Numerical Simulation Analysis of Gas Movement Law and Concentration Distribution in Goaf

Cao Jie[1, 2, a,*]

[1]Gas Research Branch, China Coal Technology Engineering Group Chongqing Research Institute, Chongqing 400037, China

[2]State Key Laboratory of the Gas Disaster Detecting Preventing and Emergency Controlling, Chongqing 400037, China

[a]cqcaoj@126.com

Keywords: Coal mine, Goaf, Gas movement, Numerical simulation

Abstract: The gas emission in the goaf is the main reason for the gas overrun in the underground working face of coal mining. In order to accurately grasp the law of gas flow in goaf, the effect of emission intensity on gas flow in goaf under the U-type return air condition is simulated and analyzed. The research results show that in the U-type return air condition, in the goaf where the main gas emission source is attenuation emission source, the gas concentration will increase first and then decrease with time. And a "fan" reduction zone of gas concentration is gradually formed extending from the intake airway side into the deep of the goaf area.

1. Introduction

In coal mining process, the gas emission from coal wall in working face and residual coal in goaf can prone to gas accumulation, threatening the safety of coal production. The pores and fissures between the caved gangue in the goaf are developed, and the gas flow velocity is relatively fast. According to the criterion of gas flow status in porous media, it is known that the gas flow in the goaf area belongs to the non-Darcy percolation and diffusion mass transfer in the porous medium[1]. a lot of researches of non-Darcy fluid flow through porous and fractured reservoirs was carried out by scholars through theoretical analysis, on-site and experimental studies, especially in the oil and gas industry. Guppy et al. obtained the semi analytical solution and graphical solution show that the fracture conductivity is a value changes with time[2]. On the basis of previous studies, Wu got a model formulation incorporates the Forchheimer equation to describe single-phase and multiphase non-Darcy flow through porous and fractured media[3]. And then, CFD modelling has been considered a useful approach in simulating fluid dynamics to research the gas flow law in longwall goaf[4,5]. Guo et al. studied the goaf flow of methane released from unmined adjacent coal seams[6]. Qin et al. analyzed the variables such as gas sources, the heights of caved and fractured zones of the goaf, the location of the drainage borehole, effect on the goaf gas flow and borehole drainage efficiency[7]. Therefore, in order to grasp the characteristics of the gas flow in the goaf more accurately, it is necessary to predict the gas emission law, and then analyze its influence on the gas flow in the goaf.

2. The control equation of gas flow in goaf

The gas in the fissures space of the goaf can be regarded as ideal gas mixture, consisting of methane and air. The gas flow is the non-Darcy seepage and molecular diffusion migration caused by the pressure gradient and the concentration gradient, which follows the mixed gas state equation, mass conservation equation, momentum equation and so on.

(1) The mass conservation equation

$$\frac{\partial(\varphi\rho)}{\partial t}+\nabla g(\rho V)=\rho Q \tag{1}$$

Where ρ is the density of the ideal gas (kg/m^3), φ is the porosity (%), V is the volume of mixed gas (m^3), Q is the intensity of source (sink), t is the time.

(2) The equation of motion (momentum equation)

The flow of air in the roadway and the working face can be seen as the flow of fluid in the pipeline, described by the Navier-Stokes equation, whose dependent variable is the velocity vector and gas pressure:

$$\left.\begin{array}{l}(-\nabla\cdot\eta(\nabla\mathbf{u}_{ns}+(\nabla\mathbf{u}_{ns})^{T}))+\rho\mathbf{u}_{ns}\cdot\nabla\mathbf{u}_{ns}+\nabla p_{ns}=0\\ \nabla\cdot\mathbf{u}_{ns}=0\end{array}\right\} \tag{2}$$

Where η is coefficient of viscosity (kg/(m·s)), $\mathbf{u}_{ns}$ is velocity vector (m/s), p_{ns} is gas pressure (MPa).

The flow pattern of gas in the fissure space of the goaf is the transition flow between the Darcy seepage and the pipeline flow, and it can be described by the Brinkman equation. Based on the Darcy equation, the equation considers the viscous shear stress term of the Navier-Stokes equation, and extends the Darcy's law to describe the loss of the dynamic energy caused by the viscous shear, which describes the rapid flow in porous media with dynamic potential driven by fluid velocity, pressure and gravity. The Brinkman equation can be expressed as:

$$\left.\begin{array}{l}(-\nabla\cdot\frac{\eta}{\varepsilon}(\nabla\mathbf{u}_{br}+(\nabla\mathbf{u}_{br})^{T}))-(\frac{\eta}{k}\mathbf{u}_{br}+\nabla p_{br})=0\\ \nabla\cdot\mathbf{u}_{br}=0\end{array}\right\} \tag{3}$$

Where ε is the porosity (%), k is the permeability (μm^2), $\mathbf{u}_{br}$ is velocity vector in goaf (m/s), p_{br} is gas pressure in goaf (MPa). The dependent variable of the Brinkman equation is also the velocity vector and the pressure, and the velocity vector. So the pressure at the interface between the working face and the goaf area are the same: $\mathbf{u}_{ns}=\mathbf{u}_{br}$, $p_{ns}=p_{br}$.

(3) The gas diffusion migration model

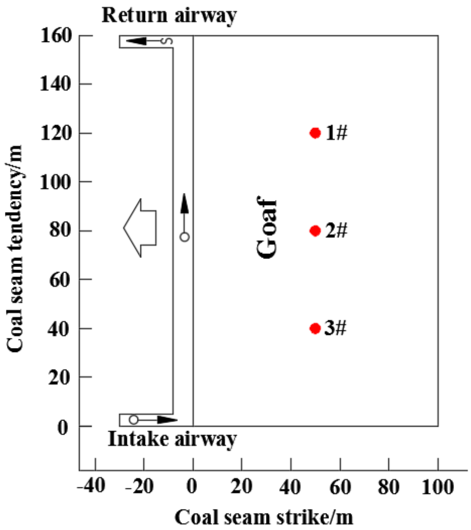
Diffusion movement is the process that the gas molecules migrate from high concentration to low concentration and finally reach equilibrium under the action of free movement. The migration law of solute in the flow field of porous media can be described by the convection-diffusion equation of porous media:

$$\theta_s\frac{\partial c}{\partial t}+\nabla\cdot(-\theta_s D_L\nabla c+uc)=S_c \tag{4}$$

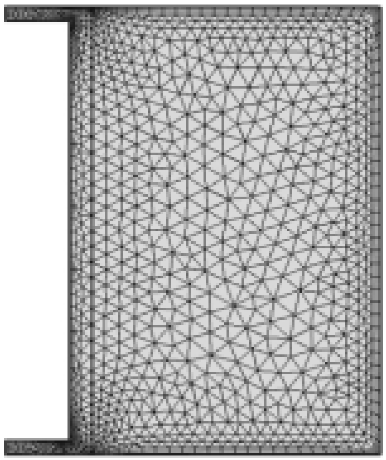
Where θ_s is the volume fraction of fluid, c is the concentration of dissolved (kg/m^3), D_L is the pressure diffusion tensor (m^2/d), S_c is the increment of solute in the porous medium per unit time and volume, ie, the relative emission rate of the gas.

3. Model construction and parameter setting

Combined the gas movement equation and the diffusion equation, the gas concentration, the velocity and pressure distribution of the working face and goaf can be obtained by using COMSOL Multiphysics software. Therefore, according to the situation of the site, the working face and the goaf area are simplified to construct a two-dimensional plane model which is 160 m inclined width and 100 m long. The concrete model and the meshing are shown in Fig.1.



(a) The model



(b) The meshing

Fig. 1 The computational model and meshing

The main parameters and boundary conditions of the model are as follows: the air density is 1.29 kg/m^3, its dynamic viscosity coefficient is 5×10^{-5} Pa·s, the gas density is 0.7168 kg/m^3, and its dynamic viscosity coefficient is 1.79×10^{-5} Pa·s, the diffusion coefficient is 2×10^{-5} m^2. The initial gas pressure in the goaf is 101325 Pa and the initial gas concentration is 3 %. The intake airway of working face is the inlet boundary, the wind speed is 2.6 m/s, the gas concentration is 0 %, the return airway is the outlet boundary, controlled by the gas pressure, and the other solid boundary is the wall. The fluid motion of roadway and working face is free-flowing, controlled by Naiver-Stokes equation. The fluid movement in goaf is nonlinear seepage, controlled by Brinkman equation. According to the established model and parameter setting, numerical simulation is carried out until the residual error convergence, the distribution of gas flow field and concentration can be obtained.

In order to analyze the influence of gas emission law on the gas flow in goaf, two kinds of gas emission conditions in goaf were set up: (1) No gas emission, that is, without considering the effect of gas emission on the law of flow. (2) The gas emission is in accordance with the attenuation source model, for the thick coal seam stratified mining or coal seam which has a closer upper adjacent layer mining, the gas emission using the following Eq. (5) to calculate.

The gas effusion intensity model of the gas emission is as follows:

$$q_{\mathrm{v}} = \rho_m \cdot l \cdot \frac{q_0}{V_m} e^{-b \cdot t} \tag{5}$$

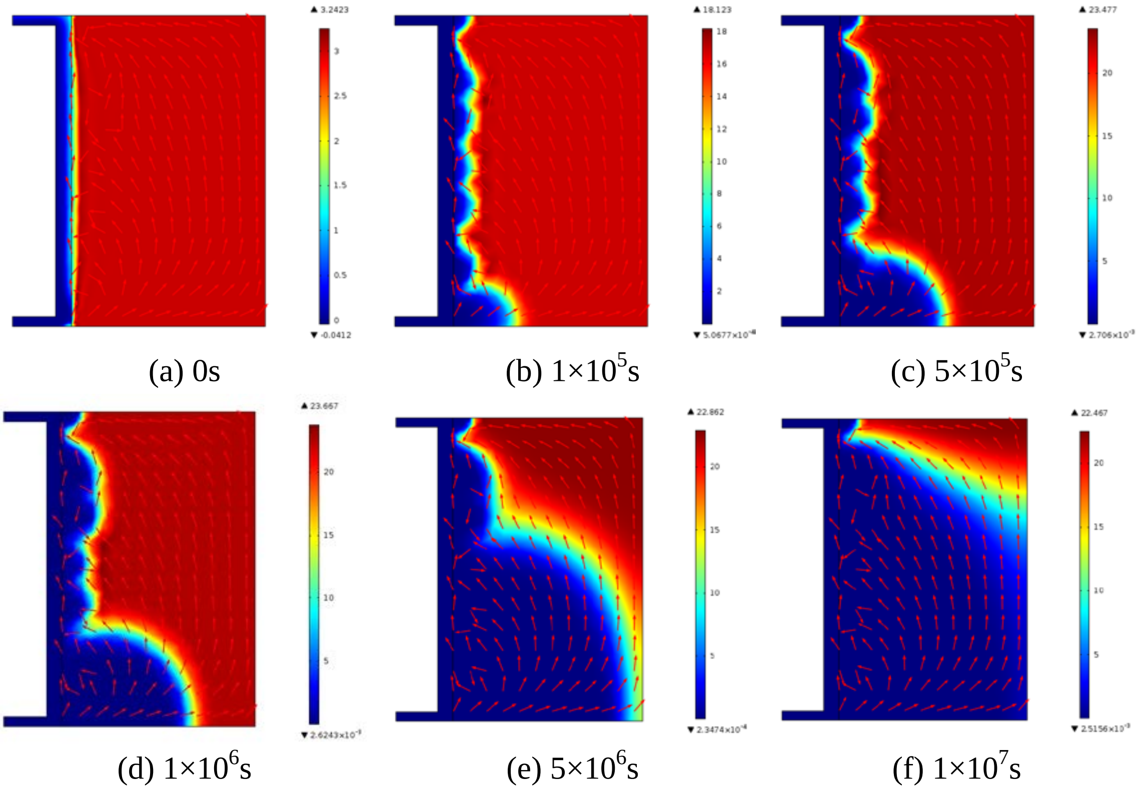
Where, q_v is the gas effusion intensity (mol/(m^3·s)), ρ_m is the density of residual coal in goaf (g/m^3), l is the volume ratio of residual coal in goaf, V_m is the molar volume of gas (m^3/mol),q_0 is the initial gas desorption rate (m^3/ (g·s)), b is the fitting parameters, t is the time of desorption (day).

4. Simulation results and analysis

The gas concentration distribution and flow at different times are shown in Fig.2, different colors indicate different gas concentrations and arrows indicate gas flow direction. It can be seen from Fig. 2 that the gas concentration in the goaf is 3 % at the initial time (0 s), and the gas concentration varies with the time of the air return of the working face and the gas emission from the goaf.

From the whole analysis, the gas concentration in the whole goaf gradually increased at the initial time, reaching the highest 23.67 % at about 1×10^6 s. This shows that the gas concentration in this stage is less affected by the return air, and the amount of gas taken away by the return air is smaller than the supply of gas emission from the goaf. With time passed by, the overall gas concentration of goaf area is gradually reduced which is due to the gradual reduction of gas emission at this stage, smaller than the amount of gas taken away by return air.

From the local analysis, the gas concentration on the intake airway side is lower than that on the return airway side. This is because the return air flow from the intake airway, leakage into the goaf area, resulting in the gradual reduction of air pressure from the intake airway side to the return side of goaf, causing the gas flow from the intake airway side to the return airway side. In the initial time the gas concentration is relatively high near the open cut due to the smaller impact of the return air, the amount of gas taken away by the return air is smaller than the supply of gas emission. As the time progresses, a "fan" reduction zone of gas concentration is gradually formed extending from the intake airway side into the deep of the goaf area. And part of the gas from the gob gradually back to the working face of the return airway side due to the air flow, which may form accumulation area near the corner. Therefore, when design the gas drainage program in goaf, can consider arrange the location of the drilling near the return airway side to ensure a better extraction efficiency and longer extraction time.



(a) 0s (b) 1×10^{5}s (c) 5×10^{5}s

(d) 1×10^{6}s (e) 5×10^{6}s (f) 1×10^{7}s

Fig.2 The gas concentration and flow pattern of goaf in different time(%)

5. Conclusion

Through simulation analysis the gas flow law in goaf under U-type return air condition, the results show that under different conditions, the gas concentration of the goaf near intake airway side is influenced by the return air more earlier and significant. And a "fan" reduction zone of gas concentration is gradually formed extending from the intake airway side into the deep of the goaf area.

Acknowledgments

The research described in this paper was financially supported by National Natural Science Foundation of China (No.51874348, No.51774319, No.51574280), National Key Research and Development Program (No.2016YFC0801402) and Chongqing science and technology innovation leader talent support program (CSTCKJCXLJRC14).

References

[1] Zhou, H., Liu, J., Xue, D., Xue, J.. Numerical simulation of gas flow process in mining-induced crack network[J].International Journal of Mining Science and Technology,2012,22(6), 793-799.

[2] Guppy, K. H., Cinco-Ley, H. and Ramey, H. J.. Effects of non-Darcy flow on the constant-pressure production of fractured wells[J]. Soc. Pet. Eng. J., 1981:390-400.

[3]Wu, Yushu. Numerical simulation of single-phase and multiphase non-Darcy flow in porous and fractured reservoirs[J].Transport in Porous Media, 2002,49, 209-240.

[4]Hu Qianting, Liang Yunpei, Liu Jianzhong . CFD simulation of goaf gas patterns[J].Journal of China Coal Society,2007,32(7):719-723 .

[5]Karacan, C.Ö. .Prediction of porosity and permeability of caved zone in longwall gobs[J]. Transport in Porous Media, 2001,82, 413-439.

[6] Fan L. Research on Economic Effect of Wind Power Accommodation Based on Electric Boiler and Heat Accumulator [J][J]. Journal of Applied Science and Engineering Innovation, 2018, 5(2): 55-58.

[7]Qin, R., Teng, L., Yuan, S., Shi, L. Numerical simulation gob gas field of the roof tunnel drainage method[J].AGH Journal of Mining and Geoengineering, 2012,36(3), 283-290.