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APPLICATION OF NITROGEN INJECTION DISPLACEMENT FOR FIRE EXTINGUISHMENT

1. Introduction

According to statistics, the coal spontaneous combustion fire accounted for more than 94% of the total number of coal mine fire, of which 60% occur in gob [1]. With the mining depth increasing, coal pillar become so easy to be crushed that coal spontaneous combustion is easier to occur. The fire's occurrence and development not only affect the safety in production and the surrounding environment, but also easily lead to explosion of gas or coal dust [2]. Therefore, the research of new technology and new method on the coal spontaneous combustion fire prevention and control are of great significance.

Professor Zhang Guoshu presented a new method of nitrogen injection for fire extinguishment in sealed gob. Practice has proved that this method is effective. The article applied this technology in coal mine, and then verified the results through numerical simulation, and then presented some new views in specific implementation of nitrogen injection displacement for fire extinguishment.

2. Introduction of nitrogen injection displacement for fire extinguishment

Inert gas mainly refers to suffocating gas, such as N_2, CO_2, H_2O, and alkyl halides etc, or a mixture of these gases, which may contain a small amount of oxygen, but its content is lower than combustion, explosion or ignition limit. Fire prevented and extinguished technology

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using inert gas provides a method to suppress combustible material combust, smolder and explosion. Inert gas can not only make fire area inert, even reduce air leakage and temperature in fire area, but also pierce through caving zone easily. Fire disaster emergency rescue, disaster relief and return to work will be safer, faster and there is lower cost. Fire prevented and extinguished technology using inert gas also has the disadvantages of longer time required to make the fire completely extinguished, and the fire also has the chance to renew, especially when Gas injection process and operating system are not reasonable [1]. In view of this, the research and development of advanced and reasonable gas injection process and operating system contribute to the promotion, and application of Fire prevented and extinguished technology uses inert gas [3].

The mechanism of nitrogen injection displacement for fire extinguishment is that nitrogen is poured into the goaf artificially and the displaces original air. The method can reduce oxygen concentration by nitrogen injection more efficiently with less volume of nitrogen. That is because nitrogen injected may not mix with air or mix lightly. Therefore, a moving nitrogen level or nitrogen wall will be formed in the form of laminar and diffusion with less volume of nitrogen.

3. Replacment of nitrogen injection model and estimation of nitrogen injection time

It needs four elements for spontaneous combustion of coal to happen. Firstly, the coal should have tendency to spontaneously burn. Secondly, the fractured coal should be supplied with enough oxygen. Thirdly, heat generated by coal oxidation can be accumulated. The only one element that can be controlled easily is amount of oxygen in closed gob. If the gob filled with nitrogen, then the coal itself will stop heating, and there will be no risk of spontaneous combustion of coal. The Coal Mine adapts mining method of longwall mining on strike. The coalface’s inclined length, strike length and coal seam thickness are respectively 1813 meters, 200 meters and 4.42 meters. The height of gob will reach three to four times the thickness of the coal seam. It’s absolutely impossible to fill with nitrogen in the huge gob in economy and in technology.

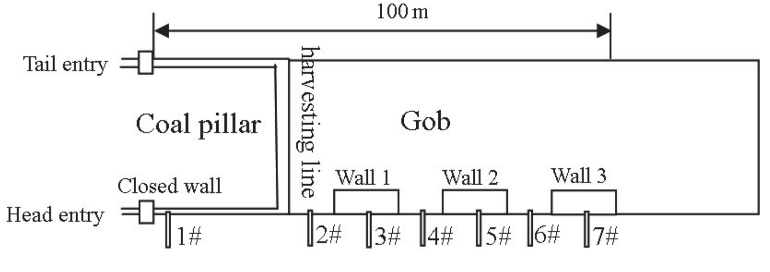

Fig. 1. Replacing nitrogen injection diagram (simplify)

According to the analysis of leakage, air leakage distributes with in 100meters range near the mining stop line, as shown in Figure 1, so the high temperature should also be distributed in the region. Making the region filled with nitrogen will reduce the oxygen concentration to prevent the oxidation of residual coal and coal pillar, inert the high temperature zone, thus eliminate the risk of occurrence of spontaneous combustion of coal. The problem is how to control the nitrogen flow, and distribute within 100 metres near harvesting line.

As shown in Figure 1, 1#, 2#, 4#, 6# represent drill holes for nitrogen injection, and 3#, 5#, 7# represent drill holes through grouting in order to form wall 1, wall 2, and wall 3 for the nitrogen been isolated and induced. Keep the pressure in tail entry equal to or slightly lower than atmospheric pressure. Firstly, the nitrogen injected from 1# drill holes, diffuses along "head entry → harvesting line → tail entry" path, pushed the mixed gas based methane and oxygen to the deep gob. The excess of the gas passes through the cracks and releases from drainage pipe which was in the high pumping Lane before. At the same time we can take gas samples from measures holes and test the gas composition. When nitrogen accounted for 90% or more, the head entry, harvesting line and tail entry have been filled with nitrogen. Since then, we should block the nitrogen injecting holes, and begin to inject nitrogen from drill hole 2#. At this point, we need to determine the time which spent in nitrogen inject through drill hole 2# before shifting to drill hole 4#.

Calculate the volume of the cube space between wall 1 and the harvesting line:

$$V = X \times Y \times Z \tag{1}$$

where:

V — volume of the cube space, m^3,

X — inclined length, m,

Y — strike length, m,

Z — height of gob, m.

This project,

$$X = 20 \text{ m}, Y = 200 \text{ m}, Z = 4.42 \times 4 = 17.68 \text{ m},$$

then

$$V = 20 \times 200 \times 17.68 = 70720 \text{ m}^3$$

Set Q represents nitrogen flow, m^3/H, This project, $Q = 700 \text{ m}^3/\text{H}$, Calculate the time spent in nitrogen injecting.

$$T = V/Q = 70720/700 \approx 101 \text{ hours} \tag{2}$$

By calculating, nitrogen injecting through 2#, 4# and 6# holes respectively spent 4.5 days, 9 days and 9 days.

The above process continues to cycle, until the proportion of CO in the sample gas taken from the measures holes in the closed walls less than 10 p.p.m. After the end of the loop, we should check the nitrogen injection holes and measure holes regularly ensuring blocked tightly, and take sample gas from the measures holes in the closed walls. The nitrogen injection process repeats, when the proportion of nitrogen in the sample is less than 78%.

4. Numerical simulation of replacing nitrogen injection [4, 5]

Inject nitrogen into 1#, 2#, 3# and 6# drilling holes one by one, as shown in Figure 1, then simulate the process of nitrogen injection using mass transport model defined by professional fluid simulation software — FLUENT 6.0.

The principle of the mass transport model is shown by equation 3.

$$\sum_{i=1}^{N}\left(\frac{\partial}{\partial t}(\rho Y_i)+\nabla\cdot(\rho\vec{v}Y_i)=-\nabla\vec{J}_i+R_i+S_i\right) \tag{3}$$

R_i represents the chemical reacting rate of the i-th substance in the mixture ($R_i = 0$), S_i represents the extra generating rate of the discrete phase and the user-defined phase ($S_i = 0$). We need to solve $N - 1$ equations like this, when the system have n substances. Y_i represents The mass fraction of the i-th substance. Because the sum of the mass fraction is zero, we should get the proportion of the N-th kinds substances by 1 minus the proportion of other gas. The N-th kinds of substances must choose the biggest amount of material in order to minimize the numerical error. In this project, we should choose nitrogen.

j_i represents flux of diffusion of the i-th substance, that can be Calculated by equation 4.

In equation 4, $D_{i,m}$ represents coefficient of Diffusion the i-th substance.

ρ represents the density of the i-th substance. ν represents the Rate of diffusion of the i-th substance.

$$J_i = -\rho D_{i,m}\nabla Y_i \tag{4}$$

Gas properties are set according to Table 1. Boundary conditions of 1# nitrogen injecting hole are set as this: pressure inlet, volume percent of $N2$ 99%. Boundary conditions of measure hole of tail entry set as this: pressure outlet, volume percent of $N2$ 40%.

Numerical simulation results are nearly similar with the observed gas concentrations. Nitrogen concentration distribution is also similar with the estimated one. Obviously, the exploration of the engineering practice is successful.

TABLE 1

Physical properties of gas in the mixture

Gas	Temperature T, °C	Density ρ, kg/m^3	D-viscosity μ, N·s/m^2	K-viscosity υ, m^2/s	R R, J/kg·K	H-capacity γ
CO	20	1.150	1.69E-05	1.50E-05		
O_2	20	1.330	2.04E-05	1.53E-05	259.8	1.4
CH_4	20	0.667	1.10E-05	1.65E-05	518.3	1.31
CO_2	20	1.830	1.47E-05	8.03E-06	188.9	1.3
N_2	20	1.160	1.76E-05	1.52E-05	296.8	1.4

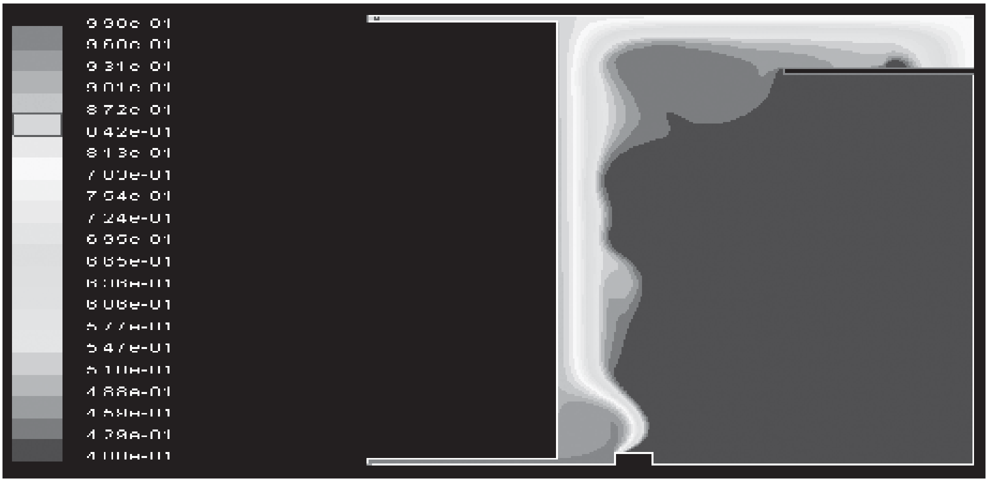

Fig. 2. Simulating result about 1# nitrogen injecting hole

5. Achievements and Implications

Replacing nitrogen injection obtains great significances and the main following results.

Firstly, this project has verified the rationality and feasibility of replacing nitrogen injection by means of practice and numerical simulations. It can be seen from Figure 2, through the replacing nitrogen injection, nitrogen concentration in the regional is near the harvesting line accord with the expected results. The height concentration of nitrogen can effectively inert fire area, and reduce air leakage and the temperature of the fire area.

Secondly, as shown in Figure 3, after carrying out the replacing nitrogen injection, the percentage of CO in 115(3) gob decreased from 15% to 0%, and stabilized. This phenomenon shows that coal self-heating near the harvesting line has been successfully suppressed, to prevent the occurrence of spontaneous combustion of coal disasters, to ensure the safety of state property and people’s lives.

Thirdly, the projection provides a new method for the management of the closed gob, so that we can prevent the spontaneous combustion of coal better.

Fourthly, the isolated and replacing nitrogen injection technology is a new development of fire extinguishing technology using inert gas and explores a new way of Fire Prevention using nitrogen.

Fifthly, we should get a first-hand practical data and information, and expose the inadequacies of the isolated and replacing nitrogen injection technology, lay the foundation for the improvement and maturity of the technology.

Since the isolated and replacing nitrogen injection technology is pioneering activity for Fire Prevention using inert gas, so in practice we have encountered many difficulties, and exposed some shortcomings, mainly because of the consideration to the problem there is not comprehensive enough, and isolated and replacing nitrogen injection is not studied thoroughly, mainly in the following areas:

First of all, gas release law and release amount are directly related to the replacing nitrogen injection effect, which is more complicated, and influenced by many factors, not studied thoroughly, therefore, further research about gas release law in gob is needed.

Then, a variety of anti-fire materials can't reach the engineering requirements, so that we need to find and develop more colloidal materials in line with the engineering. In order to fill the collapsed space completely, the colloidal material has moderate mobility, and enough hardness. But because of the limitations of the objective conditions, the properties of the material are difficult to meet the requirements.

Finally, research in gas diffusion and flow pattern is not enough, therefore, the practice process can not be reasonably explained, and many conclusions based on speculation need theory validation.

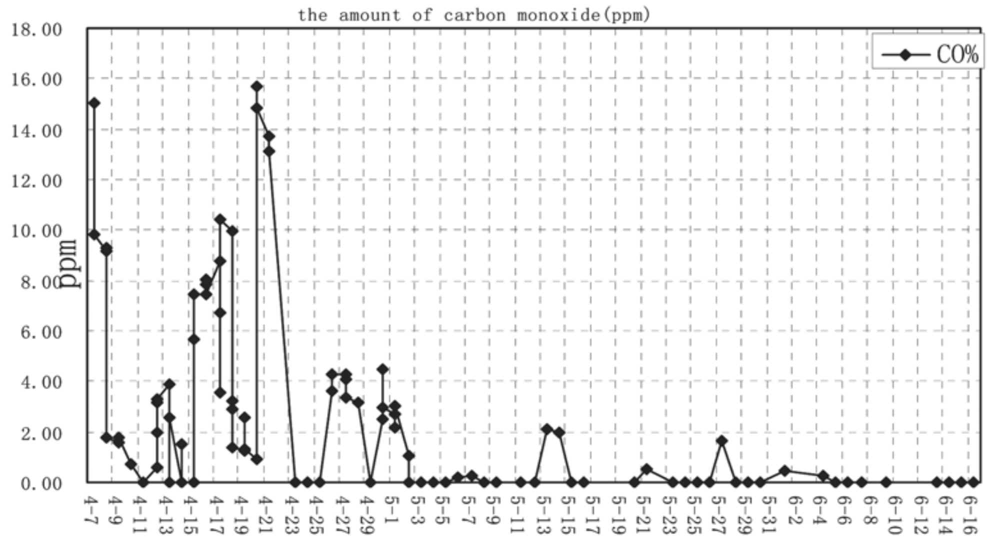

Fig. 3. The change in the amount of carbon monoxide

REFERENCES

[1] *Yingmin Qi*: Coal Mine Safety Manual Part IV Coal Mine Fire Prevention.Beijing: Coal Industry Press, First edition March 1991.

[2] Jiaozuo Mining Institute Fuxin Mining Institute. Coal Introduction(Amendment). Beijing: Coal Industry Press, First edition March 1991 April 1986.

[3] *Guangwei Gao*: Current situation and future about fire prevention using nitrogen in Chinese coal mine. Journal of China Coal Society, Vol .24 No. 1 Feb. 1999.

[4] *John D., Anderson Jr.*: Computation Fluid Dynamics the basics with Applications.McGraw-hill.

[5] *Zhanzhong Han, Jing Wang, Xiaoping Lan*: Example of Numerical Simulation in Fluid engineering. BeiJing: Beijing Institute of Technology Press, 2004.6.