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LEMI-SYSTEM IN THE AEROLOGY OF THE UNDERGROUND MINING

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One of the most important problems of contemporary mining aerology is considered in the present paper - the ensuring of normal atmosphere, when working underground and using stationary and mobile diesel equipment there. Taking oil shale mines in Estonia as an example, it has been shown that a convective-diffusional removal of harmful components from the exhaust gases of diesel equipment in the operating zones of mines by means of general mine ventilation is impossible. It has also been indicated that, when trying to solve this problem, such methods seem to be effective that make it possible to reduce the concentrations of exhaust gases already at the initial stage of gas formation. The description of one of the most modern methods is given here, worked out by a Swedish firm LEMI AB. The results of the tests were carried out on bulldozers operating in mines and the LEMI-System was applied.

A chamber-pole system makes it possible to use a series of mining equipment, and ensures a high mechanization level of production processing of cleaning faces.

Preparation of chamber blocks is carried out by means of sinking between the panel drifts of an assembly drift, two side drifts and a cutting chamber. Panel drifts pass through 600-700 m, the width of a chamber block is up to 400 m (Fig. 1).

The demolition of a statum (bed) in chamber blocks is carried out by drilling-blasting hammering having previously notched the bed with notching machines. The drilling of boreholes is done by drilling machines. When loading the rocky mass on the faces, machines with combing claws ŠNB-2 are used, as well as underground bulldozers.

Indirect roofing in cleaning faces of chamber blocks is fixed with a wedge-shaped ripping timbering with the length of 1.6-2.3 m. Transportation of the rocky mass along the chamber block is carried out with combing conveyors and conveyor belts.

Rocky mass is brought to the yard close to the props by rail transport or by conveyor belts.

In spite of a number of shortcomings inherent in a chamber system, e.g., such as oil shale losses of 25-28 % in props, the transportation of about 15 % of limestone seams inside the mass, and inclusions, there is the necessity of

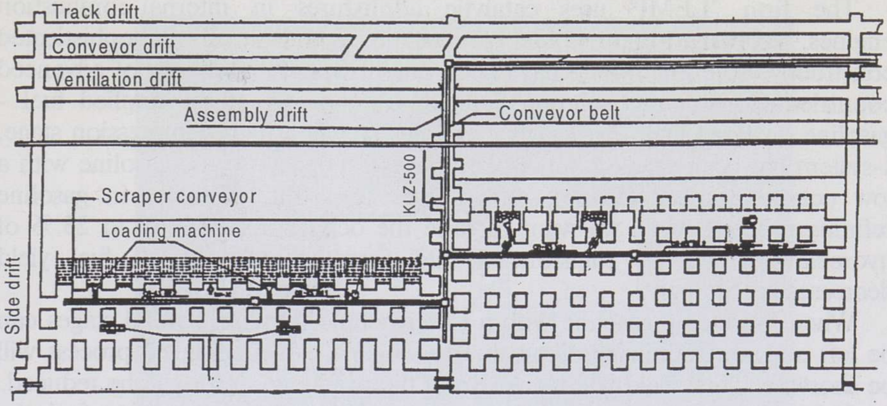


Fig. 1. Diagram of the cleaning face with the equipment set

enriching the mass, in order to get commercial oil shale, and one can say that the chamber-prop system has high technical-economical indices. We foresee the development of this system, when applying new and more productive mining techniques.

One of the trends lies in using loading-transportation machinery in cleaning operations.

Since 1988, in the mine *Ahtme*.

The efficiency of applying the chamber system of processing at the present time depends, to a considerable extent, on the way of utilizing bulldozers in cleaning operations. The surplus of an extensive space in chamber blocks leads to the fact that rocky mass falls into it, when carrying out blasting operations. Loading it on conveyors by slow-moving rock-loading machinery is a lengthy process and not a very productive one. Attempts in trying to use bulldozers with electric drives for cleaning the soil proved to be not very productive as well.

Up till now, a mobile diesel bulldozer has been indispensable, when transferring face-fixing conveyors from chamber to chamber.

The design improvement of intercombustion engines is mainly concerned making the combustion process effective. The respective theoretical foundations in this field were worked out by Prof. Yuan T. Lee, who was awarded the Nobel Prize for this in 1986. The necessary technical solutions and means were worked out by the firm "LEMI" [1].

When experimenting with different makes of cars, it was proved that, when applying the firm "LEMI" technical solutions, carbon oxide (CO), hydrocarbons (HC) and nitric oxides (NO_X) would be reduced, respectively, to 80, 75 and 75 % in exhaust gases.

Depending on different load conditions and the type of an engine, the actual reduction of harmful admixtures in exhaust gases varies from 20-60 %. Catalytic admixtures worked out by the firm "LEMI" are dosed into the engine by means of a special carburettor-catalyzer. In the engines of the vehicles supplied with this auxiliary device, due to a more complete fuel combustion at the same fuel consumption and engine capacity, fuel consumption decreases.

The firm "LEMI" uses catalytic admixtures in internal-combustion engines, in order to improve fuel combustion, as well as various sophisticated constructive solution, which have been patented in the majority of advanced countries. Constructive solution depends on the sort of the applied fuel - gasoline or diesel fuel. For gasoline engines having a high compression stage, I-system has been worked out, which makes it possible to use gasoline with a low octane number (55-60), and is free of sulfur. Namely, in gasoline refining process, when we want to raise the octane number, up to 25 % of hydrocarbons will be transformed into gases, due to which fuel yield decreases accordingly.

When producing gasoline with a lower octane number, several stages can be left out in a refining process, due to which the technological process will be shortened, fuel yield will increase and the production cost will be reduced.

In case of diesel engines, LEMI injector is applied for squirting fuel. An injector, when combined with catalytic additives in the fuel, will substantially raise the effect of reducing harmful components and soot content in exhaust gases.

The "LEMI" firm's carburettor-catalyzer system consists of a receptacle, a hose and its nozzle and catalytic liquid, together with hydrogen peroxide (activizer). The unit is connected with the engine draught pipe by a hose and its nozzle (Fig. 2).

When starting the engine, air is sucked into the unit by the low compression that crops up. The air is dispersed and directed to circulate the liquid. The dispersed air gone through the unit, already contains the fuel additive in the form of microscopic droplets. The air flown from carburettor-catalyzer meets the fuel mixture coming from the engine carburettor in a sucking pipe and goes on to the cylinders.

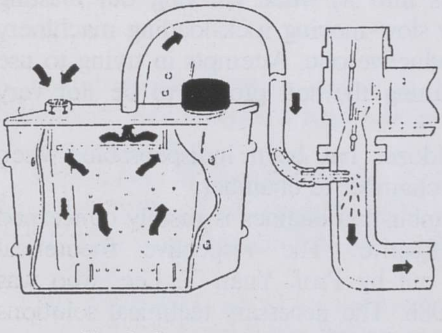


Fig. 2. Carburettor-catalyzer of the LEMI-System

Improvement in combustion is achieved in the way that the catalytic admixture itself affects the fuel (gasoline, diesel fuel) at the initial stage of combustion. The greater the fuel need of cylinder, the greater the consumption of catalytic liquid. For example, for an engine with an operational capacity of 2000 cm^3, one bottle (0.5 l) is sufficient, the cost being ~ 9 EEK for covering 2000 km.

A limiting factor, when applying bulldozers with DVS in chamber blocks, is their little efficiency in removing exhaust gases from the operational zones by means of overall ventilation in mines. In order to find out the maximum possibilities for such kind of airing of chamber blocks, we carried out investigations in mines, as to the convective-diffusional characters of ventilation flows, generated by sectional and main ventilators of airing.

The experiments resulted in determining the fields of mean and pulse velocities, microscales of turbulence, coefficients of turbulent diffusion.

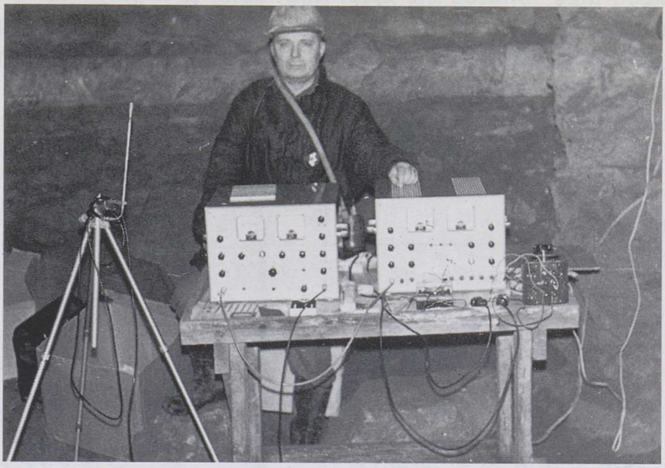


Fig. 3. Thermoanemometer with probes 55A25 and 55A32

Measurements of mean and pulse velocities were carried out with a thermoanemometer DISA ELEKTRONIK. Probes 55A25 having a tungsten filament with the length of 1.5 mm, diameter of 5 μm, and X-shaped probes of 55A32, were device for measuring turbulent characteristics of the ventilation flow and the probes 55A25 are shown in Fig. 3.

Thermoanemometer sensors were tarred in a standard test device, measuring probes were fixed to the supporter on a regulated tripod. Levelling of the probes was carried out by means of a cathetometer.

Airflow temperature was registered by a self-reading equally hung bridge in a set of a platinum resistance thermometer, with the diameter of 1.4 mm and length of 2 mm.

Coefficients of turbulent diffusion were determined by means of local turbulence characteristics [1].

In transverse chambers, from the collecting drift to the processed area and towards the face, air velocity is the variable size, and it depends on the volume of the processed area, Figures 4 and 5. Air velocity is differently distributed in the other directions as well.

According to the curve characteristics, indicating air consumption changes, the face area can conditionally be divided into the following zones:

- Zone of jets, formed, when airflow passes from the collecting drift into the semi-block. Air exchange of this zone depends on the aerodynamic resistance of the chamber semi-blocks;
- Zone of the ventilating jet of minimum activity, which is formed in the central part of the transverse chamber of the semi-block. Depending on the aerodynamic resistance of the processed area and the absorption spectrum of the side drift mouth, up to 30-40 % of air takes part in the air exchange here, of the air that is entering the semi-block;
- Zone of ventilating jet's maximum activity, to be formed because of the absorption spectrum, and is formed at the side drift, depending on the processed area of the chamber semi-block. Airflow takes place from the

processed area towards the face, and along it towards the side drift. In this zone, the flow-out of gaseous admixtures reaches its maximum, in spite of the fact that part of the air, entering this zone, is previously put out. Air amount increases, when it approaches the side drift, because of air influx from the processed area.

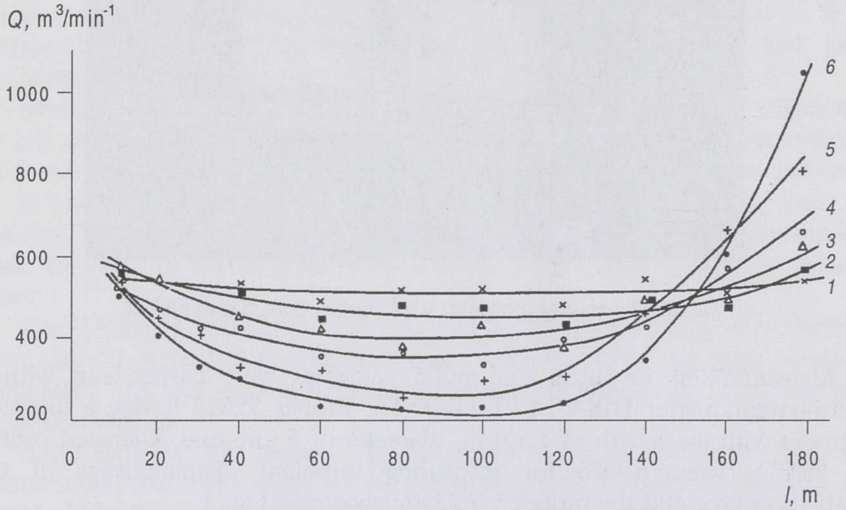


Fig. 4. Air amount distribution depending on the length of the processed area: *1* - l_1 = 75 m, *2* - l_1 = 150 m, *3* - l_1 = 225 m, *4* - l_1 = 330 m, *5* - l_1 = 450 m, *6* - l_1 = 600 m

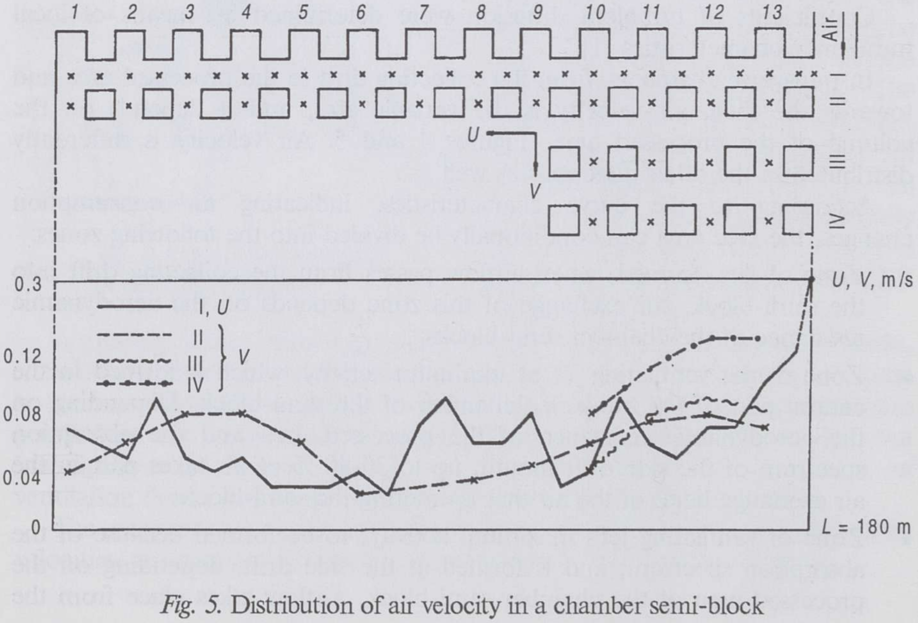


Fig. 5. Distribution of air velocity in a chamber semi-block

Table 1. **Emission Tests**

Emissions	Test 1	Test 2	Test 3	Test 4	Improvement, average %
Soot (Bosch units)	7.2->0.7	5.1->0.7	5.8->0.8	5.8->0.8	89
NO_x ppm 10^{-6}, m^3/m^3	700->50 NO, NO_2	600->100 NO, NO_2	1400->400 NO_x	600->200 NO, NO_2	78
CO ppm 10^{-6}, m^3/m^3	1000->50	120->20	2600->15	3000->0	94
CH ppm 10^{-6}, m^3/m^3	1400->25	600->10	200->150	30->9	73

Table 3. **D_x Coefficients in the Dead End Parts of the Longitudinal Chambers at $B = 7.5$ m, $h = 2.8$ m**

Ne	Dead end length l (m)	Outer flow velocity U_{cp} (m/s)	L/B	Coefficient D_x (m^3/s)
1	2	0.25	0.27	0.1
2	3	0.25	0.4	0.08
3	5	0.25	0.67	0.05
4	8	0.25	1.1	0.001
5	2	0.15	0.27	0.007
6	3	0.15	0.4	0.04
7	8	0.15	0.67	0.02
8	8	0.15	1.1	0.0003

In order to get numerical values of turbulence intensity, $\frac{\sqrt{u'^2}}{U}$, of the operational zone of the semi-block and other processed areas; measurements were done with a thermoanemometer.

The results of these measurements are presented in Table 1, and it can be seen from there that the surplus of direct and T-shaped dead ends will not bring about a noticeable rise in the turbulence intensity going along to dead ends of the transverse chamber part. Turbulence intensity increases in the straight part of the T-shaped dead end. In the other part of the dead end, turbulence intensity is rather small.

In the drift-type output, timbering elements stipulate the rise in the mean turbulence intensity alongside the section. Mean turbulence intensity increase is stipulated by the rise in aerodynamic resistance of processing.

Turbulence intensity measurements, $\frac{\sqrt{u'^2}}{U}$, in the dead end, are presented in Fig. 6. As can be seen from the Figure, turbulence intensity increases in the layer of mixing the circular flow with the surging one. When increasing the length of the dead end, turbulence intensity in the area of a break-off decreases in inverse ratio to the length of the dead end.

On the basis of the research into turbulent mixing in limited jets, one can describe the process of diffusion in the dead end.

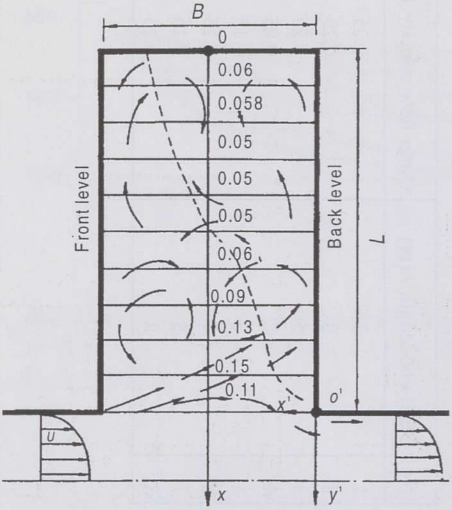


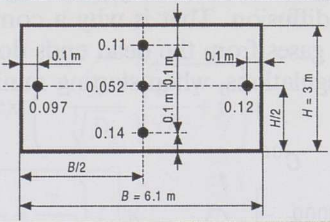
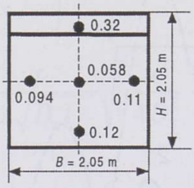
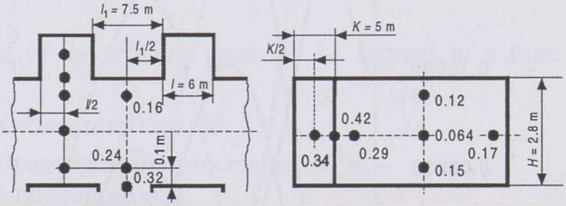
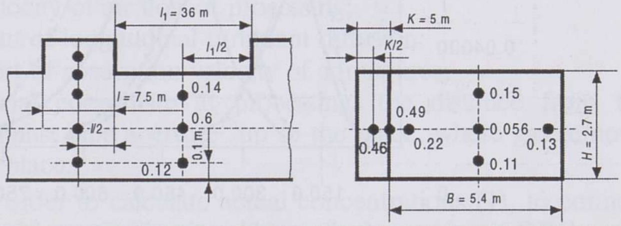
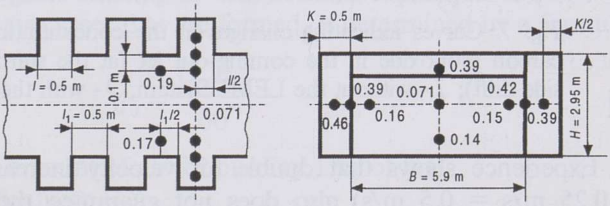
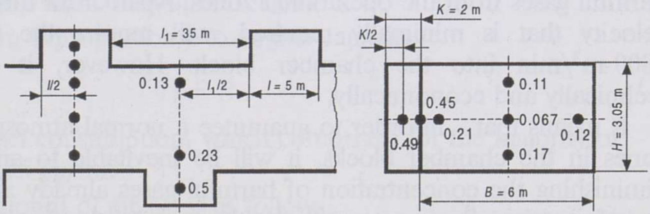
Fig. 6. Measuring turbulence intensity in the dead end part of the longitudinal chamber

Coefficients of turbulent diffusion are closely connected with the intensity of velocity pulsations. When increasing the latter ones, the coefficients of turbulent diffusion increase as well. It means that greater values of coefficients of longitudinal turbulent diffusion D_x are observed in the zone of mixing circular flow with the outer flow. When increasing the length of the dead end, maximum D_x end in the mixing layer practically remains constant (Fig. 7). In the conditions of airing the chamber block, maximal values of D_x in the dead end parts of longitudinal chambers do not exceed 0.1 m^3/s (Table 2).

The analysis of the obtained results indicates that:

- airing the chamber blocks on account of general mine (or sectional) ventilation will not ensure normal sanitary-hygienic labour conditions for miners, envisaged by safety regulations of the mining industry, since:
- ventilating jet's activity is rather small, especially in the central part of the semi-block;

Table 2. **Measurements of Turbulence Intensity of Processed Areas**

Type	Diagrams of processed areas and location of measured points
Outputs achieved by drilling blasting method with an anchor timbering	
Output fixed from three sides with concrete, with metallic cross-beams, with a longitudinal calibre 10	
Output fixed with pipes of reinforced concrete, with metallic girders from "I"	
Output with one-sided necks	
Output with two-sided necks	
Output with two-sided necks	

- air flow velocity does not exceed the values of 0.09 m/s (the required minimal air velocity $U = 0.25$ m/s);
- diffusion coefficients in longitudinal chambers are the same as those of molecular diffusion. That is why a convective transition and the removal of harmful gases from the dead ends do not take place, which contradicts to safety regulations, when starting mining operations.

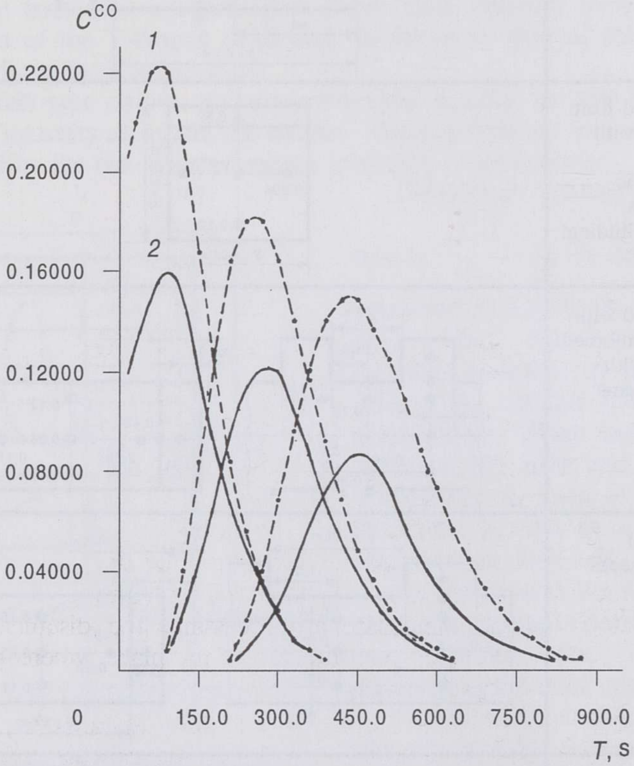


Fig. 7. Curves indicating changes in the concentrations of conditional carbon monoxide in the coming-out jet (at the starting section of the side drift); *1* - without the LEMI-System, *2* - with the LEMI-System

Experience shows that double air velocity increase in chamber blocks (2·0.25 m/s = 0.5 m/s) also does not guarantee the turbulent outflow of harmful gases from the operational zones. Apart from this, the increase of air velocity that is minimally required, will require the air input of about 2800 m^3/min into the chamber block. However, it is impossible both technically and economically.

It means that - in order to guarantee a normal atmosphere of operational zones in the chamber blocks, it will be inevitable to apply local means in diminishing the concentration of harmful gases already at the initial stage of their formation. Such means can be the ones by the firm's "LEMI" system.

Calculation Model of Concentrations of Exhaust Gases, when a Bulldozer Is in Operation at a Face

The distribution of exhaust gases in a chamber semi-block can be expressed by the following equation:

$$c(x,t)=\frac{c_0}{2}\exp\frac{ux}{2D_x}\left\{\exp\left(-\frac{x}{\sqrt{D_x}}\sqrt{\frac{u^2}{D_x}+\gamma}\right)\times\right.$$

$$\times\, ercf\left[\frac{x}{2\sqrt{D_x t}}-\sqrt{\left(\frac{u^2}{4D_x^2}+\frac{\gamma}{D_x}\right)t}\right]\times \tag{1}$$

$$\left.\times\exp\left(\frac{x}{\sqrt{D_x}}\sqrt{\frac{u^2}{D_x}+\gamma}\right)\, ercf\left[\frac{x}{2\sqrt{D_x t}}+\sqrt{\left(\frac{u^2}{4D_x^2}+\frac{\gamma}{D_x}\right)t}\right]\right\}$$

where $c_0=\frac{c_0^{/}q_0}{Q}$;

q_0 - the amount of the exhaust gases, to be formed in a time unit, m^3/s;

$c_0^{/}$ - exhaust gas concentrations, %;

Q - air amount passing at the processing, m^3/s;

C - exhaust gas concentrations;

U - mean velocity of air flow at processing;

D_x - coefficient of longitudinal turbulent diffusion;

γ - coefficient of absorption velocity of admixtures;

x - longitudinal coordinate at processing, the distance from the DBC exhaust pipe aperture up to the place, where gas removal is taking place.

It is expedient, in order to calculate actual concentrations (1), to connect the amount of exhaust gases entering it, with nominal capacity of DBC.

The amount of exhaust gases that are formed, is determined by a formula

$$q_0=\frac{Q_T q_T}{60} \tag{2}$$

where Q_T - necessary amount of air for burning 1 kg of fuel, kg·mole/(kg·fuel);

q_T - an hourly fuel consumption, kg/h.

Fuel consumption is proportional to engine capacity

$$q_T=g_N \tag{3}$$

where g - specific fuel consumption, which comprises, for the majority of DBC, 0.175 kg/h.f.

The necessary amount of air Q_T is as follows

$$Q_T=kL_0 \tag{4}$$

where k - coefficient of surplus air (usually $k = 2$);

L_0 - theoretical needed amount of air for full combustion of 1 kg of fuel, kg·mole/(kg·fuel)

$$L_0 \frac{1}{0.21}\left(\frac{\mathrm{C}}{12}+\frac{\mathrm{H}}{4}+\frac{\mathrm{S}}{32}-\frac{\mathrm{O}}{32}\right) \tag{5}$$

where C, H, S, O - composition of main components in the fuel, as to its weight, kg/(kg·fuel).

For average diesel fuel C = 0.87, H = 0.126, O = 0.004. Consequently, $L_0 = 11.11$ and $Q_T = 22.2$.

When presenting the obtained values in (2), we get

$$q_0 - 0.65N \tag{6}$$

Referring to (6), the dependence (1) looks as follows:

$$\begin{aligned} c(x,t) = {} & \frac{0.65N}{2uS} c_0 \exp\frac{ux}{2D_x}\left\{\exp\left(-\frac{x}{\sqrt{D_x}}\sqrt{\frac{u^2}{D_x}+\gamma}\right)\times\right. \\ & \times\, ercf\left[\frac{x}{2\sqrt{D_x t}}-\sqrt{\left(\frac{u^2}{4D_x^2}+\frac{\gamma}{D_x}\right)t}\right]+ \\ & \left.+\exp\left(\frac{x}{\sqrt{D_x}}\sqrt{\frac{u^2}{D_x}+\gamma}\right) ercf\left[\frac{x}{2\sqrt{D_x t}}+\sqrt{\left(\frac{u^2}{4D_x^2}+\frac{\gamma}{D_x}\right)t}\right]\right\} \end{aligned} \tag{7}$$

When determining the engine toxicity, operating underground, concentrations of nitrogen oxides are taken into consideration (recalculating them to N_2O_5), oxides of carbon and aldehydes. As there are few aldehydes forming, one does not need to consider them as important.

Then

$$c_0 = \frac{13.0C^{N_2O_5} + C_0^{CO}}{C_{gon}} \tag{8}$$

Now we finally get c_0:

$$\begin{aligned} c(x,t) = {} & \frac{0.65N(13.0C_0^{N_2O_5} + C_0^{CO}}{2uS} c_{gon} \times \\ & \times \exp\frac{ux}{2D_x}\left\{\exp\left(-\frac{x}{\sqrt{D_x}}\sqrt{\frac{u^2}{D_x}+\gamma}\right) ercf\left[\frac{x}{2\sqrt{D_x t}}-\sqrt{\left(\frac{u^2}{4D_x^2}+\frac{\gamma}{D_x}\right)t}\right]\times\right. \\ & \left.\times \exp\left(\frac{x}{\sqrt{D_x}}\sqrt{\frac{u^2}{D_x}+\gamma}\right) ercf\left[\frac{x}{2\sqrt{D_x t}}+\sqrt{\left(\frac{u^2}{4D_x^2}+\frac{\gamma}{D_x}\right)t}\right]\right\} \end{aligned} \tag{9}$$

Calculations according to (9) are carried out by PC. At that

$$D_x = 5.05u \cdot d\text{э} \qquad (10)$$

$$\gamma = 0.051 S_M m u \qquad (11)$$

where $d\text{э}$ - diameter of a cross-section in an operational zone,
$d\text{э} = 1.12\sqrt{S}$;
S_M - middle-left section of the machine with DBC;
M - gas exchange coefficient, the value of which is equal to ~0.2

In Fig. 7 curves are presented indicating the changes in the concentrations of conditional carbon monoxide, obtained by means of a mathematical model (1) and also changes in the initial concentrations of exhaust gases.

In order to determine the dynamics of concentration, and the movement of bulldozer's exhaust gases in the chamber block, gas probes were taken at the outlet of the exhaust pipe and in various sections of longitudinal and transverse chambers, as to the movement of the ventilating flow. Temperature, relative moisture and air quantity were measured by means of the firm's appliances.

Gas-air admixture probes were selected, indicating the content of carbon oxide, nitrogen oxides and other ingredients, while using special methods. The probes were analyzed in chemical laboratories of the Academy of Sciences and at the State Enterprise *Eesti Põlevkivi*.

The outcome of the analyses is presented in Table 3.

The processing and analysis of gas-air surveys, carried out in mining conditions, indicate that the application of LEMI-System is effective, when trying to reduce the concentrations of harmful components of the bulldozers' exhaust gases at the initial stage of their formation.

Probes, concerning soot extraction, were not systematically processed by us. However, the analysis of some taken probes indicates considerable soot reduction in the exhaust gases, when bulldozers operate with the LEMI-System.

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