International Journal of Mining Science and Technology xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Influence of gas ventilation pressure on the stability of airways airflow

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ARTICLE INFO

Article history:
Received 18 January 2017
Received in revised form 15 May 2017
Accepted 9 September 2017
Available online xxxx

Keywords:
Gas accumulation
Gas ventilation pressure
Airflow stability
Underground ventilation

ABSTRACT

Coal mine ventilation is an extremely complicated system that can be affected by many factors. Gas ventilation pressure is one of important factors that can disturb the stabilization of airflow in airways. The formation and characteristics of gas ventilation pressure were further elaborated, and numerical simulations were conducted to verify the role of gas ventilation pressure in the stability of airway airflow. Then a case study of airflow stagnation accident that occurred in the Tangshan Coal Mine was performed. The results show that under the condition of upward ventilation, the direction of gas ventilation pressure in the branch is the same to that of the main fan, airflow of the branches beside the branch may be reversed. The greater the gas ventilation pressure is, the more obvious the reversion is. Moreover, reversion sequence of paralleled branches is related to the airflow velocity and length of the branch. Under the condition of downward ventilation, the airflow in the branch filled with gas may be reversed. Methane in downward ventilation is hard to discharge; therefore, accumulation in downward ventilation is more harmful than that in upward ventilation.

1. Introduction

Coal mine ventilation system plays important roles in the underground mining. It offers a sufficient quantity of air to the underground mine workers to dilute methane and other contaminants, maintain a suitable working environment and prevent accidents [1–3]. During the mining operating, the status of the ventilation system cannot simply be kept constant. Generally, coal mine ventilation is an extremely complicated system. A large number of influencing factors can control or impact the behaviors of the system [4,5]. These include the ventilation network geometry (diagonal network, airway resistance, etc.), the location and operation characteristics of each of the other fans in the system and other external influencing factors [6]. Natural ventilation pressure is an important form of the external disturbance factors and has been observed ever since the beginning of underground mining. Natural ventilation pressure in underground constructions can help to optimize the design of their ventilation systems, reduce their energy consumption and avoid the risk of accumulation of gases or toxic agents [7]. However, natural ventilation pressure can also induce airflow reversal or reduce the airflow rate of some airways in mine ventilation. Scholars worldwide have conducted extensive research in the field of natural ventilation pressure [8–11]. Natural ventilation pressure is produced by the difference in air density between the intake and return airways. Previous studies have shown that the difference in air density is determined by air temperature and airway elevation difference. Therefore, natural ventilation pressure always occurs in airways with differences in elevation and temperature [12–15]. For instance, when fire occurs in an underground mine, the smoke flows along the airway airflow direction and the airflow temperature in the airway increases as the smoke spreads. Thus natural ventilation pressure is induced by fire if the airway has an elevation difference, which can be named as fire ventilation pressure. However, apart from temperature differences, natural ventilation pressure also can be produced in an airway with an elevation difference by the accumulation of gas, which is called gas ventilation pressure in this paper. Gas ventilation pressure is similar to that of a fire ventilation pressure due to the gas density and elevation differences [16–21]. However, the density difference of a fire ventilation pressure is caused by the air temperature difference between the intake and the return shafts of the mine, whereas the gas ventilation pressure does not consider the impact of temperature changes on the gas density. Because of the density difference between air and methane, the average density of the airflow changes when high-concentration methane flows into the airway. The gas ventilation pressure can be observed as increments in the potential energy

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https://doi.org/10.1016/j.ijmst.2017.09.004
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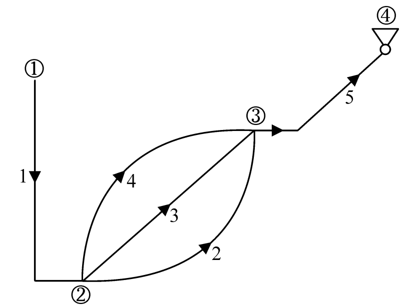

Fig. 1. Simple mine ventilation network graph.

in the airway. Gas ventilation pressure is often neglected by researchers and field staff, but it plays an important role in the stability of airway airflow in underground mines. This phenomenon can lead to airflow stagnation or airflow reversal in normal airways. For instance, an accident involving the cessation of the airflow in an airway had occurred in one inclined airway of the Tangshan coal mine in China. At first, the airflow stagnation accident was regarded being caused by the roof falling, but after a detailed site investigation was conducted, the results clarified that the accident was a result of gas accumulation.

This paper aims to explore the mechanism by which the stability of airway airflow in underground mines is induced by gas ventilation pressure, to present measures to prevent airway airflow disasters caused by gas ventilation pressure and to propose advice for mine ventilation design.

2. Formation and characteristics of gas ventilation pressure

2.1. Factors that influence on gas ventilation pressure

Gas ventilation pressure is caused by the accumulation of gas in inclined airways, the accumulated gas may induced by coal and outbursts or gas emission for coal seam in the conditions of the ventilation system fails. It can be regarded as one form of natural ventilation pressure. The amount of gas ventilation pressure is mainly affected by the gas concentration and the elevation difference in the airway. Temperature is not considered as a factor when a high concentration gas accumulates in the airway. Because the density of methane is lower than that of air, the density of the mixed gas changes. When the airway also has an elevation difference, gas ventilation pressure is formed. Gas ventilation pressure is calculated as follows:

$$h_M = (\overline{\rho} - \rho_a)[z(0) - z(L)]g \tag{1}$$

where h_M is the gas ventilation pressure of airway, Pa; $\overline{\rho}$ the average density of the airway airflow after mixing with gas, kg/m^3; ρ_a the density of air, kg/m^3; $z(0)$ and $z(L)$ respectively the elevations of the beginning and end junctions, m.

Table 2
Characteristic curve data of the fan.

	First point	Second point	Third point
Fan pressure (Pa)	385	248	148
Airflow rate (m^3/s)	16	37	52

3. Analysis of gas ventilation pressure under different ventilation ways on mine ventilation network

The roles of gas ventilation pressure play in mine ventilation network were conducted by the unsteady ventilation network calculation program [22,3].

3.1. Basic models and initial conditions

The designed simple mine ventilation network is shown in Fig. 1.

As shown in Fig. 1, branch 2 is filled with methane due to a coal and gas outburst, the methane concentration was 100%. By setting elevation differences of branches, the upward ventilation and the downward ventilation can be simulated. Basic parameters of branches were listed in Table 1, the characteristic curve data of the fan were shown in Table 2. The methane density is 0.717 kg/m^3, air density is 1.225 kg/m^3, the calculation time was 2400 s, time interval was 1 s, and space interval was 5 s.

3.2. Influences of gas ventilation pressure on the mine ventilation network under the condition of upward ventilation

3.2.1. Gas ventilation pressure and the airflow rate of branches

Fig. 2a presents gas ventilation pressure variation with time under the condition of upward ventilation, Fig. 2a shows airflow rate variation with time under the condition of upward ventilation.

As shown in Fig. 2, it can be concluded as follows:

(1) Under the condition of upward ventilation, the direction of gas ventilation pressure produced by methane accumulation in branch 2 is the same to that of the main fan. Under the influences of gas ventilation pressure, airflow rate of branch 2 increases while airflow rate of branches beside branch 2 (branch 3 and branch 4) decreases gradually.
(2) At about $t = 12$ s airflow rate of branch 4 reduces to zero and about $t = 14$ s airflow rate of branch 3 reduces to zero. The initial airflow rate of branch 3 and branch 4 are 6.4 m^3/s, 4.2 m^3/s respectively, the larger the airflow rate, the later the airflow reversals.
(3) The total airflow rate (branch 5) of the mine gradually increases. And then it increases from normal volume of 25.8 m^3/s to maximum volume of 47.0 m^3/s at t = 173 s. Then it decreases.

Table 1
Basic parameters of branches.

Branch number	From	To	Resistance (N s^2/m^8)	Length (m)	Area (m^2)	Circumference (m)	Methane concentration (%)	Elevation difference (m)	
								Upward	Downward
1	1	2	0.125	1020	9.20	14	0	300	300
2	2	3	0.131	980	7.62	12.1	100	−120	100
3	2	3	0.720	980	6.14	11	0	−120	100
4	2	3	1.631	980	6.14	11	0	−120	100
5	3	1	0.314	620	9.20	14	0	−180	−400