Ventilation in long blind stopes during operation of load–haul–dumpers with combustion engines

EV Nakaryakov* and EL Grishin
Mining Institute, Ural Branch, Russian Academy of Sciences, Perm, Russia
E-mail: *nakariakov.ev@gmail.com

Abstract. The paper describes the in-situ test data and mathematical modeling results on ventilation in long (more than 10 m) blind stopes during operation of load–haul–dumpers with combustion engines. The change in the toxic gas concentration versus the running time of the machinery in the stopes is determined, and the appropriate relations are derived.

1. Introduction
In Russia there are no standards on ventilation in blind stopes formed as expansion of board gates during retreat mining [1]. The total length of such blind stopes, for instance, in mines of Talnakh copper–nickel province reaches 30 m. The working area in a blind stope can reach the length more than 10 m (Figure 1). Due to the lack of regulatory documents, it is required to investigate the processes of ventilation in blind stopes and study efficiency of removal of harmful exhaust gas generated during operation of load–haul–dumpers, as well as the dependence of toxic gas concentrations in the miner workplace on the working conditions of machinery and on ventilation parameters.

Figure 1. Blind stope, face and workplace of remote load–haul–damper’s operator.
Table 1. Average concentrations of CO, vol.% in stopes of different length L

| L (m) | 10 | 20 | 30 | 40 | 50 | 60 |
|-------|----|----|----|----|----|----|
| cB*   | 0  | 0  | 0  | 0  | 0  | 0  |
| cO**  | 0  | 0  | 0  | 0  | 0  | 0  |
| cB    | 0  | 0  | 0  | 0  | 0  | 0  |
| cO    | 0  | 0  | 0  | 0  | 0  | 0  |

*<cB>—average gas concentration in terms of CO at the board gate and stope boundary
**<cO>—average gas concentration in terms of CO at the outlet of the board gate

2. Mathematical model and results of its verification

Mining scientists discuss ventilation of blind stopes during operation of load–haul–dumpers. The known model of emission of exhaust gases from operating load–haul–dumpers [2] takes into account parameters of LHD gas emission, supplied air and volume of the blind stope. The dependence of gas concentration in the stope, vol.%; is given by:

\[
\bar{C}(T_{\text{run}}) = C_{\text{max}} - (C_{\text{max}} - C_{\text{init}})e^{-k_{1}T_{\text{run}}},
\]

where \(C_{\text{max}}\) is the maximum possible asymptotic concentration of gas, vol.%; \(C_{\text{init}}\) is the initial gas concentration in the stope, vol.%; \(k_{1}\) is the coefficient of gas concentration velocity, s\(^{-1}\), found from the formula:
\[ k_i = \frac{k_T Q}{v}, \]  

(2)

where \( k_T \) is the coefficient of turbulent diffusion of free airflow, determined as is [2]; \( Q \) is the air flow rate, \( m^3/s \).

The maximal possible asymptotic value of average gas concentration in the working areas, according to the Ural Federal University research [3], is calculated from the expression:

\[ C_{\text{max}} = \frac{g_{ex} C_{ex}}{k_T Q}, \]  

(3)

where \( g_{ex} \) is exhaust gas after scrubbing, \( m^3/s \); \( C_{ex} \) is the concentration of toxic exhaust gases (carbon oxide, nitrogen dioxide in terms of NO2), vol.\%.

Applicability of the model of incremental gas concentration as function of running time of load–haul–dumpers was evaluated during field research and during mathematical modeling of ventilation in blind stopes formed as expansion of board gates during retreat mining with broken ore loading by remotely operated load–haul–dumpers.

First, we determined parameters of the mathematical model. At the outlet of the vent duct, we set the average air flow velocity, the turbulence intensity \( I_{\text{turb}} = 2\% \) and the turbulence eddy size \( E_{\text{turb}} = 0.2 \) m [4]. Air flows about the stope and the gate drift and leaves the computational domain along the surface where the zero static pressure is set. On the sidewalls of the stope, ‘adhesion’ of airflow is assigned. The calculation of the boundary layer takes into account roughness of the sidewalls. The sidewall roughness is 0.03 m. The model is verified using data of in situ measurements.

The coefficient of turbulent diffusion of free airflow and the determination procedure are discussed in [5]. With a view to evaluating the free airflow turbulent diffusion coefficient \( k_T \), ventilation of a blind stope of different length (from 10 to 60 m) was modeled mathematically. From the modeling results, the average values were obtained for the gas concentration at the boundary of the board gate and the stope and at the outlet of the board gate. These values are compiled in Table 1.

The average concentrations in terms of CO (vol.\%) for stopes of different length in Table 1 are approximated by the exponential dependence (formula (1)) in Wolfram Mathematica. The resultant approximated relationship of the incremental average gas concentration and the running time of LHD in stope 60 m long is demonstrated in Figure 2.

The approximation assumed that exhaust gas after scrubbing was 0.189 \( m^3/s \); concentration of toxic exhaust gas in terms of CO was 0.1349 \%; air supply in the working area was 15 \( m^3/s \). The approximation results are summarized in Table 2.

![Figure 2. Approximated relationship of incremental average gas concentration and LHD running in stope 60 m long.](image-url)
Table 2. Coefficient of turbulent diffusion of free air flow and ventilation volume in stopes of different lengths

| Length, m | $k_T$     | $V_{vent}$ | $R^2$* |
|-----------|-----------|------------|--------|
| 10        | 1.001385  | 319.977    | 0.999534 |
| 20        | 0.994725  | 339.672    | 0.999833 |
| 30        | 0.992015  | 328.329    | 0.999878 |
| 40        | 0.988367  | 324.257    | 0.999897 |
| 50        | 0.983128  | 326.115    | 0.999978 |
| 60        | 1.013731  | 329.428    | 0.999908 |

*R^2—coefficient of determination

From the approximation results of the average gas concentration in the working zone, the coefficient of turbulent diffusion of free air flow in a long blind stope in a Talnakh ore province mine is 1 (given sufficient air supply in the working area). Also, from these results, the ventilation volume in a long blind stope ranges as 320–340 m³ (given sufficient air supply). The ventilation volumes are the same in different length stopes. This happens since with elongation, the shape of the stope to be ventilated remains the same as LHD operates nearby the stope and board gate boundary. The ventilation volume in the model is determined based on the section of the stope and the length of the ventilation jet from the vent duct to the muck pile. The ventilation volume in the model is 780 m³. Due to this difference between the approximation result and the model result, we introduce a correction factor of 0.5 in (2).

At the second stage of the modeling, we evaluated the effect of air supply quality and initial gas concentration in the stope on the gas concentration in the operator’s workplace. The modeling results and the resultant data approximation are depicted in Figure 3.

Figure 3. Approximated relationships between incremental average gas concentrations and LHD running time at different air supply: 1—7, 2—15 and 3, 4—21 m³/s. The points and lines depict the modeling and approximation, respectively. The abscissa axis is time, s; the ordinate axis is the average gas concentration in terms of CO, fractions.

Curves 3 and 4 in Figure 3 depict air supply of 21 m³/s in the stope at the initial gas concentrations of 0.0006% (curve 3) and 0 (curve 4). The concentration–time curves clearly tend to an
asymptotic value (Figure 3). This asymptote is $\frac{g_{\text{out}}}{Q}$. In this manner, expression (2) is adjusted and refined with respect to gas concentration during the research.

The expression of the coefficient of gas concentration velocity in the working area takes on form:

$$k_i = \frac{Q(C_{\text{max}} - C_{\text{in}})}{0.5V_{\text{vent}}C_{\text{max}}},$$

(4)

Then, the gas concentration on the operator’s workplace as function of LHD running time in a stope is given by:

$$\bar{C}(T_{\text{run}}) = \left(\frac{g_{\text{out}}}{Q} + C_{\text{in}}\right) - \frac{g_{\text{out}}}{Q} e^{-\frac{Q(C_{\text{max}} - C_{\text{in}})}{0.5V_{\text{vent}}C_{\text{max}}}T_{\text{run}}}.$$  

(5)

This expression of increment in gas concentration on an operator’s workplace makes it possible to find the maximum time of LHD operation in a stope such that gas concentration is never higher than MAC.

The next subject of the research can be evaluation of the correction factor in case of different sections of the stope and board gate.

3. Conclusions
1. The authors have developed and verified the mathematical model of ventilation in blind stopes formed by expansion of a board gate during retreat mining with loading of muck pile by the remote control load–haul–dumpers.
2. The expression of increment in in gas concentration on an operator’s workplace versus running time of the remote control load–haul–dumpers in stopes includes parameters of gas emission from the machines, parameters of ventilation in the stope and geometrics of the stope.
3. The expression of increment in in gas concentration on an operator’s workplace makes it possible to derive formula to find maximum time of LHD operation in a stope such that gas concentration is never higher than MAC.

References
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