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Numerical Simulation of Spontaneous Oxidation Zone Distribution in Goaf under Gas Stereo Drainage

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Abstract

In order to reduce spontaneous combustion in goaf at high methane mine, spontaneous oxidation zone distribution in goaf under methane stereo drainage is numerically studied by Fluent software. For the actual case of 8403 working face in Yang-Quan, According to the combination of gas velocity and oxygen concentration distribution, the oxidation zone distribution of horizontal and vertical surfaces are determined. The results shows that the distribution of spontaneous oxidation zone is asymmetrically at horizontal surfaces, the width of spontaneous oxidation zone of inlet side is wider than outlet side; at the vertical surfaces, the spontaneous oxidation zone is below 20 meters. By the contrast of the numerical oxygen concentration and measured oxygen concentration, good agreement is obtained, which shows that the numerical results is reliable. The methane concentration distribution shows that inner tail-roadway can effectively reduce methane concentration at working face's upper corner, and high drainage roadway can reduce methane concentration in the whole goaf.

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Keywords: goaf; CFD; spontaneous oxidation zone ; gas stereo drainage; numerical simulation

Nomenclature

u, v, w	Cartesian velocities
p	pressure
c	concentration
Q	heat release rate
Greek symbols	
α	Permeability
μ	kinematic viscosity

1. Introduction

Due to the effect of air leakage in goaf, it is naturally formed "three zones"—a cooling zone, a spontaneous combustion zone and an asphyxia zone, which is the main basis of analysizing the early spontaneous combustion growth. For the high gas coal mine, to effectively improve the gas drainage efficiency, stereo drainage method combined with high pumping and tail extraction is the effective method of preventing gas disaster in coal mines. However, stereo drainage will accelerated the air leakage in goaf and lead to an aggravating spontaneous combustion of residual coal. For the consideration of safety and high efficiency mining, the study of spontaneous combustion oxidation zone distribution rule under stereo drainage is very

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important.

The partition of spontaneous combustion zone in goaf is often determinded by field measured, but it is limited by position and number of measured point, so many researchers use the CFD tool to simulate coal spontaneous combustion in goaf. Li Zong-xiang studied spontaneous combustion process of residual coal in goaf[1] and the coupling relationship of methane drainage and spontaneous combustion[2]. Wu Zheng-yan build a 3-D model to numerically simulate the species transfer in goaf[3]. Liming Yuan Numerically studied the effects of coal properties on spontaneous heating in longwall goaf areas[4]. Li Shou-qin studied “three Zones” distribution in goaf of island-like longwall[5].

Combined the methods of numerical simulation and filed measurement, spontaneous oxidation zone distribution and methane concentration distribution in goaf under methane stereo drainage is studied. On the one hand, it is beneficial to predict the possible location of spontaneous combustion, and to supply fire prevention and extinguishing medium, such as nitrogen, to the suitable place; On the other hand, it is beneficial to analysis the effect of staggered tail roadway and high drainage roadway to methane concentration.

2. Model formulation

The gas flow in goaf can be regarded as the air flow in porous media. Under consideration, the physical model and coordinate system of the problem are illustrated schematically in Fig.1. Q_{in} is the air leakage from working face to goaf, q_{CH_4} is the emission intensity of methane in goaf. Q_{out} is the exhaust air from goaf to working face, which is divided into three parts, one part is discharged along the return airway, another portion is discharged along staggered tail roadway, the remaining portion is discharged along the high drainage roadway. Considering the leakage flow is relatively small, the gas flow in goaf is approximate to laminar flow distribution, which obeyes the Darcy's law.

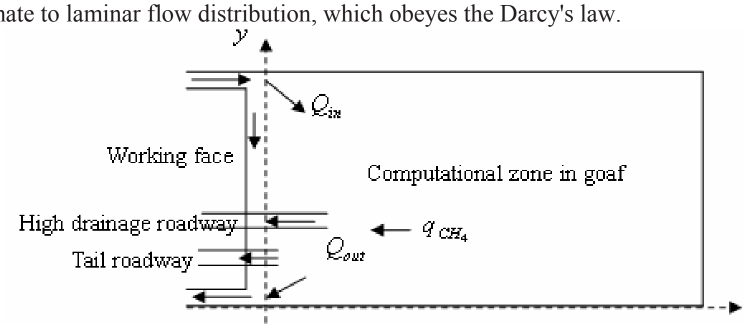


Fig.1. Schematic of gas flow in goaf

The governing equations written in conservative form are as follows:

Continuity
$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \quad (1)$$

Monentum
$$\frac{\partial}{\partial x}(uu)+\frac{\partial}{\partial y}(vu)+\frac{\partial}{\partial z}(wu)=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\nu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)+\frac{\Delta p_x}{\rho} \quad (2)$$

$$\frac{\partial}{\partial x}(uv)+\frac{\partial}{\partial Y}(vv)+\frac{\partial}{\partial z}(wv)=-\frac{1}{\rho}\frac{\partial p}{\partial y}+\nu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)+\frac{\Delta p_y}{\rho} \quad (3)$$

$$\frac{\partial}{\partial x}(uw)+\frac{\partial}{\partial Y}(vw)+\frac{\partial}{\partial z}(ww)=-\frac{1}{\rho}\frac{\partial p}{\partial z}+\nu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)+\frac{\Delta p_z}{\rho} \quad (4)$$

species equation
$$\frac{\partial}{\partial x}(uc)+\frac{\partial}{\partial Y}(vc)=D\left(\frac{\partial^2 c}{\partial x^2}+\frac{\partial^2 c}{\partial y^2}\right)+w \quad (5)$$

Where $\Delta p_x=\sum_{i=1}^{2}\frac{\mu L}{\alpha_{xi}}(u+v)$, $\Delta p_y=\sum_{i=1}^{2}\frac{\mu H}{\alpha_{yi}}(u+v)$. u, v referres to the velocity of x, y direction, respectively. μ referres to the kinematic viscosity, α referres to Permeability of air leakage in porous media. i referres to the x, y

direction, respectively. L, H referres to the length and width of goaf respectively. w referres to the source term of oxygen concentration, carbon monoxide concentration and methane concentration.

$$w_{o_2} = -(\frac{r_0 H_1 c(o_2)}{c(o_2)_0} + \frac{nHw_{CH_4}}{c - c(o_2)})\frac{c(o_2)}{H} \quad (6)$$

H_1 referres to the mining height， $r_0 = 0.68\text{mol/m}^3 \cdot \text{h}$， $c(o_2)_0 = 9.375\text{mol/m}^3$， n referres to the porosity which is kept constant 0.2, $w_{ch_4} = 1\text{mol/m}^2 \cdot \text{h}$.

The boundary conditons for the considering problems are determined as follows: the air leakage $Q_{in} = 183\text{m}^3/\text{min}$, return airway is regarded as outflow, tail roadway and high drainage roadway are regarded as pressure outlet. All walls are regarded as $u = v = 0$. The methane concentration of inlet airway, return airway, tail roadway and high drainage roadway are 0.0%, 0.6%, 1.19%, 26.5%, respectively.

Using Gambit software to establish geometry and mesh, as shown in Figure 2, consider the flow of non uniform, with non uniform meshes 90 x 80 x 34, the grides near the inlet airway, return airway, tail roadway and high drainage roadway are partially encrypted. Source term of Monentum equation and species equation are used the UDF function to imported compiled. Governing equations above are discretized by using a finite volume method on a non-uniform staggered grid system. In the course of discretization, a second order central difference scheme is implemented for convection and diffusion terms. The resulting discretized equations are solved by a line-by-line procedure, combining the tri-diagonal matrix algorithm and the successive over-relaxation iteration. The coupling between velocity and pressure is done by SIMPLE algorithm. The convergence criterion is that the maximal residual of all the governing equation were all less than 10-3.

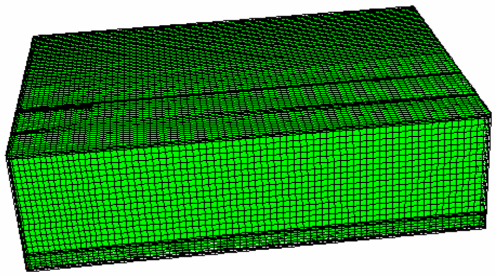


Fig.2. Mesh division

3. Results and discussions

Assumed the length of the goaf is 300 meters, the width is 220 meters, the area of inlet airway and return airway are 13m2, the area of staggered tail roadway and high drainage roadway are 10 m2 and 9 m2, respectively. Staggered tail roadway is of 30m from return airway, 3m from working face and 8m from the bottom of the goaf. High drainage roadway is of 70m from return airway, 50m from working face and 82.6m from the bottom of the goaf. The air flow, methane concentration and oxygen concentration distribution are numerically studied by Fluent software, and contrasted with the experimental observationed oxygen concentration.

3.1 Flow field distribution in goaf

Flow field distribution in goaf has an important influence on component concentration and "three zones " partition. Figure 3 shows the velocity vector distribution of horizontal planes z=3, 9.5, 41.5, 81.5 and vertical plane x=3. In horizontal plane, air leakage infiltrated the bottom of goaf at the air inlet side, and mixed with the methane from the goaf, then discharged from return airway, staggered tail roadway and high drainage roadway, respectively. the velocity magnitude of return airway is smaller than tail roadway, which the maximum speed reached 0.5m/s, the velocity magnitude of high drainage roadway is of high speed because of Large negative pressure, which the maximum speed reached 1.16m/s At vertical surface, air leakage infiltrated into the goaf upwards, after a long journey, discharged from return airway downwards. the speed of air leakage at vertical plain is much smaller than that of horizontal plane, approximately 1/10.

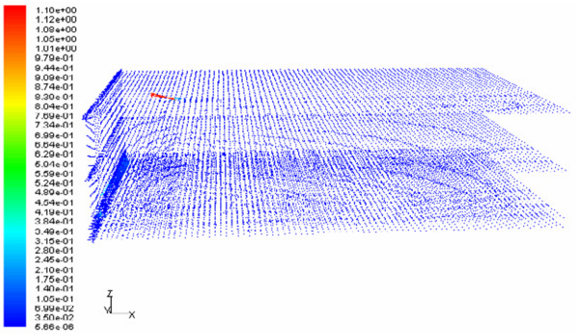


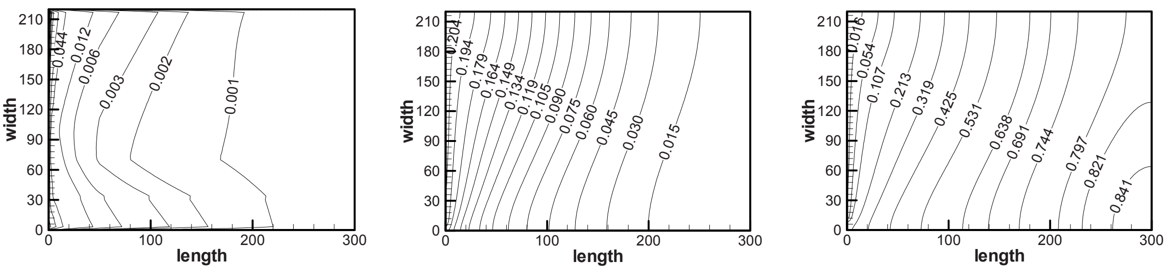
Fig.3. The velocity vector distribution of horizontal planes z=3, 9.5, 41.5, 81.5 and vertical plane x=3

3.2 Spontaneous oxidation zone and methane concentration distribution at horizontal plane

For residual coal in goaf, main conditions of spontaneous combustion are oxygen supply and heat storage. Generally, the lower limit oxygen concentration of suppressing coal self-heating is 8%-10%, the upper limit speed of air leakage is 0.013m/s, i.e. the zone which speed is less than 0.013m/s and oxygen concentration is greater than 8% is spontaneous combustion zone. Figure 4, figure 5 and Figure 6 showed the velocity magnitude, oxygen concentration and methane concentration distribution at the horizontal planes z=3, z=9.5, z=81.5, respectively. It is easy to see from Figure 4(b) and figure 5(b) that the oxygen concentration distribution is asymmetric at inlet airway and return airway. The oxygen concentration of inlet airway is higher than return airway, which is mainly due to the dilution effect by methane from goaf. At the horizontal plane z=3, the oxygen concentration of inlet airway decreases to 8% at 138m from work surface, while at the return airway, the oxygen concentration decreases to 8% at 78m from work surface. According to the combination of oxygen concentration and velocity magnitude, at the inlet airway, spontaneous oxidation zone is from 38m to138m, at the return airway, spontaneous oxidation zone is from 35m to 78m. At the horizontal plane z=9, the oxygen concentration of inlet airway decreases to 8% at 98 m from work surface, the width of spontaneous oxidation zone is about 60m, while at the return airway, the oxygen concentration decreases to 8% at 35m from work surface, i.e. the width of spontaneous oxidation zone is small at return airway. At the horizontal plane z=81.5, the oxygen concentration is zero, i.e. all the zone are Choking zones.

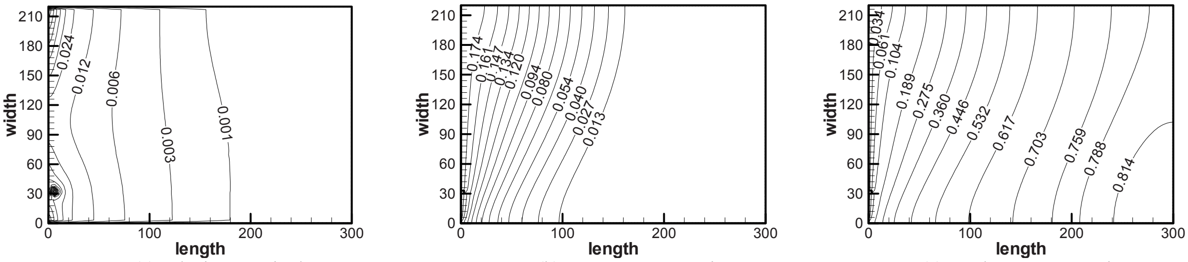
Figure 4(c), figure 5(c) and Figure 6(c) showed the methane concentration distribution of the horizontal planes z=3, z=9.5, z=81.5, respectively. It can be seen from the figure, methane concentration is high at working face's upper corner and deep goaf, which leads methane easily accumulated. Using a staggered tail roadway, it is effective to discharge the upper corner methane, thereby ensuring the upper corner methane concentration to less than 1%. High drainage roadway can reduce methane concentration in the whole goaf, at the horizontal planes z=9.5, methane concentration (83.2%) is smaller than that of the horizontal plane z=3 (86.5%), while at the horizontal planes z=81.5，methane concentration is about 26% because of the effectively extracted by high drainage roadway.

In order to validate the reliability of simulation results, oxygen concentration of numerical simulation and field measurement at the horizontal plane z=3 are compared, as shown in Figure 7, The simulation results and experimental results matched well at the inlet airway, at the return airway, the simulation results is less than the experimental results, but overall the trend of them are similar.



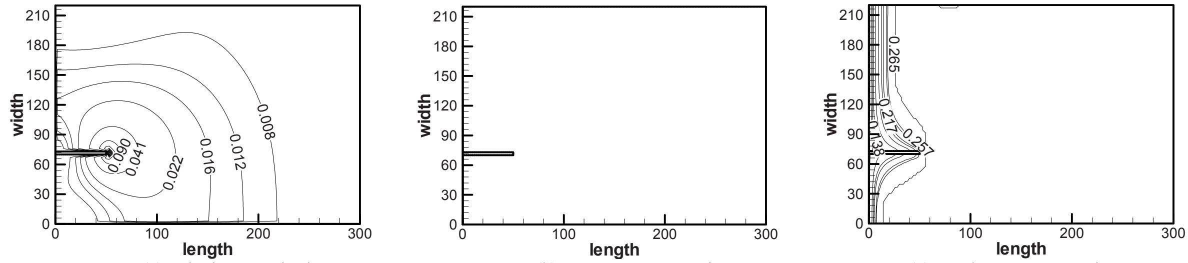
(a) velocity magnitude (b) oxygen concentration (c) methane concentration

Fig.4. Scalar distribution at the the horizontal plane z=3



(a) velocity magnitude (b) oxygen concentration (c) methane concentration

Fig.5. Scalar distribution at the the horizontal plane z=9.5



(a) velocity magnitude (b) oxygen concentration (c) methane concentration

Fig.6. Scalar distribution at the horizontal plane z=81.5

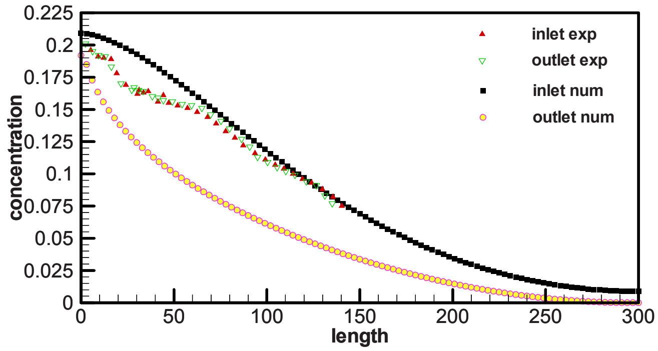


Fig.7 .Contrast of numerical oxygen concentration and measured oxygen concentration at horizontal plane

3.3 Spontaneous oxidation zone and methane concentration distribution at vertical plane

At the vertical plane, air leakage also exists due to staggered tail roadway and high drainage roadway, Vertical "three zones" division is beneficial to predict the possible location of spontaneous combustion, and to supply fire prevention and extinguishing medium, such as nitrogen, to the suitable place. Figure 8 showed the velocity magnitude, oxygen concentration and methane concentration distribution at the vertical plane x=3. Figure 8(b) showed that the oxygen concentration of inlet airway decreases to 8% at the height of 23m, while at the return airway, the oxygen concentration decreases to 8% at the height of 20m.According to the combination of oxygen concentration and velocity magnitude, at the vertical plane, spontaneous oxidation zone is below 20m. Fig.8(c) showed methane concentration at the the vertical plane x=3, it can be seen, in the vertical plane, methane concentration of return airway is higher that of inlet airway.

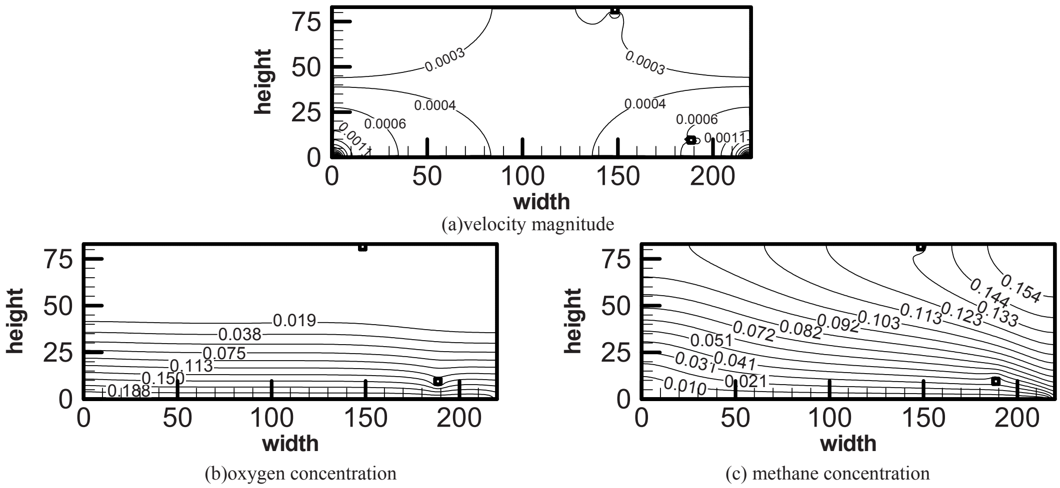


Fig.8 .Scalar distribution at the vertical plane x=2

Figure 9 showed oxygen concentration of numerical simulation and field measurement at the vertical plane x=3. It is easy to see that numerical results and experimental results matched well both inlet airway and return airway.

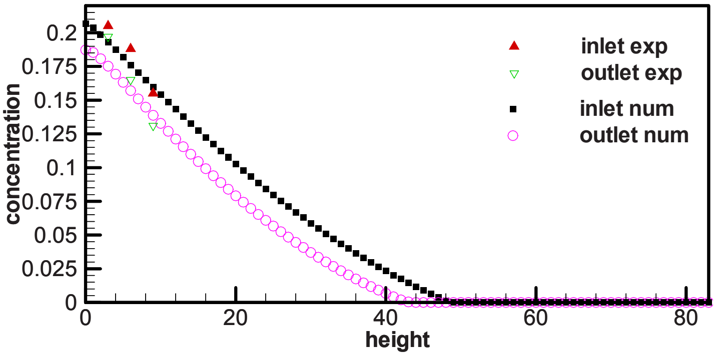


Fig.9. Contrast of numerical oxygen concentration and measured oxygen concentration at vertical plane

4. Conclusion

For the actual case of 8403 working face in Yang-Quan, spontaneous oxidation zone distribution in goaf under gas stereo drainage is numerically studied by Fluent software. The following main conclusions can be drawn: (1) The distribution of spontaneous oxidation zone is asymmetrically at horizontal surfaces, the width of spontaneous oxidation zone of inlet airway is wider than return airway due to the dilution effect by methane from goaf. At the horizontal plane z=3, spontaneous oxidation zone is from 38m to138m, at the return airway, spontaneous oxidation zone is from 35m to 78m. (2) At the vertical plane, spontaneous oxidation zone is below 20m for the velocity magnitude of air leakage is small. (3) By the contrast of the numerical oxygen concentration and measured oxygen concentration, good agreement is obtained, which shows that the numerical results is reliable. (4) The methane concentration distribution shows that inner tail-roadway can effectively reduce methane concentration at working face's upper corner, and high drainage roadway can reduce methane concentration in the whole goaf.

Acknowledgements

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References

[1]Li Zong-xiang,2005. Numerical Simulation Of Spontaneous Combustion Process Of Residual Coal In Goaf[J]. China Safety Science Journal, 15(6),p. 15.
[2]Li Zong-xiang, Lu Zhong-liang, Wu Qiang,etc. 2007.Numerical Simulation Study Of Goaf Methane Drainage And Spontaneous Combustion Coupling[J].Journal of China University of Mining & Technology, 17(4),p. 503.
[3]Wu Zheng-yan, Jiang Shu-guang, etcal,2007.. Study of 3-D Numerical Simulation For Gas Transfer In The Goaf Of Coal Mining. Jounal of China University Of Mining And Technology, 2,p. 152
[4]Liming Yuan, Alex C.Smith,2008..Numerical Study On Effects Of Coal Properties On Spontaneous Heating In Longwall Goaf Areas[J]. Fuel, , 87(15-16),p.3409
[5]Li Shou-qin, Li Ying-hui. 2011.Study On Laws Of Coal Oxidation Three Zones Distribution In Goaf Of Island-Like Longwall[J]. Journal of Anhui University of Science and Technology, 31(2),p. 49
[6]Guo Xing-ming, Xu Jing-cai Hui Shi-en.2001. Research On Key Parameters In The Process Of Coal Self-Ignition[J]. Journal of XI-AN Jiao Tong University, 35(7),p. 682.