amount of air required to dilute the main components of exhaust gases from internal combustion engines, including carbon monoxide and nitrogen oxides, can result in poisoning or even death of mining workers. However, at most production facilities, ventilation systems operate at the capacity limits with no possibility of increasing the technical reserve. This fact has a direct impact on safety of mining operations.

Therefore, it is crucial to determine the amount of air required to dilute the harmful and hazardous components of exhaust gases emitted from the machinery equipped with internal combustion engines to safe concentrations.

Regulatory Documentation

In the 20th century, especially in the post-war period, the mining industry was advancing at a rapid pace. The development of diesel technology contributed to mechanisation of mining operations. In this connection, regulations were developed to improve the industrial safety.

Earlier, Uniform Safety Requirements for Underground Development of Ore, Non-Ore, and Placer Mineral Deposits (PB code 06-111-95) regulated the rate of fresh air supply in mine workings with internal combustion engine machinery on duty in an amount that reduces the concentration of harmful exhaust products in the mine atmosphere to meet the health and safety standards, but not less than 5 m³/min per 1 HP of diesel engine power rating [1]. In 2003, the Uniform Safety Requirements [1] were cancelled to be replaced by a new version. However, the standard requirements of the fresh air supply that reduces the concentration of harmful exhaust products in the mine atmosphere were removed.

At present, Norms of Technological Design of Mining Enterprises of Metallurgy with Underground Mining Method (VNTP code 13-2-93) are one of the regulatory documents, stipulating the standards of fresh air supply for diluting exhaust gas components of 5 m³/min per 1 HP of an engine power [2]. VNTP 13-2-93 standard is not strictly binding due to the fact that it is not registered with the Ministry of Justice of Russia, and in accordance with Paragraph 10 of the Presidential Decree No. 763 of May 23, 1996 On the Procedure for the Publication and Entry into Force of Acts of the President of the Russian Federation, the Government of the Russian Federation and regulatory legal acts of federal executive bodies serve as guidelines only.

It should be noted, that it is not only in the Russian regulatory documentation that the rate of fresh air supply per 1 HP of engine power for the dilution of the exhaust gas components to the maximum permissible concentrations is stipulated. Table 1 shows a comparison of the standards of some countries with a high level of mining industry [3-11].

For a long time, the Russian standard was the only regulation used to determine the required air quantity for the operating areas of internal combustion engine vehicles. However, after the technological development and introduction of emission standards for internal combustion engines, this standard became obsolete and could only serve as guidelines.

Currently, the dilution requirements for exhaust gases of internal combustion engines in the mining industry are specified in Paragraphs

| Country         | Conditional fresh air supply limit, m³/min per 1 HP |
|-----------------|-----------------------------------------------------|
| Australia       | 4.2–5                                               |
| Canada          | 4.0–7.7                                             |
| USA             | 5.0                                                 |
| Chile           | 5.3                                                 |
| China           | 5.5                                                 |
| South Africa    | 5.0                                                 |
| Russian Federation | 5.0                                                 |
### Table 2

CO and NOx emission limits for diesel engines in off-road vehicles according to the USA and EU toxicity standards, g/kWh

| USA standards | EU standards |
|---------------|--------------|
| Name          | Engine power | CO | NOx | Name          | Engine power | CO | NOx |
| Tier 2        | 130–560 kW   | 3.5 | 6.4 | Stage II      | 130–560 kW   | 3.5 | 6   |
| Tier 3        | 130–560 kW   | 3.5 | 4   | Stage IIIA    | 130–560 kW   | 3.5 | 4   |
| Tier 4        | 130–560 kW   | 3.5 | 0.4 | Stage IIIIB   | 130–560 kW   | 3.5 | 2   |
|               |              |     |     | Stage IV      | 130–560 kW   | 3.5 | 0.4 |

154, 335 and 344 of the Federal Rules and Regulations Safety Rules for Mining and Processing of Solid Minerals [12], stipulating that the required volume of air for dilution of the exhaust gas components is to be determined by carbon monoxide and nitrogen oxide components, as well as the minimum permissible air oxygen content of 20 %.

Another issue is the present-day quality of the diesel fuel and the impact of its composition on the concentration of the exhaust gas components.

At present, there are two national standards (GOST) for EVRO diesel fuel grades for diesel engines applicable in Russia:

- GOST R 52368-2005 (EN 590:2009) Diesel fuel EVRO. Specifications. [13] (National Standard)
- GOST 32511-2013 (EN 590:2009) Diesel EVRO. Specifications. [14] (Interstate Standard).

These standards provide requirements for the diesel fuel composition, including such properties as cetane number, fuel density, content of sulphur (mg/kg) and polycyclic aromatic hydrocarbons (mass %) in fuel, and other indicators for summer, winter and inter-season diesel fuel grades.

However, the content of sulphur and polycyclic aromatic hydrocarbons does not affect the content of carbon monoxide and nitrogen oxides in the exhaust gases of internal combustion engine vehicles. The emissions of carbon oxides and nitrogen oxides in exhaust gases are controlled by after-treatment and depend mainly on an engine’s emission class [15-20].

Internal combustion engine toxicity standards for off-road vehicles are determined in accordance with the following standards:

1. Stage - certification standard adopted in the European Union (EU) countries. It was first implemented by EU Directive 97/68/EC [21] in 1997, further revised in 2002 by Directive 2002/88/EC [22], setting emission limits for Stage I and Stage II emission standards. EU Directive 2004/26/EC [23] introduced emission limits for Stage IIIA, Stage IIIB and Stage IV emission standards in 2004.

2. EPA Tier – certification standard adopted in the USA. It was first introduced by the Code of Federal Regulations [24] in 1999, setting emission limits for Tier 1, Tier 2 and Tier 3 emission regulations. In 2012, the Code of Federal Regulations [25] was supplemented with emission limits for Tier 4 emission regulations.

These standards stipulate a limit of emissions for off-road vehicles by nitrogen oxides and carbon monoxide. The emission standards are given in Table 2.

Therefore, the procedure for determining the air quantity required to dilute exhaust gas components should provide determination variability subject to specific conditions to ensure safe working conditions.

### Determination of Air Quantity Requirement for Operating Areas of Internal Combustion Engine Vehicles in Underground Mines

Based on the previously mentioned, the following approaches are proposed to define the air quantity required for the operating areas of internal combustion engine vehicles.

1. By exhaust combustion gas parameters. The amount of harmful substances in the exhaust combustion gases can be determined through direct measurements in operating modes of the internal combustion engine vehicles. Based on these data, the airflow rate required to dilute the emitted harmful gases to the maximum permissible concentrations should be determined.

When designing mining enterprises, this approach can be used during technical upgrades or reconstructions of mines, when it is planned to engage some portion of the machinery fleet currently in operation. A long-term monitoring will help to identify the level of the harmful...
exhaust gas emissions, which will allow to define the required amount of air in the project.

However, this approach has its limitations. During machinery operations, the engine performance can vary entailing the increase in the emission of harmful and hazardous substances. In this case, the supply of previously calculated air quantities may be insufficient to dilute these substances. A comprehensive approach is essential to avoid the possibility of such a situation by introducing a limit on emissions that is higher than the actual level. For example, the emission standard can be adopted from the most contaminating vehicle in use. In addition, the quantity of harmful substances in the exhaust gases shall be monitored during operation by direct measurements in accordance with the requirements of paragraph 343 of the Safety Rules for Mining and Processing of Solid Minerals [12]. If the established emission limit is exceeded, such vehicle shall be withdrawn from operations for maintenance or repair. In this way, the operating company is encouraged to perform timely maintenance and renewal of the internal combustion engine machinery fleet.

On the other hand, exhaust-gas measurements for new vehicles with internal combustion engines, which are in a perfect technical condition, may indicate a low level of harmful substance emissions in exhaust gases. Furthermore, there is a risk of insufficient air supply in case of errors in the routine measurements of harmful combustion gas components of internal combustion engines. In this case, it would be advisable to reduce the risks by recalculating the level of harmful emissions to a conditional air supply limit per unit of the engine power and introducing a minimum airflow limiting rate.

The case of one of the underground mines can illustrate the situation described above. Based on the measurement statistics of the exhaust gas parameters, the required air supply limit per 1 HP of the internal combustion engine vehicles was determined. The standard air supply rate of 1.5 m³/min per 1 HP was adopted as the minimum value. The air supply below the value determined as per this limit is not allowed, even for those types of internal combustion engine vehicles with an air supply value of 0.8-1 m³/min per 1 HP, calculated based on the harmful substances emission level. An additional permissible emission standard providing for the air supply rate of 3 m³/min per 1 HP, determined with reference to the required airflow rate, was also introduced, allowing the vehicle operation.

2. By the engine emission class. The level of contaminants in the exhaust combustion gases of the procured vehicles cannot be determined directly under working conditions for newly designed mines. In this case, it is advisable to apply the maximum possible level of emissions that is guaranteed by the equipment manufacturer through the engine certification as per its emission class.

3. By oxygen content in the operating area of internal combustion engine vehicles. The issue of rating the oxygen content in the operating areas of the internal combustion engine vehicles should be also considered, as it is related to emissions of harmful substances. The quantity of air required to ensure the standard-compliant oxygen content is determined based on the specific fuel consumption rate of the internal combustion engine vehicles.

Thus, the quantity of fresh air supplied to the workings in the operating areas where the internal combustion engine vehicles are on a continuous or intermittent duty (Q_{CG}) shall be no less than required for static dilution of the main exhaust gas components (carbon monoxide, nitrogen dioxide calculated as NO₂) to the maximum permissible concentrations or for ensuring the standard-compliant oxygen content, and is defined by the expression given below:

\[
Q_{CG}, \ m^3/c = K_s \cdot \Sigma Q_{ICE}, \quad (1)
\]

where \( K_s \) is the simultaneity factor of operation of the internal combustion engine vehicles in a separate working, \( K_s = 1; 0.9; 0.85 \) at the simultaneous operation of one, two, three and more vehicles, respectively; \( Q_{ICE} \) is the air quantity required to ventilate each vehicle from harmful factors of internal combustion engines, m³/s [26].

\( Q_{ICE} \) is determined separately for each specified exhaust gas component (carbon monoxide, nitrogen dioxide calculated as NO₂) at the maximum possible engine speed and for oxygen. The highest obtained value of the airflow rate is taken as the required air quantity.

Determining the Required Air Quantity for Operating Areas of Internal Combustion Engine Vehicles

A more detailed determination principle is shown on the examples of some mining equipment.
used at producing mines. The equipment specifications given in Table 3 were used for the calculations.

### Table 3

| Model         | Toxicity Class | Engine capacity, l | Crankshaft speed, rpm | Power, kW |
|---------------|----------------|--------------------|-----------------------|-----------|
| ST-14 Tier 3B | Б              | 10.8               | 2,100                 | 224       |
| Cat R1700 Tier 3B | Б         | 11.1               | 2,100                 | 242       |
| MT-42 Tier 4  |                | 15.0               | 1,800                 | 391       |

**Principles of the Required Airflow Determination by Exhaust Combustion Gas Parameters**

To determine the required airflow based on the factor of an independent emission of the harmful exhaust gas components of the internal combustion engine vehicles in operation, the following expression for defining the required fresh airflow rate is used to dilute the harmful exhaust gas components to permissible values:

\[
Q_{ICE} = \frac{C_{exh}}{C_{mpc}} \cdot g_{exh},
\]

where \( C_{exh} \) is the concentration of the exhaust gas toxic components (carbon monoxide, nitrogen dioxide calculated as \( NO_2 \)), vol. %; \( C_{mpc} \) is the maximum permissible concentration for the corresponding component, the volume percent for CO is 0.0017 %, and 0.00026 % for NOx; \( g_{exh} \) is the quantity of the exhaust gases, m³/s.  

The quantity of the exhaust gases \( g_{exh} \) is determined by on-site measurements with the use of a flowmeter in modes stipulated by Paragraph 344 of the Federal Rules and Regulation (FNиP) [12]. When it is impossible to have a direct measurement of the exhaust gas flow, \( g_{exh} \) is calculated from the data in the vehicle technical data sheet using the expression for a four-stroke engine given below [27]:

\[
g_{exh} = \frac{k V n}{2},
\]

where \( k \) is the factor correcting for the pressure excess; \( V \) is the total cylinder capacity, m³; \( n \) is the crankshaft speed, rps (full speed as per the engine specification).

The results of calculating the required air quantity using the above method are shown in Table 4. Air sampling data of the mining equipment at one of the operating mines were used for calculations.

The use of the above formula is reasonable, as it takes into account the technical reserve, since the engine does not always run at full speed, and the average amount of the exhaust gas emissions is less than the maximum value calculated by the expression. This expression is applicable for both atmospheric and turbocharged engines, as confirmed by regulatory documents [28, 29] and scientific literature [30-39].

The measured volume concentration of the exhaust gas does not require recalculations when the exhaust gas flow temperature changes, according to the expression of the gas component volume concentration given below:

\[
C_i = \frac{V_i(P, T)}{V(P, T)},
\]

where \( V_i(P, T) \) is the volume occupied by the \( i \)-th gas component; \( P \) is the gas pressure, Pa; \( T \) is the temperature, K; \( V(P, T) \) is the total gas volume equal to the sum of volumes of all the components composing the gas.

### Table 4

| Model       | Air sampling, volume % | Required air quantity, m³/s |
|-------------|------------------------|-----------------------------|
|             | CO         | NO₂       | CO    | NO₂ |
| ST-14       | 0.0106     | 0.0052    | 1.2   | 3.8 |
| ST-14       | 0.0132     | 0.0104    | 1.5   | 7.6 |
| Cat R1700   | 0.0061     | 0.0052    | 0.7   | 3.9 |
| Cat R1700   | 0.0106     | 0.0026    | 1.2   | 1.9 |
| MT-42       | 0.01       | 0.002     | 1.3   | 0.2 |
| MT-42       | 0.01       | 0.01      | 1.3   | 8.7 |

With the change in atmospheric conditions (pressure and temperature), the parameters of all gas components change accordingly. Therefore, the volume occupied by a single gas component varies in proportion to the total volume of the gas. In such a case, the volume concentration does not change with the changes in atmospheric conditions.

If there are no required baseline data on measured harmful substance concentrations, the data sheet specifications of the engine’s hazardous
emissions are used for calculations. The expression (2) for such case is given below:

\[
Q_{ICE}, \text{m}^3/\text{min} = k \cdot \frac{C_{exh}}{C_{mpc} \cdot \rho} \cdot N, \quad (5)
\]

where \(k\) is the conversion factor, converting between hours and minutes, and between percentage and unit fractions; \(C_{exh}\) is the specific quantity of emissions for the corresponding component, kg/kWh; \(C_{mpc}\) is the maximum permissible concentration for the corresponding component, vol. %; \(\rho\) is the density of the corresponding gas, kg/m\(^3\), taken as equal to 1.15 kg/m\(^3\) for CO, and 2.1 kg/m\(^3\) for NOx; \(N\) is the engine power, kW.

### Air Quantity Determination by Engine Emission Classes

When designing new mines, sites or horizons, the procurement of new internal combustion engine equipment is considered. In this case, the air quantity requirement cannot be determined based on the actual harmful exhaust gas emissions. However, the equipment procured for mining operations is subject to mandatory engine toxicity certification, and the manufacturer confirms the engine's compliance to a certain emission class.

When a project provides for the procurement of the internal combustion engine vehicles, the airflow is calculated by the exhaust gas components based on the engine’s emission class according to the emission limits given in Table 2.

The airflow rate for the internal combustion engine vehicles is defined by the expression given below (5):

\[
Q_{ICE}, \text{m}^3/\text{c} = \frac{NY}{60}, \quad (6)
\]

where \(N\) is the engine power, HP; \(Y\) is the specific airflow rate per 1 HP of the engine power in accordance with the diesel engine toxicity standards, which are defined from Tables 5 and 6.

### Air Quantity Determination by Oxygen Content

According to paragraph 335 of FNiP [12], the quantity of air supplied to the operating areas of the internal combustion engine vehicles is to ensure a minimum oxygen content in the air of the operating areas of the internal combustion engine vehicles of 20% by volume.

Therefore, the air quantity shall also be determined based on the oxygen content factor in the operating areas of such vehicles.

#### Table 5

| Standard Engine power, HP | \(Y\), m\(^3\)/min per 1 HP |
|--------------------------|---------------------------|
| Tier 2/Stage II          | 177–760                   |
| Tier 3/Stage IIIA        | 177–760                   |
| Stage IIIA               | 177–760                   |
| Tier 4/Stage IV          | 177–760                   |

#### Table 6

| Model          | Standard | Engine power, HP | Required air quantity, m\(^3\)/s |
|----------------|----------|-----------------|----------------------------------|
| ST-14 Stage IIIB | 304.5    | 11.4            | 23.2                             |
| Cat R1700 Stage IIIA | 329.0    | 12.3            | 25.1                             |
| MT-42 Tier 4     | 531.6    | 19.8            | 8.2                              |

The oxygen content is determined based on the expression describing the chemical reaction of hydrocarbon fuel oxidation. According to this expression, there is a stoichiometric level of oxygen for each fuel grade, i.e. the amount needed for the complete fuel combustion (\(L_0\)).

The fuel contains C/100 kg of carbon, H/100 kg of hydrogen, S/100 kg of volatile sulphur and O/100 kg of oxygen. Therefore, the stoichiometric amount of oxygen (\(L_0\)) is determined subject to the complete combustion of all fuel by stoichiometric equations, as given below [17-20, 40]:

\[
L_0, \text{kg} = \frac{2.67C + 8H + S + O}{100}. \quad (7)
\]

Therefore, the stoichiometric amount of oxygen is determined for each fuel grade individually and depends on its chemical composition. The elemental composition of diesel fuel grades is given in Table 7 [17-20, 41].

Based on the elemental composition data of diesel fuel grades, the content of individual components in fuels varies within a narrow range and should be considered as relatively constant. In
this case, the stoichiometric amount of oxygen can also be considered a constant number. The average of mass fraction of air oxygen is taken as equal to 0.232. The combustion of 1 kilogram of fuel requires the quantity of air that is called the stoichiometric amount of air \( L_0 \). According to [17-20, 42], the stoichiometric amount of air \( L_0 \) is 14.42 kg for the summer-grade diesel fuel.

The above conditions present an ideal case. However, under real conditions the mixing of fuel and air in the engine working cylinder is different. Commonly, the engine runs with air excess or deficiency. For this reason, to determine the required air supply to the engine, \( \alpha \) value, referred to as the air excess factor, which shows the ratio of the actual quantity of air supplied to the engine to the theoretical amount, is used. The \( \alpha \) value is always greater than 1, and for diesel engines it ranges from 1.3 to 2.2 depending on the design features [15-19, 43-45]. It should be noted that the same amount of oxygen is used in the fuel combustion, and the oxygen not used in the process is emitted into the atmosphere as part of the exhaust gases. The amount of residual oxygen is defined by the expression given below:

\[
I_{\text{resc}}, \text{kg} = 0.21 (\alpha - 1) L_0.
\]  

(8)

Therefore, for the internal combustion engine vehicle, the airflow rate \( (Q_0) \) required for the engine operation is defined by the expression given below:

\[
Q_0, \text{m}^3/\text{c} = \frac{21 \cdot L_0 \cdot N \cdot q}{3600 \cdot \rho \cdot K_0},
\]  

(9)

where \( N \) is the engine power rating, kW; \( q \) is the specific fuel consumption at rated power, kg/kWh; \( \rho \) is the air density (taken as equal to 1.23 kg/m\(^3\)); \( K_0 \) is the oxygen content in the air supplied for ventilation, vol. %, assumed as equal to the oxygen content in the atmosphere, as the mines use a separate ventilation of the operating areas (Table 8).

### Table 7

**Elemental composition of diesel fuel**

| Chemical element | Component’s proportion, mass % |
|------------------|--------------------------------|
| Carbon           | 85.5–87.0                      |
| Hydrogen         | 12.8–14.0                      |
| Volatile sulphur | 0.2–1.0                        |
| Oxygen           | 0                              |

### Table 8

**Air quantity determination results by oxygen content**

| Model         | Required air quantity, m\(^3\)/s |
|---------------|----------------------------------|
| ST-14         | 4.1                              |
| Cat R1700     | 4.4                              |
| MT-42         | 7.8                              |

### Table 9

**Air quantity determination results by toxicity standards**

| Model         | Samples | Toxicity standard | \( O_2 \) | Max | \( Y \) \(_{\text{m3/min per 1 HP}}\) |
|---------------|---------|-------------------|---------|-----|----------------------------------|
| ST-14         | 1.2     | CO 3.8            | 11.4    | 23.2| 4.1                              |
|               | 1.5     | CO 7.6            | 11.4    | 23.2| 4.1                              |
| Cat R1700     | 0.7     | NO\(_x\) 3.9       | 12.3    | 25.1| 4.4                              |
|               | 1.2     | CO 1.9            | 12.3    | 25.1| 4.4                              |
| MT-42         | 1.3     | CO 0.2            | 19.8    | 8.2 | 7.8                              |
|               | 1.3     | NO\(_x\) 8.7      | 19.8    | 8.2 | 7.8                              |

Calculations based on the above procedure allow us to determine the amount of air required to dilute the exhaust gas components. A comparison of the calculated values of the components is given in Table 9.

The component with the highest calculated value should be used in the final calculation. The proposed procedure for the air quantity requirement determination provides variability of the approach. Depending on specific situations and the availability of the required baseline data, the air quantity required for dilution of the exhaust gas carbon monoxide and nitrogen oxides can be determined based on on-site sampling.
operating vehicle data sheet or engine toxicity standards. In the case in question, the exhaust gas samples were taken from vehicles in operation, and the determination by engine toxicity standards was performed as an example. In the final comparison, the results of the calculation based on the diesel engine toxicity standards should not be taken into account due to the availability of test measurements of the exhaust gas components for a number of similar vehicles. The calculations based on engine toxicity standards should be performed at the design stage for new sites, horizons or mines in case new vehicles are being procured, where on-site exhaust gas sampling data or engine data sheet specifications are not available.

Conclusions

By using the above calculations as an example, it can be concluded based on the exhaust gas sampling data from the vehicles in service that the actual fresh air supply rate is in fact lower than the toxicity standard requirements. This may be partly due to the technological process of mining equipment, its operating cycle differing from that of an engine certified to EPA Tier and Stage standards.

Modern machinery with good exhaust gas after-treatment units ensures reduction of the exhaust gas component concentrations to the values stipulated by the applied overseas Stage and EPA Tier standards. However, the actual mining equipment operating conditions impact real emissions of hazardous and poisonous exhaust gas components, which affects the determination of the air quantity required for their dilution. As evidenced in practice, many mining enterprises validate the fresh air supply rate for the exhaust gas components dilution ranging from 1.5 to 3.0 m³/min per 1 HP of the engine power in the Russian Federal Service for Environmental, Technological, and Nuclear Supervision.

The application of the above methods to determine the air quantity required for the exhaust gas components dilution will make it possible for mining companies to define the actual fresh air supply requirement when operating machinery powered by the internal combustion engines, and to identify the most suitable equipment for design companies subject to the specific conditions of each deposit, which will allow us to enhance the effectiveness of the ventilation equipment resources.

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