ISSN : 0974 - 7435 Volume 10 Issue 10

2014

BioTechnology
An Indian Journal

FULL PAPER
BTAIJ, 10(10), 2014 [4546-4555]

Mine ventilation system disorder induced by coal and gas outburst

Chen Chen, Haiyan Wang*, Xiaolong Cui
Faculty of Resources and Safety Engineering, China University of Mining & Technology (Beijing), Beijing 100083, (CHINA)
E-mail:whyhyp@163.com

ABSTRACT

With large-scale coal and gas outburst as the object, this paper established mathematical model of mine gas migration during gas outburst based on the analysis of source ventilation network. And then, a real mine accidents was taken as examples to simulate the process of airflow disorder and the change trace of the fan operation point. Under the direct action of the swarming force of gas “outburst source”, the airflow moves mainly along the major airway, even can reversed into the main intake working or the auxiliary shaft. After the outburst, because of the gas residual in the airways of the ventilation system, the natural gas air pressure could maintain reverse current for a period of time probably. Under the action of the main fan, the mine ventilation would recover gradually, but the gas natural air pressure could also bring local airflow reverse. The reversed airflow can make the range of gas flow keep expanding and the states of the airflow changing and complicated, which could increase the probability of gas explosion greatly.

KEYWORDS

Gas outburst; Source air network; Natural gas air pressure; Outburst reverse current; Airflow reverse.

INTRODUCTION

Coal and gas outburst is a kind of dynamics phenomenon of coal, rock mass and gas gushing in bulk towards the excavation under comprehensive actions of ground pressure, gas and mechanical characters of rock. It has been proved that coal and gas outburst can generate great effect on mine ventilation system, resulting in airflow reverse of the intake working 0[5], then inducing airflow disorder and causing underground personnel to suffocate or forming explosive gas accumulation[6][7].

In October of 2004, the "10.20" accident happened in Daping coal mine in Zhengzhou, Henan Province, in which gas explosion was caused in the inlet air area 33 minutes after gas outburst. In February of 2005, the "2.14" accident occurred in Sunjiawan coal mine in Fuxin, Liaoning Province, during which a large number of gas burst out because of deformation of the underground roadway caused by rock burst (mine earthquake) and 11 minutes later gas explosion was caused in the low gas airway. In October of 2010, coal and gas outburst occurred when the fourth coalmine of Henan Pingyu Coal Power Company was carrying out burst prevention drilling, resulting in the 37 deaths for buried and suffocation. An important reason of the heavy casualty in accidents is that large coal and gas outburst can cause the airflow disorder in mine ventilation system, which will produce suffocating gas or explosive gas, and then expand the range of accidents.

At present, scholars from home and abroad study the impact process and destruction effect of coal and gas outburst on local airways mainly. Zhou[8] analyzed the conditions of a large-scale outburst accident inducing the airflow reverse and mine ventilation pressure energy change. Cheng[9] set up a shock wave-superpress-spread-maths model based on aerodynamics theory, and drew a conclusion of non-linearity relation between super-press and gas press of coa-l bed, and linearity one between super-press and outburst intensity. Li[10] compared the potential for outbursts from coal seams with a roadway constructed into the seam. Yan[11] analyzed the growth extent of deformed coal and the distribution of high-energy gas depositing based on the idea that the common areas of high-energy gas and deformed coal. Li[12] considered the gas outburst in the process of coal and gas outburst as continuous jet flow, and concluded the relationship between gas outburst pressure and maximum velocity of outburst jet is approximately linear. Yan[13] experimented various levels of coal and gas outburst, and then simulated the whole process of coal and gas outburst during coal mining. Based on classification of the destructions of coal and gas outburst in roadways, Hao[14] analyzed the movement and propagation law of outburst gas in single roadway briefly. The above research has made great contribution to understanding the mechanisms of coal and gas outburst. However, little was studies about the influencing process of outburst gas on the whole mine ventilation system as well as the superimposed dynamical effect of gas flow and ventilation system after the gas burst. Thus, this paper will analyze the influencing range and characteristics of coal and gas outburst on mine ventilation system and the fan by means of a real coal and gas outburst accident, in order to provide theoretical support for the prevention of similar accidents.

MATHEMATICAL MODEL OF COAL AND GAS OUTBURST PROCESS

Fundamental assumption

The physical absorption process of the gas after the coal is destructed is much slower than the process of gas explosion. Seen from the representation, if the primary energy of the coal and the corresponding amount of gas could complete the outburst process within several or dozens of minutes, the present local outburst velocity is strong high-speed, high-pressure shocking process of coal-gas flow, which belongs to aerodynamics category [8],[9]; thus, the following assumptions are made:

Firstly, impact destruction of outburst high-speed flow happens in the incident roadway mainly; the energy of high-speed impact gas flow is lowered for the throttling action of outburst open;

Secondly, the outburst would slow down when passing through the open mouth and the airway branch, and transmit in the form of gas flow at a distance;

Thirdly, large-scale unstable failure of coal and gas outburst is completed gradually and gradually[0,[2]].

Mathematical description of coal and gas outburst

The source ventilation network refers to the ventilation network which has the nodes or the roadway branches with gas source outflow. In the mine source ventilation network, gas outburst mainly occurs in coalfaces, which belongs to node air source. Here adopts the hypothesis that there is no temperature change before and after gas outburst, so the available source ventilation network satisfies conservation mass. The mass balance equation of the gas outburst i

$$\boldsymbol{A\,Q = D} \quad (1)$$

Where, $A = [a_{ij}]_{(m-1)\times n}$ is independent node incidence matrix. If the node i is the starting point of j branch, $a_{ij}=1$; if the node i is the ending point of j branch, $a_{ij} = -1$; otherwise, $a_{ij} = 0$. $Q = [Q_j]_{n\times 1}$ is vector of the air quantity, Q_j is the volume air quantity of branch j, m^3/s; $D = [D_i]_{(m-1)\times 1}$ is vector of node air source, D_i is the node air source, which is the source item of node i, namely is volume flow rate of the gas, m^3/s.

The gas desorption intensity during outburst, namely, the intensity of the outburst gas source, can be expressed with fitting function[0] according to the experience and observational data on gas outburst. So, it can be simplified into average source function as simulating the outburst action within short time τ_0, namely

$$D_i = \frac{V_0}{\tau_0} \quad (2)$$

Where, V_0 is the total quantity of the gas outburst, m^3; τ_0 is the time of the gas outburst, s.

In the meantime, the outburst source ventilation network satisfies the law of conservation of energy, the energy-balance equation of which is

$$\boldsymbol{B\,H = B\,H_f + B\,P_e} \quad (3)$$

Where, $B = [b_{sj}]_{(n-m+1)\times n}$ is the fundamental circuit matrix. If branch j is the homonymous branch of circuit s, $b_{sj}=1$; if branch j is the reverse branch of circuit s, $b_{sj}=-1$; otherwise, $b_{sj} = 0$; $H = [h_j]_{n\times 1}$ is vector of air pressure. h_j is the air pressure deviation of branch j, Pa; when considering the directivity of the airflow, $h_j = R_j Q_j\,|\,Q_j\,|$; $H_f = [h_{f,j}]_{n\times 1}$ is the vector of the fan, $h_{f,j}$ is the air pressure of the fan of branch j, Pa; $P_e = [p_{e,j}]_{n\times 1}$ is the vector of location differential pressure, $p_{e,j}$ is the location differential pressure, Pa; $p_{e,j} = (Z_{j,1} - Z_{j,2})\rho_j$ g, $Z_{j,1}$ and $Z_{j,2}$ are respectively the starting and ending node elevation of branch j, m; ρ_j is the density of the air flow of branch j, kg/m^3.

During the period of gas outburst, the gas current flows in the airway and the gas density can reach to 60%. The density of mixed flow of gas with air is lower obviously, and then it will result in significant natural air pressure in the circuit, here it is called natural gas air pressure. After the gas outburst, natural gas air pressure takes some effect on the airflow disorder. The natural air pressure in certain circuit of the air network can be calculated with algebraic sum of the branch location deviation in equation (3).

The density of the gas mixed with the airflow can be calculated with the following equation, that is,

$$\rho_j = \frac{\rho_{j,0} Q_j + \rho_{j,g} W_j}{Q_j + W_j} \tag{4}$$

Where, $\rho_{j,\,g}$ is the density of the gas gushed by branch j, kg/m^3; $\rho_{j,\,0}$ is the primary density of air flow of branch j, kg/m^3.

Since there is concentration difference between the gas and the mine atmosphere, mass transfer will occur. The mass transfer process satisfies mass transfer equation, namely

$$\frac{\partial c_j}{\partial \tau} + v_j \frac{\partial c_j}{\partial l} = \frac{\partial}{\partial l}\left(\lambda \frac{\partial c_j}{\partial l}\right) + \frac{c_A - c_j}{c_A} W_j \tag{5}$$

Where, τ is time variable, s; c_A is the density of air, kg/m^3; λ is the diffusion coefficient of gas relative to air.

When gas is generated in the air source, the gas density in branch airway would change, the added density value of which is

$$\Delta c_j = \frac{W_j}{Q_j + W_j} \tag{6}$$

Where, Δc_j is the value added of density of gas gushed in branch j airflow, dimensionless; W_j is the same direction component of D_i with airflow of branch j.

The node gas density after gas mixes with airflow can be calculated with the following equation[15], that is

$$c_i = \frac{\sum_{k=1}^{k_n} c_{j,0} Q_j}{Q_j + W_j} \tag{7}$$

Where, c_i is the gas density of node i, %; $c_{j,\,0}$ is the density of gas (from the upper stream) accumulated to airflow of node i and branch j, %.

BASIC CONDITION OF ONE COAL AND GAS OUTBURST ACCIDENT

In 2010, a coal and gas outburst occurred in one mine of China. The direct reason of the outburst was that the gas outburst occurred in heading face 601 as uncovering coal. The outburst was about 60000 m^3 in gas total volume, 2.5 min in duration, and 400.00 m^3/s in outburst source flux. The mine was a production mine, a coal and gas outburst mine, equipped with safety monitoring system. The ventilation system of the mine is main vertical shaft and auxiliary vertical shaft for air inlet and vertical airshaft for air outlet. The ventilation system of the mine (Figure 1) included coalface 401, main down-hill reserve coalface 402, heading face 3011, heading face 4031, coal exploration cross drift 601. The fan has an air quantity of 42. 9 m^3/s, an air pressure of 804.2 Pa, a natural air pressure of -89. 97 Pa, and an efficiency of 0.719 (Figure 2). The total air resistance of airways was 0.436 N.s^2/m^8, the working air resistance of the fan was 0.486 N.s^2/m^8, the equivalent orifice was 1. 8 m^2. The allocation air volumes of the coalface 402 and coalface are 7.6m^3/s and 13.63m^3/s respectively. The absolute gas emission quantity of working face was 0.18 m^3/s. Next part will analyzes the impact range of the coal and gas outburst accident and its superimposed effect with ventilation system.

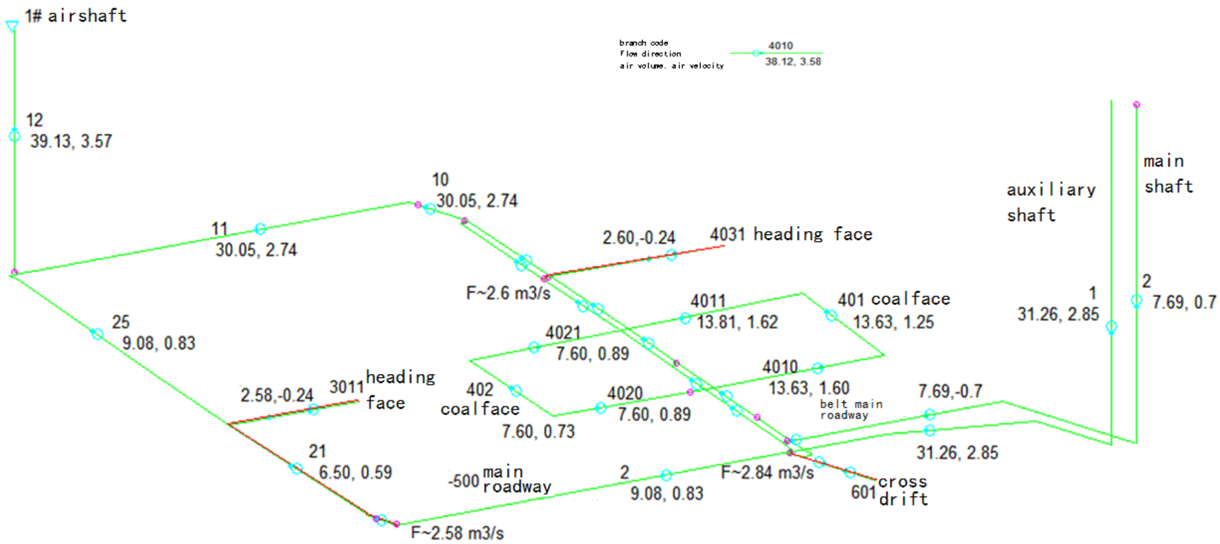


Figure 1 : Mine ventilation system before the outburst

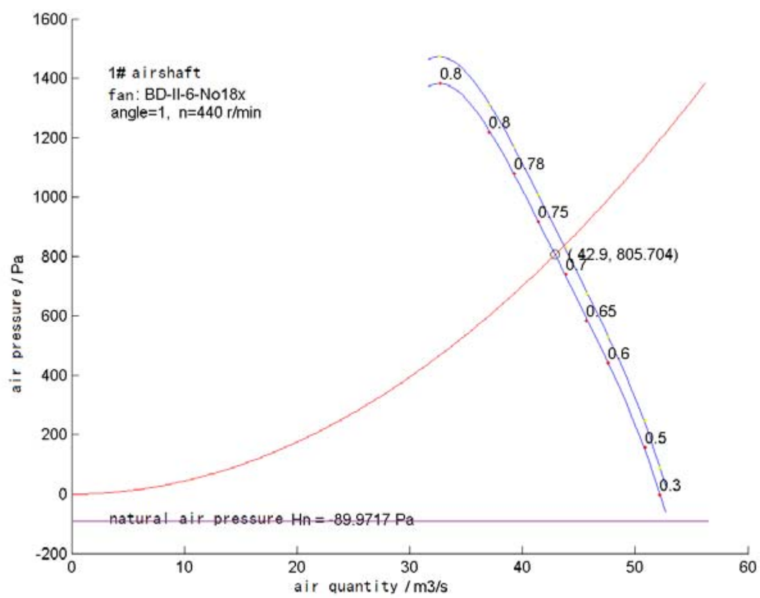


Figure 2 : The basic parameters and operating points of the main fan during normal ventilation

DISORDER OF MINE VENTILATION SYSTEM AFTER THE GAS OUTBURST AND THE INFLUENCE LAW OF THE OUTBURST

Basic changes of the ventilation system after outburst

The influence of the outburst gas on the ventilation system when the outburst occurred was shown in Figure 3 and Figure 4. It showed that the outburst point, heading face 601, formed gas storm at a countercurrent velocity of 35.59 m/s (i.e. lower than the aerodynamics velocity of 70 m/s). 7 seconds after the outburst, the outburst filled the cross heading with 230m long. At the moment of the outburst, the air quantities of coalface 401 and coalface 402 increased to 37.11 m^3/s and 20.65 m^3/s respectively. Under the emission action of gas outburst, the original air flow of the main shaft and the subsidiary shaft reversed, with the countercurrent air quantity of the subsidiary shaft of 250.75 m^3/s and the countercurrent velocity of 22.88 m/s. At 78 s, the countercurrent occurred at the subsidiary shaft and gushed out from the shaft mouth. But the countercurrent in the main shaft lagged behind in the subsidiary shaft because the air resistance of the former was larger than that of the later. At 150 s, the outburst finished.

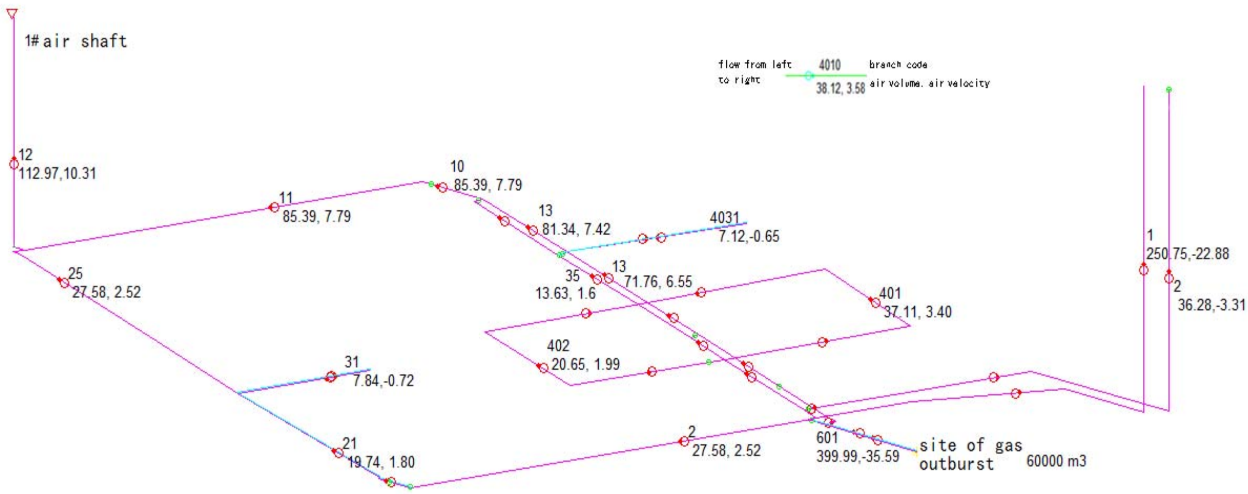


Figure 3 : The air quantity and velocity of every branch in the ventilation system at the beginning of the outburst

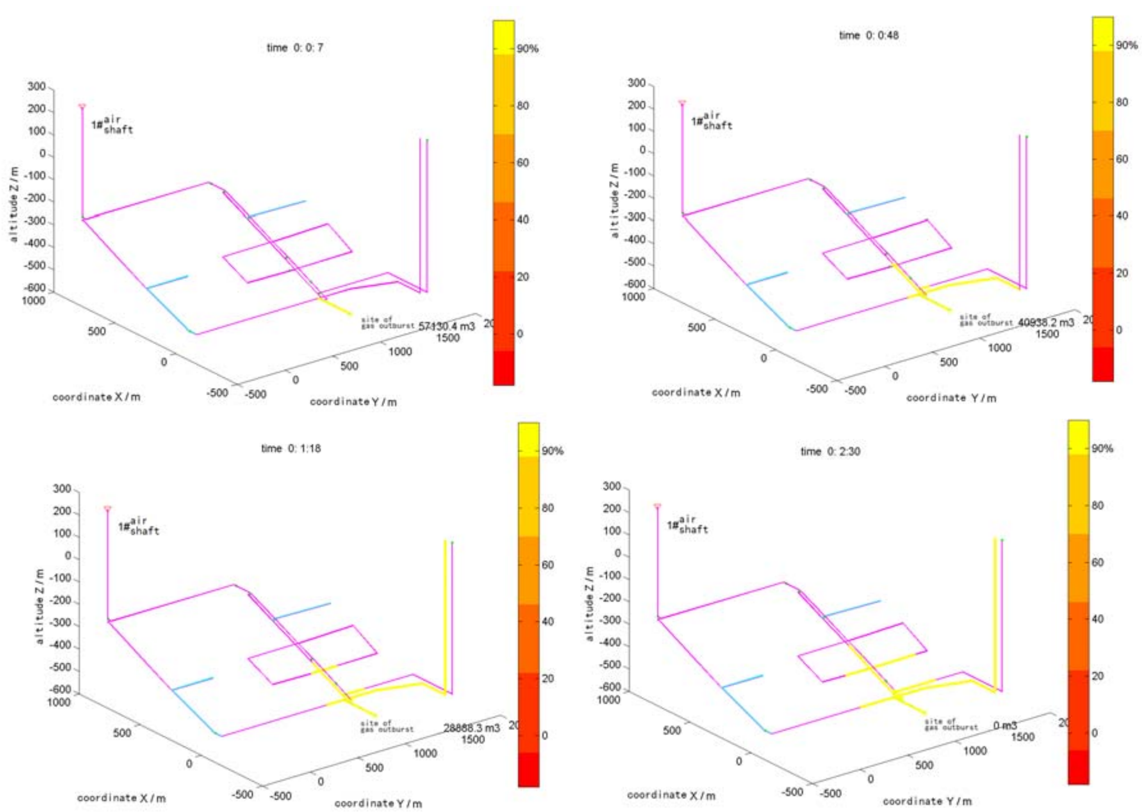
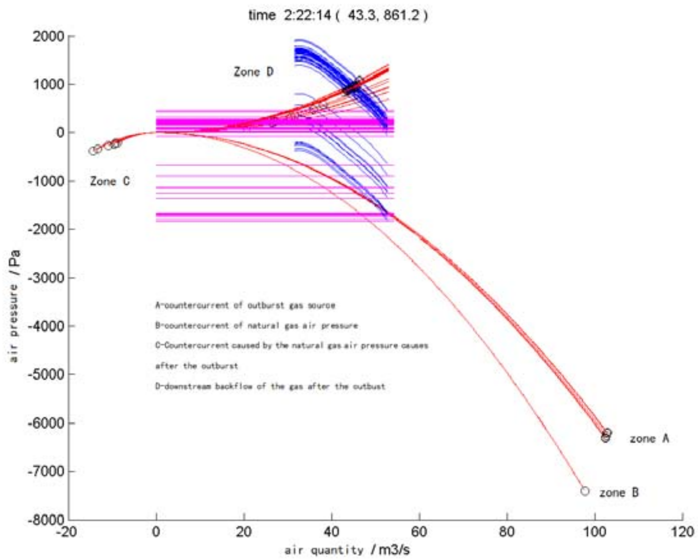


Figure 4 : The range of gas countercurrent in the mine ventilation system as outburst happening

Dynamic change of the operating conditions of the fan after the outburst

Figure 5 is the operation points of mine ventilation and the air resistance trace when the gas bursts out. It showed that the air quantity of the fan increased suddenly to 112.97 m^3/s from 42.9 m^3/s and the air pressure of the fan reached -6321.67 Pa when countercurrent occurred after the outburst (zone A in Figure 5). After the outburst, at the action of the natural gas air pressure, the subsidiary shaft overcame the pressure of the fan and maintained reversed flow for about 20 min. Then, the gas in the mine airway system flew and diffused with the air flow, and began the down-flow discharge under the co-action of fan air pressure with the natural gas air pressure. Two hours and twenty-two minutes 14 seconds later, all the outburst gas was discharged from the whole airway system.



(The set of curves is the dynamic operating conditions, among which the horizontal line represents the natural air pressure at different time)

Figure 5 : The operating points of mine ventilation and the air resistance trace when the gas bursts out

In the whole process of outburst-stability recovering, the air flow of the system was a unsteady; the natural gas air pressure in the ventilation system changed continuously with the flowing of the gas, which produced great influence on the operating points of the fan with dynamic changes. The operating points showed gradual change of each zone and jumping process between different zones. Firstly, when the outburst occurred, large-scale countercurrent occurred to the system in the action of the outburst force. The operating point jumped to zone A from the point during normal ventilation suddenly. When the reversal gas flow arrived at the subsidiary shaft mouth, it burst out form the mouth. With the loss of the gas, the natural gas air pressure changed a lot (zone B); after the finish of the outburst, the outburst gas remained in the airway system resulted in imbalance of the location pressure of each circuit. At this time, the natural gas air pressure also performed great function, especially along the major ventilation circuit of the airshaft – the subsidiary shaft, could overcome the fan pressure for a period and maintained countercurrent (zone C). With the gas in the main roadway and the subsidiary shaft discharged continuously, the natural gas air pressure against the fan reduced and recovered to the normal ventilation operating point gradually (zone D). The operating point change in zone D also reflected that the natural gas pressure in the system interior also changed continuously with gas discharging out.

The airflow disorder state induced by the gas outburst

Figure 6 and Figure 7 are about the gas transfer process and the airflow distribution of the ventilation system after the gas outburst. It showed that there were two kinds of mine airflow disorder after the gas outburst, one is the countercurrent of outburst gas source and the other is the countercurrent of natural gas air pressure. Outburst countercurrent was a reversed flow resulted from the gushing force of the gas outburst air source formed by a great number of gas disrobed from the outburst coal body; natural gas air pressure countercurrent referred to the natural air pressure which was formed in the process of the gas accumulated after the outburst and its movement with the mine ventilation, and could make the air flows in each circuit of the ventilation system reverse. The relative density of gas is 0.554 times of the air. The gas countercurrent filled all or part the airway affected by the outburst. Thus a higher natural gas air pressure formed, which was much larger than the normal natural air pressure in the mine, and it even could overcome the fan air pressure and generate continuous countercurrent.

The influence of gas outburst on mine ventilation system not only could generate gas countercurrent, but also could induce local air flow reverse. Because of the progression difference between the backflow gas flowing between the main ventilation airway and the side associating airway, the low-density gas could produce natural gas air pressure, making the airflow reverse of the local ventilation system.

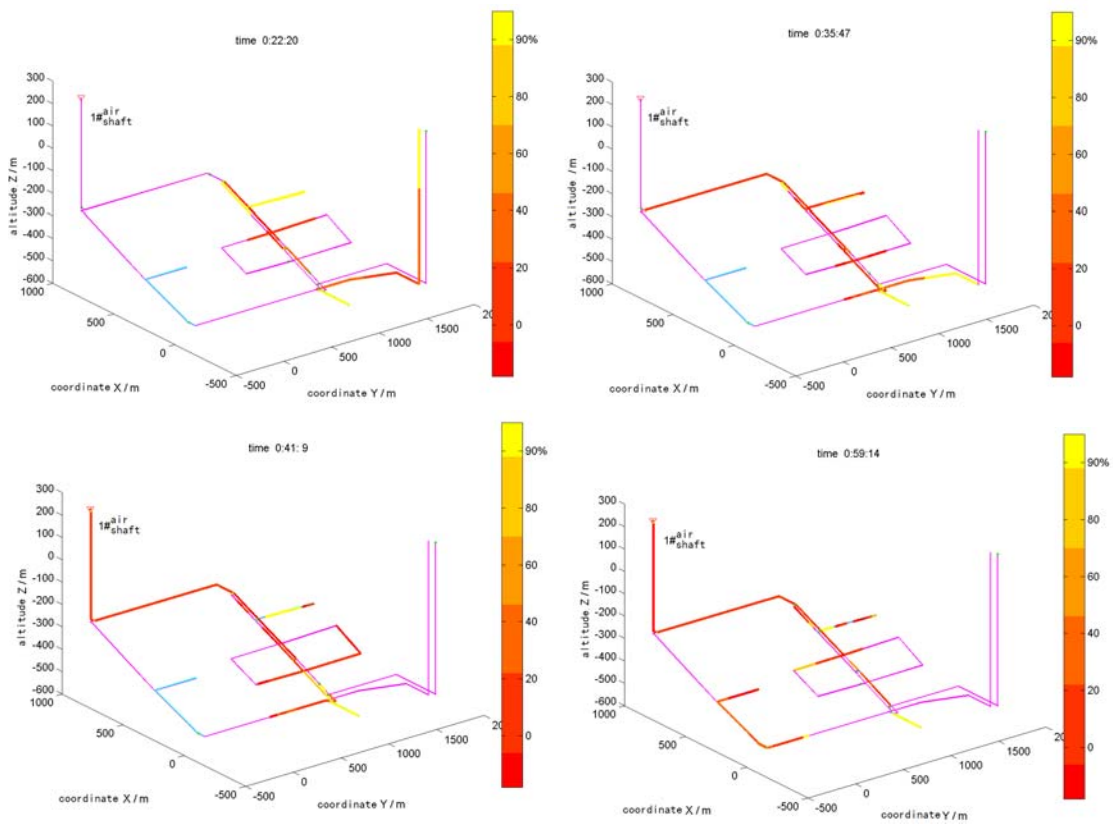


Figure 6 : The gas distribution as gas downstream moving after the outburst

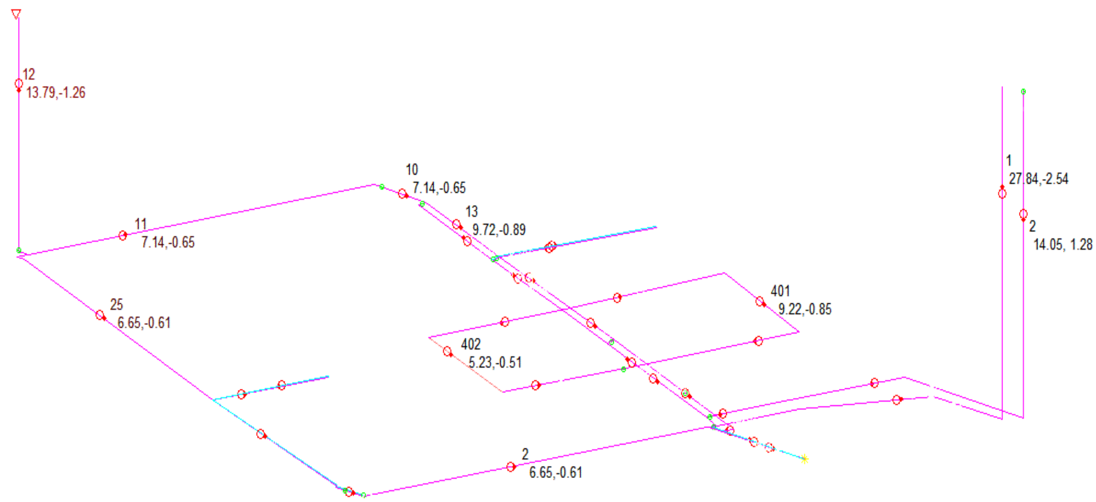


Figure 7 : Distributions of airflow direction, air volume and air velocity after the outburst stoped (time=462.6s)

It shall be pointed out that influencing range of gas outburst was related to the construction of the ventilation facilities besides above mentioned. For example, if the isolating ventilation door of heading face was set at the side of the return air, it could avoid the gas countercurrent entering intake roadway and flowing towards all directions efficiently as soon as outburst happened.

CONCLUSION

(1) The movement of gas outburst-abnormal gas flow of the mine is analyzed. The result simulated conforms to the actual experience of mine gas outburst. Large-scale coal and gas outburst could induce gas countercurrent and natural gas air pressure, which could produce air flow reverse.

(2) Airflow disorder in the mine ventilation system after coal and gas outburst related with the gas residual in the roadway system and its movement. Therefore, the actions generated by natural gas air pressure could not be neglected.

(3) The reasons for gas countercurrent, which included the source gushing driving force of the outburst gas and the action of natural gas air pressure, are revealed. When the scale of the outburst is large enough, the outburst gas countercurrent could gush out directly from the intake subsidiary shaft mouth. After the outburst ended up, the outburst countercurrent in shaft is the result of action of outburst gas source gushing and natural gas air pressure.

ACKNOWLEDGEMENT

This paper belongs to the project of "National Science Foundation of China Program", No. 51304211.

REFERENCES

[1] Lin Boquan; The Theory and Technology of Gas Treatment in Coal Mine, Beijing: Coal Industry Press, **(1998)**.
[2] Dong Gang-Feng, Liang Yun-Pei; Coal Science & Technology Magazine, **4**, 46-48 **(2001)**.
[3] Zhang Ren-Song, Tang Ji-Dong; Mining Safety & Environmental Protection, **5**, 31-33 **(1997)**.
[4] Zhang Quan-Xuan, Zhang Qi-Ming; Coal Science & Technology of Zhongzhou, **4**, 24-26 **(1988)**.
[5] Wang Wenduo; Safety in Coal Mines, **7**, 13-17 **(1996)**.
[6] R.D.Lama, J.Bodziony; International Journal of Coal Geology, **35**, 83-115 **(1998)**.

[7] Javier Toraño, Susana Torno, Eliseo Alvarez et al; International Journal of Rock Mechanics & Mining Sciences, **50**, 94-101 **(2012)**.
[8] Zhou Guangjong, Yan Zongyi, Xu Shixiong et al; Hydrodynamics, Beijing: Higher Education Publishing House, **(1993)**.
[9] Cheng Wu-Yi, Liu Xiao-Yu, Wang Kui-Jun et al; Journal of China Coal Society, **29(1)**, 57-60 **(2004)**.
[10] Li Guoqing, Sagha Fi Abouna; International Journal of Mining Science and Technology, **24**, 391-396 **(2014)**.
[11] Yan Jiangwei, Wang Wei, Tan Zhihong; Procedia Engineering, **45**, 329-333 **(2012)**.
[12] Li Liping, Pan Yishan; Journal of Liaoning Technical University, **26**, 98-100 **(2007)**.
[13] Yan Aihua, Xu Tao; China Safety Science Journal, **18(9)**, 37-42 **(2008)**.
[14] Hao Yu; Coal Technology, **28(11)**, 74-76 **(2009)**.
[15] Lu Guang-Li, Li Cong-Shan, Xin Song; Journal of Shandong University of Science and Technology, **19(2)**, 120-122 **(2000)**.