Flow field analysis of Jiangou mine goaf

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Abstract. With the increase of mining depth, many coal mines have the co-occurrence of natural fire and gas disasters. According to the actual situation of alkali ditch coal mine, this paper established a mathematical model and geometric model of mined-out area by using COMSOL software to carry on the numerical simulation. Study of nitrogen injection and gas extraction of goaf flow field and the influence of oxidation temperature zone, provided the basis for mine fire and gas disaster prevention and control.

1. Introduction
Coal mine fire is one of the major disasters that affect mine safety, and the proportion of coal spontaneous combustion fire in goaf is about 85%. Data show that about 56 percent of the country's mines are threatened by natural fire. Mine fire not only damages coal resources, damages a large number of underground equipment, but also causes secondary disasters such as gas and coal dust explosion. With the wide application of fully mechanized top-coal mining technology in China, the production efficiency of mine has been improved significantly. At the same time, there are also problems such as the reduction of the driving speed of the working face, the increase of the air leakage and the large amount of coal left in the goaf, which have greatly increased the occurrence probability of spontaneous combustion fire in the goaf. With the increase of mining depth, the gas disaster on the working face is also increasing day by day. At present, the fire-fighting technologies in the goaf mainly include pressure ventilation, grouting, spraying inhibitors and nitrogen injection, or the comprehensive use of these technologies. Studies have shown that if the oxygen concentration in the enclosed area falls below 5%, the fire will slowly weaken and eventually die out. According to this principle, the nitrogen injection technology is to inject the inert gas N\(_2\) into the goaf to dilute the oxygen concentration in the fire zone and meet the requirements of fire retardation. Because of N\(_2\) injection may generate a positive pressure in the goaf, reduce leakage air volume, and N\(_2\) density than air, can be in goaf buoyancy, diffusion, can impact on the mine d-out area of deep and high fire good governance effect. Coupled with the economic cost of nitrogen injection is lower, so the fire prevention technique of nitrogen injection as an economic and reliable means of governance has been widely used. In order to prevent gas explosion in goaf, gas drainage measures are mainly adopted. In order to determine reasonable nitrogen injection and gas extraction parameters, it is necessary to study the flow field of goaf in detail. Based on the predecessors research results, in view of the jin alkali colliery B3 + 6 coal seam working face to carry out the experimental study. The measuring points are arranged on the inlet and return air sides of the goaf for actual measurement. Based on CFD theory, COMSOL computational software of fluid mechanics was used to study the goaf flow field. This
paper provides theoretical guidance for coal spontaneous combustion and gas explosion prevention in goaf.

2. Working face overview
Jiangou coal mine is a wholly owned mine owned by shenhua xinjiang energy co., LTD., located in the midong district of urumqi city, xinjiang uygur autonomous region.

The geological structure of the working face of coal seam B3+6 is relatively simple, without faults and folds, the roof bedding and joints of the coal seam are relatively developed, and it is easy to break and collapse. The coal seam contains a thin layer containing gangue, mostly less than 0.3m, and its lithology is carbonaceous mudstone and carbonaceous shale, which affect the stability of the coal seam. The working face length is 160m, the working face section is 23m high, and the coal seam is explosive dangerous. The spontaneous combustion period of coal is 1-2 months.

3. Establishment of goaf model

3.1 Establishment of mathematical model
It is assumed that the fluid is incompressible and the goaf is anisotropic porous medium, which conforms to the linear permeability law (Darcy law). The viscosity resistance coefficient and the inertial resistance coefficient does not change in the Z direction. Thus, the control equation of the porous media model in goaf can be obtained as follows:

(1) Mass conservation equation
\[
\frac{\partial (\rho u)}{\partial x} + \frac{\partial (\rho v)}{\partial y} + \frac{\partial (\rho w)}{\partial z} = S_m
\]

(2) Momentum equation
\[
\frac{\partial (\rho u u)}{\partial x} + \frac{\partial (\rho u v)}{\partial y} + \frac{\partial (\rho u w)}{\partial z} = \frac{\partial}{\partial x} \left( \eta u \frac{\partial u}{\partial x} \right) + \frac{\partial}{\partial y} \left( \eta u \frac{\partial u}{\partial y} \right) + \frac{\partial}{\partial z} \left( \eta u \frac{\partial u}{\partial z} \right) - n \frac{\partial \rho}{\partial x} - \frac{\mu}{e} u + F_x
\]

(3) Component transport equation
\[
\frac{\partial (\rho c_S u)}{\partial x} + \frac{\partial (\rho c_S v)}{\partial y} + \frac{\partial (\rho c_S w)}{\partial z} = D_s \left( \frac{\partial c_S}{\partial x} \right) + \frac{\partial}{\partial y} \left( \frac{\partial c_S}{\partial y} \right) + \frac{\partial}{\partial z} \left( \frac{\partial c_S}{\partial z} \right) + S_S
\]
ρCS —— component productivity;
Dₜ —— diffusion coefficient of this component.

3.2 Establishment of geometric model
According to the actual conditions in the mine, the goaf area is simplified and the following data are obtained:
1. Assume that the roadway space is not affected by underground equipment;
2. The width of the return lane is 4m, the working face is 160m long and 7.5m wide;
3. The goaf is 160 m deep and 160 m wide. According to the difference in porosity, the goaf is divided into three parts: the boundary of part 1 is 0-20 m from the working face, the boundary of part 2 is 20-100 m from the working face, and the boundary of part 3 is 100-160 m from the working face.
4. Buried pipe drainage is adopted in the goaf of the comprehensive mining face;
The model was built as showed in figure 1.

3.3 Boundary conditions and calculation parameters setting
When selecting the main calculation conditions and parameters, it is necessary to follow the actual situation of the site and set the inlet of the working face as the inlet boundary. The outlet boundary of goaf is free boundary. The nitrogen inlet was set as the velocity inlet and the concentration of nitrogen was 97%. The measured air temperature in the wind tunnel is 18.6 °C. The oxygen concentration is 20.9%, and the actual wind speed on the working face is 1.62m/s. The average air density of the mine is 1.225 kg /m³, and the air viscosity coefficient at room temperature is 1.789 × 10⁻⁵ kg /ms, the gas diffusion coefficient is 2.88 × 10⁻⁵ m³ /s, and the loose coefficient is set to 1.5. The porosity of the goaf can be obtained from the empirical formula according to the actual situation of roof bursting fracturing and expansion:
\[
n = \begin{cases} 
0.00001x^2 - 0.002x + 0.3, & x < 100 \\
0.2, & x \geq 100 
\end{cases}
\]
The permeability of goaf is calculated by Carman formula of porous media:
\[
K = \frac{D_m^2 n^3}{180 (1 - n^2)}
\]
Where, x is the distance between the goaf and the working face, m; D_m is the average particle size, m; n is the porosity.
4. Numerical simulation of flow field in goaf

Numerical simulation was conducted for four states: no nitrogen injection, no gas extraction, 300m³/h nitrogen injection, 450m³/h nitrogen injection, 300m³/h nitrogen injection and 20 m³/min gas extraction., and the distribution of flow field in goaf was shown in Fig. 1-4. The oxidation heating zone is shown in Fig. 6-9.

Goaf spontaneous combustion "three zones" division provides support for coal spontaneous combustion prediction, oxidation heating zone is the most critical area in the three zones. It is to analyze the technological parameters of coal spontaneous combustion by face and ventilation parameters affect the main reference point, according to the experience of the predecessors' research. According to the principle of superposition of two, combined with romantic oxygen concentration field division of spontaneous combustion "three zones", is the boundaries between the wind speed 0.004 m/s as oxidation with the upper limit of temperature rise, to the boundaries of oxygen concentration is 8% for oxidation heating up for the lower limit. Oxidative heating zones in the four states were respectively plotted as showed in FIG. 5-8.
Fig. 2 Flow field distribution without nitrogen injection and without gas extraction

Fig. 3 Flow field distribution when nitrogen injection amount is 300 m$^3$/h
Fig. 4 Flow field distribution when nitrogen injection amount is 450 m$^3$/h

Fig. 5 Flow field distribution when nitrogen injection amount is 300 m$^3$/h and gas extraction flow is 20 m$^3$/min
Fig. 6 oxidization and heat accumulation zone without nitrogen injection and without gas extraction

Fig. 7 oxidization and heat accumulation zone when nitrogen injection amount is 300 m$^3$/h
As can be seen from FIG. 1-8, when no nitrogen injection or gas extraction is carried out, the maximum wind speed of the goaf is 0.0956 m/s, the upper limit of the zone is 36 m, and the lower limit is 78 m. When the nitrogen content is 300 m³/h, the maximum wind speed in the goaf is 0.2323 m/s, the
upper limit of the oxidation temperature belt is 47 meters, and the lower limit is 80 meters. When the nitrogen injection amount is 450m3/h, the maximum wind speed in the goaf is 0.3336m/s, the upper limit of the oxidation temperature belt is 50m, and the lower limit is 78m. When the nitrogen injection is 300m3/h and the gas extraction flow is 20m3/h, the maximum wind speed of the goaf is 0.25m/s, the upper limit of the oxidation temperature belt is 46 meters, and the lower limit is 78 meters.

5. Conclusion
1) When working face is normally mined, the upper limit of the oxidation heating zone is 36 meters, the lower limit is 78 meters, and the width is 42 meters.
2) Four kinds of goaf under top sustained winds are near the working face location or nitrogen injection, in tropical little impact on the prevention and control of fire and gas. With the increase of nitrogen injection volume oxidation heating with cap, cap have not changed much, narrowing the scope, result in goaf gas drainage of leakage air volume increase, widen oxidation heating belt.

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