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Numerical Simulation on Danger Zone for Spontaneous Combustion in Goaf at Fully-Mechanized Caving Face

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Abstract: Most coal mines in China have a tendency to spontaneous combustion, which is outstanding in goaf. To effectively solve the problem, CFD technology is used for flow field in the goaf, and superposed field between volume fraction of oxygen and velocity is adopted as the standard. The influence of air quantity on danger zone for spontaneous combustion and width of oxidation zone is analyzed. The results show that with increasing of air quantity, shape of oxidation zone which is “L” has not changed but moves towards back, however, area of danger zone of spontaneous combustion increases. And width of oxidation zone exhibits an impact of quadric relationship on air quantity.

Keywords: *Fully-mechanized caving face; Goaf; Spontaneous combustion; Numerical simulation*

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1. Introduction

Underground Coal fires are the serious problems in coal mine, which cause significant economic and environmental impacts. Especially, spontaneous combustion in goaf is more critical in the process for mining thick seam. In order to solve the problem, spontaneous combustion dangerous zone in goaf must be determined, and it is helpful to determine the parameters for prevention and control of fire. Computational fluid dynamics codes including Fluent[1-4], PHOENICS and COMSOL[5-7] are adopted for calculating flow field in goaf in China. Howerve, there is no uniform dividing standard of spontaneous combustion danger zone[8]. There are three recognized standards: leakage rate, volume fraction of oxygen and temperature rise characteristic at test point. Leakage rate and volume fraction of oxygen essentially are consistent to leakage size for dividing standard. Generally speaking, temperature is not as main index[9]. There are two reasons: (1) internal heat transport is very complex in goaf, and the part of heat loss to roof or floor which it is hard to get by testing; (2) heat exchange between flow and rocks is too complex to be gotten[10,11]. So either testing or simulation, temperature can be auxiliary index rather than the main one[12]. For these reasons, Superposed field between oxygen concentration and velocity in goaf is adopted as the dividing standard in this paper.

2. Governing Equations for Flow Field in Goaf

Goaf belong to porous media, and gas flow in the pore of goaf. It is assumed that goaf seepage, diffusion and chemical reaction is steady state process, and Soret effect and Dufour effect are ignored. The governing equations which describe the motion of fluid flow, include set of the Navier-Stokes equations, continuity and any additional conservation equations, such as energy or species concentrations[13-15].

$$\begin{cases} \frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x_i}(\rho u_i)=S_m \\ \frac{\partial}{\partial t}(\rho u_i)+\frac{\partial}{\partial x_j}(\rho u_i u_j)=-\frac{\partial P}{\partial x_i}+\frac{\partial \tau_{ij}}{\partial x_j}+\rho g_j+F_i \\ C_e\frac{\partial T}{\partial t}+n\sigma_g V_i\frac{\partial T}{\partial x_i}=Q_s+\lambda_e\frac{\partial^2 T}{\partial x_i^2} \\ \frac{\partial C}{\partial t}=D_d div(gradC)-V_i gradC+V(t) \end{cases} \tag{1}$$

Where, ρ—density, Kg/m^3; t—time, s; u—velocity, m/s, S_m—gas source including gas, nitrogen and oxygen, Kg/m^3·s; P—static pressure, Pa; τ—stress tensor, N/㎡; $\rho g, F$—gravity and external body force，N, F includes the source attached to a model, such as porous media settings; V_i— velocity components in *x*, *y* and *z* directions, m/s; C_e—effective heat capacity for porous media，J/m^3·℃ ; λ_e—equivalent thermal conductivity for porous media, W/m·℃; σ_s, λ_s—total equivalent heat capacity and thermal Conductivity of the solid for porous media; σ_g, λ_g—total equivalent heat capacity and thermal Conductivity of gas for porous media; n—porosity ; Q_s—heat release from oxidation of lost coal in goaf, J/m^3·s; *C*—component concentration ; D_d—diffusion coefficient of oxygen in the media, m^2/s ; *V(t)*—gas consumption or production rate when gas concentration is *C*.

3. Numerical Simulation on Danger Zone for Spontaneous Combustion in Goaf

3.1 Physical Model

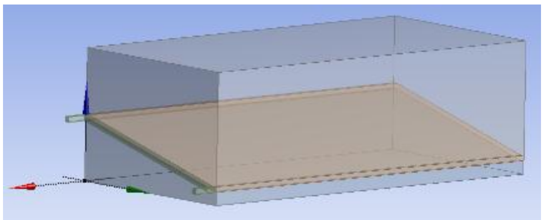
In this study, this situation is simulated with one caving fully-mechanized longwall face, simulated goaf area is 500 m long, 150 m wide, 15°dip angle and 4 m high starting from the bottom of coal seam. The coal is candle coal, which is one level easy spontaneous combustion coal and the shortest spontaneous combustion time is 20 days. Absolute gas emission rate of longwall face is 40 m^3/min～60 m^3/min.

3.2 Simulation Model

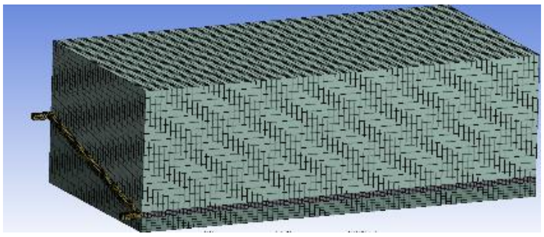
Simulated area is 300m long×150m wide×100m high. The layout of computational domain and the ventilation system is shown in Figure 1. Grid number is 56352. Porous media model is adopted for simulated area, and gas is incompressible and ideal. flow models and boundary conditions are set up through UDFs including permeability, distribution of O_2, CH_4, CO_2, CO, N_2, temperature and inert gas etc.. Permeability (shown in Figure 2) is set as the following:

$$K_p(x,y)=K_{p,\min}+\left(K_{p,\max}-K_{p,\min}\right)\times\exp\left(-a_1d_1\left(1-e^{-\xi_1a_0b_0}\right)\right)\quad\left(\xi_1<1\right)(2)$$

Where, a_0, a_1—Attenuation rate from wall or working face; $K_{P,\max}$—initial bulking factor; d_0, d_1—Attenuation rate from point (*x*,*y*) to wall or working face, m^{-1}; $K_{P,\min}$—compacted bulking factor; ξ_1—Adjustment number for controling the distribution of "O" model; K_P—bulking factor.



(a)simulated area



(b) Meshing

Fig. 1: *goaf model*

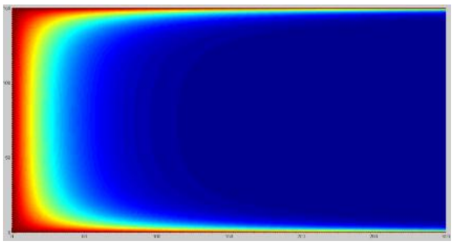


Fig.2 *coefficient of bulk increase distribution for gob*

3.3 Boundary Conditions

Boundary conditions for goaf model is the following.

(1) Entrance for inlet roadway

Velocity inlet is selected for boundary conditions of entrance, which is calculated by actual ventilation amount. The temperature is 293K, oxygen volume fraction is 21%, nitrogen volume fraction is 79% and absolute pressure is 10,325Pa at inlet roadway.

(2) Outlet for return roadway

Pressure outlet is selected for boundary conditions of outlet. The temperature is 296K.

(3) Surrounding rock

Porosity of surrounding rock of goaf remains consistent with the original one due to little effect by collapse of goaf. Gas flow is so low that boundary condition can be as wall.

(4) roof and floor of goaf

Gas flow in roof and floor of goaf is viewed as laminar flow. Permeability of porous media is given by deformation law of stratum.

Gravity is considered because Gas will appear obvious floating phenomenon.

3.4 Results and Discussion

The "three zones" of spontaneous combustion is shown in Figure 3~7 under conditions of no-dumping gas and no nitrogen injection. The results show that leakage rate and amount of oxygen supply will increase with increase of air flow. So distribution range of high oxygen concentration will expand. Generally, wind speed near working face is so high that oxygen concentration becomes high. However, heat produced is less than heat dissipation. This area is called cooling zone. At more distant from working face, the pore of goaf are compacted so that oxygen concentration becomes lower, where it is called oxidation zone. When oxygen concentration cannot meet demand of coal oxidation, oxidation of coal automatically will stop where it is called choking zone. Distribution width of oxidation zone at inlet side is narrower than the middle part, and width of oxidation zone increases with air quantity increasing. At outlet side, gas accumulates on upper corner of fully mechanized coal mining face as gas density is lighter than air, on the contrary oxygen concentration reduce. It is shown in Figure 6 that oxygen concentration at inlet side can still reach more than 5% at 210m from working face, less than 5% at 35m from working face at outlet side when air quantity is 1400 m^3/min.

It is found that oxygen concentration distribution in goaf is inhomogeneous. Oxygen concentration at inlet side is higher than return air side, but wind speed remains same at the both sides. Danger zone of pontaneous combustion gathered at inlet side in goaf[10], stack field between oxygen concentration and velocity shapes "L". Oxidation zone shape has not changed rather than shifting along with air volume supply increasing, simultaneously area of spontaneous combustion danger zone increases. Hence risk of fire in goaf increases.

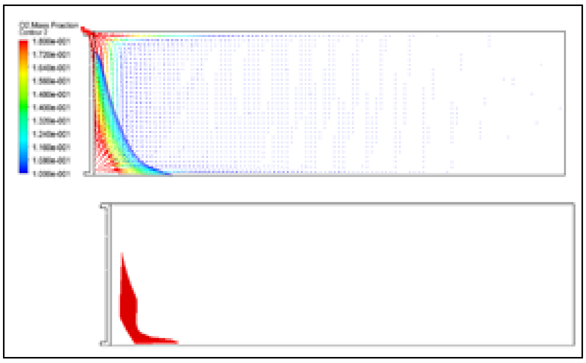


***Fig. 3**: Stack field between oxygen concentration and velocity and spontaneous combustion position for goaf when air volume is 300 m^3/min*

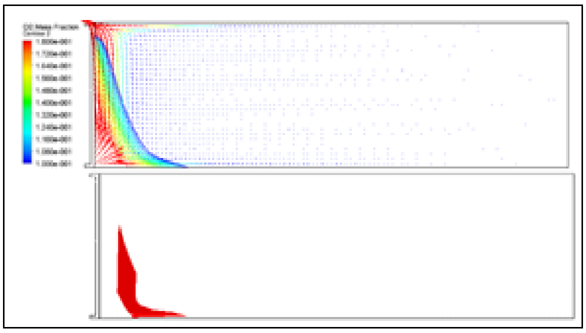


***Fig. 4:** Stack field between oxygen concentration and velocity and spontaneous combustion position for goaf when air volume is 400 m^3/min*

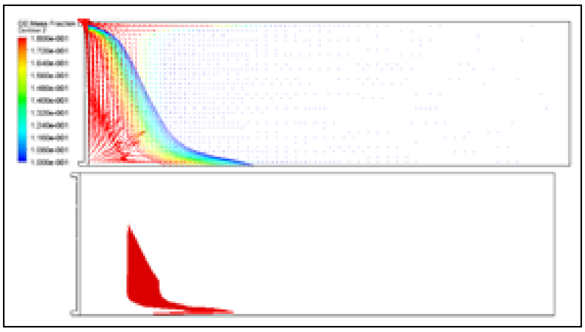


***Fig. 5:** Stack field between oxygen concentration and velocity and spontaneous combustion position for goaf when air volume is 1000 m^3/min*

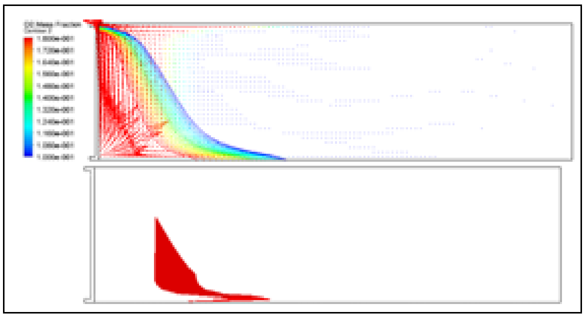


***Fig. 6:** Stack field between oxygen concentration and velocity and spontaneous combustion position for goaf when air volume is 1400 m^3/min*

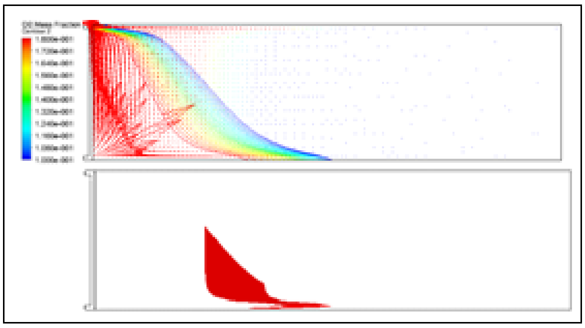
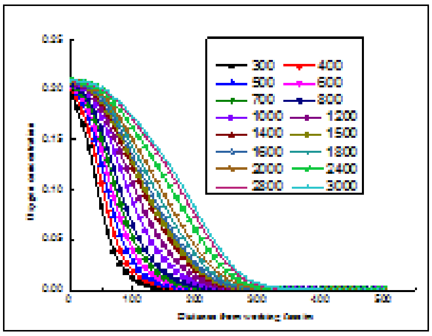
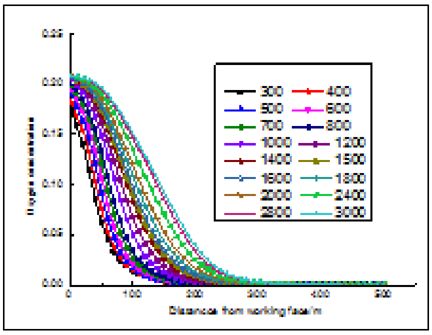


***Fig. 7:** Stack field between oxygen concentration and velocity and spontaneous combustion position for goaf when air volume is 3000 m^3/min*

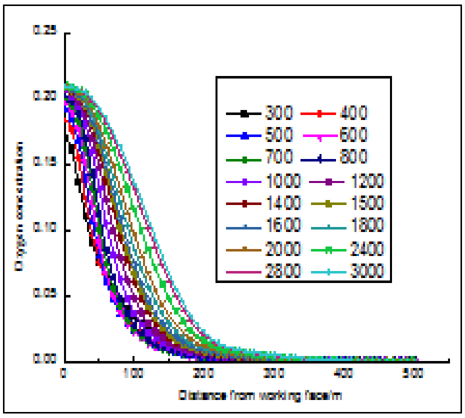
Oxygen concentration distribution of orebody trend at 40m, 80m and 120m from down pillar is shown in Figure 8. Oxygen concentration reduces with the distant increasing from working face, and scope is inversely proportional to air quantity, while width of oxidation zone increasing.



(a) at 40m from down pillar



(b) at 80m from down pillar



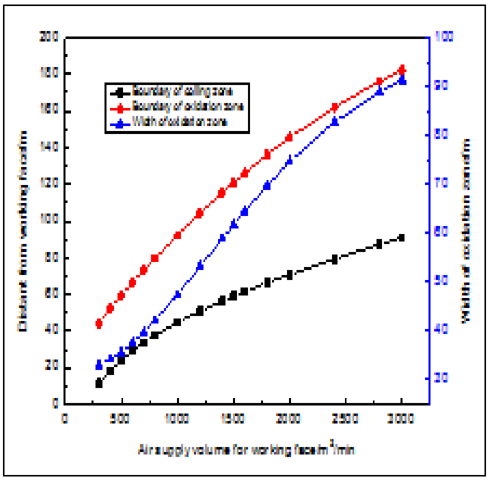
(c) at 120m from down pillar

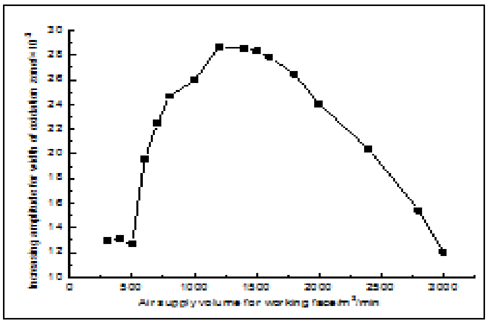
Fig. 8: *Oxygen concentration change along deep of goaf in different positions distance from conveying*

4. Relationship between air volume supply and oxidation zone

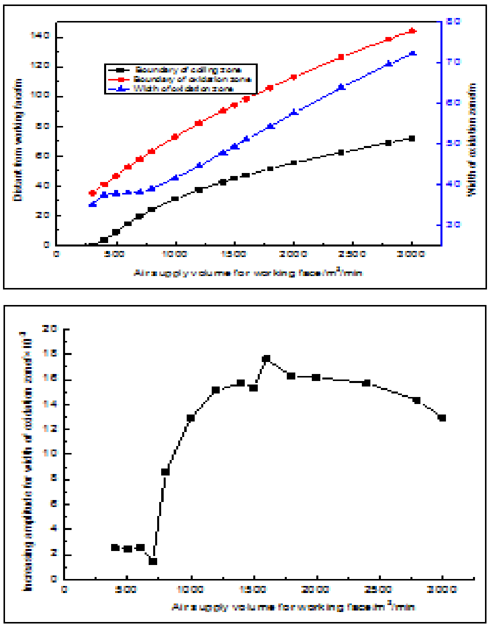
Leakage rate, width of oxidation zone and gas emission intensity increase with increase of air quantity for working face. At a certain advancing speed, risk of spontaneous combustion depend on the width of oxidation zone. The relationship between air quantity and width of oxidation zone is studied for determining air quantity of working face and controlfire in goaf.

Oxidation zone shape has not changed with air volume supply increasing(shown in Figure 3~7). However, boundary of cooling zone moves toward open-off cut, and moving velocity is lower than the one of oxidation zone. Width of oxidation zone at inlet side exhibits an impact of quadric relationship on air quantity. But when air quantity is far less than 500 m^3/min, width of oxidation zone at inlet side changes unconspicuously, and the one at the central and outlet side is approximately proportional to air quantity. Increasing amplitude of oxidation zone's width also exhibits an impact of quadric relationship on air quantity, and the value achieve maximum due to degree of compaction.

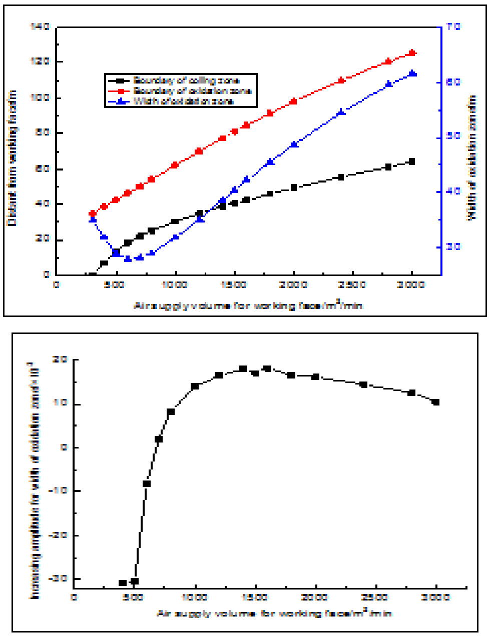




(a) at 40m from down pillar



(b) at 80m from down pillar



(c) at 120m from down pillar

Fig. 9*: Width of oxidation zone change along deep of goaf in different positions distance from conveying with air volume*

5. Conclusion

(1) Oxidation zone shape has not changed rather than shifting along with air volume supply increasing, simultaneously area of spontaneous combustion danger zone increases. Hence risk of fire in goaf increases.

(2) Width of oxidation zone at inlet side exhibits an impact of quadric relationship on air quantity. But there are some difference at different distant from down pillar. turning-point of increasing amplitude of oxidation zone’s width appears at 1 500 m^3/min.

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