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Numerical Simulation and Inversive Study of Gas Flow Field Around Coal Bed Borehole
Xiaoyan SONG a Zhongpeng XIE b,c a*

* Safety Engineering College, North China Institute of Science and Technology, Beijing, 101601, China
b Resource and Environmental Engineering Institute, China University of Mining and Technology, Beijing, 100083, China
c Safety and Environmental Engineering Institute, Capital University of Economics and Business, Beijing, 100026, China

Abstract

Using bore gas flux inverse analysis gains coal bed gas flow equation on the basis of coal bed gas occurrence and flow theory, gas radial flow differential equation, using large scale finite element analytical software ANSYS analyse the stress of bore, and gain the stress distributing graph of and further analyze the stress had an impact on coal bed air permeability coefficient and the various rule of gas pressure and coefficient of permeability distribution following stress around bore and gas pressure gradient impacts on gas flow. It has real meaning to gas evacuation, coal mine safety design and coal-bed gas development.

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1. Introduction

Flow of gas in coal seam and coal body around the drill is a relatively complicated gas-transiting process. It is affected by various factors, such as gas press, mine press, pressure bump, rheological property of coal body, and so on[1]. Gas permeability coefficient of coal bed is an indication for gas

* Corresponding author. Tel.: +0-010-6159-0332; fax: +0-010-6159-0332.
E-mail address: xiao.yansong@163.com.
flow difficulty in coal seam, so it is important for improving drainage rate of gas and ensuring safety produce of coal mine to find out change rules of gas permeability coefficient of coal bed in drainage.


2.1. Continuity Equation of Gas Flow

In accordance to conservation of mass, net quality flux passing every tiny cubage unit for unit time equals fluid quality chage in the unit, and then continuity equation is

\[
\text{div}(\rho \mathbf{u}) = \frac{\partial M}{\partial t}
\]

(1)

Where,
\( \text{div}(\rho \mathbf{u}) \)—divergence of gas quality velocity vector;
\( \rho \)—gas density in case gas pressure is \( P \), \( \text{t/m}^3 \);
\( \mathbf{u} \)—gas flow velocity vector, \( \text{m/s} \);
\( M \)—gas quality in unit cubage coal body, \( \text{t/m}^3 \);
\( t \)—baring time of coal wall, s.

2.2. Equation of Gas Flow

As the result of linear penetration hypothesis of gas flow in coal bed, we can gain flow equation is

\[
\nu \partial u \frac{\partial P}{\partial n} = \frac{\mu}{\partial n} (2)
\]

Where,
\( \mathbf{u} \)—flow velocity, \( \text{m/s} \);
\( k \)—penetration factor,\( 10 \text{ to } 6 \text{ m}^2 \);
\( \mu \)—absolute viscosity of gas, \( \text{Pa} \cdot \text{s} \);
\( p \)—gas pressure, \( \text{MPa} \);
\( \frac{\partial P}{\partial n} \)—gradient of gas pressure, \( \text{MPa/m} \).

2.3. State Equation of Gas

Gas content of coal-bed equals to the summation of dissociative gas content and adsorptive gas content. Generally adsorptive gas content is calculated according to Langmuir equation and then gains gas content of coal-bed as follows,

\[
X = nP + \frac{a b P}{P_n} \cdot \gamma \cdot K
\]

(3)

Where,
\( X \)—gas content in unit cubage coal bed, \( \text{m}^3/\text{m}^3 \) coal;
\( n \)—porosity of coal bed, \( \text{m}^3/\text{m}^3 \);
\( a \)—maximal sorption gas quantity of coal, \( \text{m}^3/\text{t coal} \);
\( b \)—adsorption constant, \( 1/\text{MPa} \);
\( \gamma \)—unit weight of coal, \( \text{t/m}^3 \);
\( K \)—correction factor of moisture and ash content in coal;
\[ K = \frac{(100 - W - A)}{100(1 + K'W^z)} \%; \]

- \( W \) — moisture content in coal, \( \% \);
- \( A \) — ash content in coal, \( \% \);
- \( K' \) — coefficient, for lean coal, \( K' = 0.27, z = 1 \); for rich coal, \( K' = 0.45, z = 0.5 \); for lignite coal, \( K' = 0.20, z = 1 \); for anthracite coal, \( K' = 0.31, z = 1 \).

In addition, Academician Zhou Shining considers that adopting parabola equation of gas content can basically meet engineering application in circumstance of non-prodigious gas pressure. The parabola equation of gas content is

\[ X = \alpha \sqrt{P} \]  

\[ \alpha — \text{coefficient of gas content, m}^3/(\text{m}^3 \cdot \text{MPa}^{1/2}). \]

### 2.4. Establishment to Radial Unsteadily Flow Differential Equation of Bore Gas

Unite foregoing four basic equations and solve, Considering

\[ M = \rho_n \cdot X \]  

And let \( P^2 = U \), then gains

\[ \frac{\partial U}{\partial t} = \varphi(U) \text{div}(\lambda \text{grad}U) \]  

Where,

\[ \varphi(U) = \frac{2\sqrt{U}}{P_n + \left(1 + b\sqrt{U}\right)} \cdot \gamma \cdot K \]

Or \( \varphi(U) = \frac{4U^{3/4}}{\alpha} \)

\[ \lambda — \text{penetration factor of coal bed, } \lambda = \frac{k}{2\mu P_n}, \text{m}^2/(\text{MPa}^2 \cdot \text{d}). \]

For radial flow, then gains

\[ \frac{\partial U}{\partial t} = \varphi(U) \left[ \frac{\partial}{\partial r} \left( \frac{A}{\lambda} \frac{\partial U}{\partial r} \right) + \frac{\lambda}{r} \frac{\partial U}{\partial r} \right] \]  

Where,

- \( r \) — the distance from spot to coal wall of bore in coal body, \( \lambda = f(r) \).

Equation (7) is radial unsteadily flow differential equation of bore gas.

### 3. Solve Conditions of Gas Flow Equation

Gas flow around bore is permeation flow driven by gas pressure\[^5\]. Its characteristics are that bore uncovering coal body causes coal around bore to depressurize, and permeability factor to increase. Gas flow comes of infinite flow field. Namely, first it takes place in uncovered bore wall, subsequently it extends outward, and then flow field enlarges, and is controlled by deformation and breakage of coal body around bore. In depressurization area around bore, increase of permeability factor intensifies gas flow, but gas flow isn’t confined by depressurization radius\[^6\]. When gas flow field extends to the boundary of depressurization area in certain time, it will naturally extend outside depressurization area,
and just flow trend outside depressurization area and extension velocity of flow field greatly weaken. Weaken degree is related with parameters of original coal bed.

Suppose the pressure outside uncovering coal body is $P_1$. Gas pressure of each spot on coal body around bore is $P_0$.


First establish finite element model based on boundary conditions, and adopt the software ANSYS for large finite element analysis to analyze stress and gain charts of stress distribution of bore, and further analyze the influence upon permeability factor of coal bed caused by stress. Last adopt the software MATLAB for mathematical calculation simulate gas flow field in coal bed and around bore, and gain various parameters that affect gas to flow, pump and discharge.

4.1. Calculate Parameter Determination

Increase of permeability factor in depressurization area around bore caused by bore uncovering coal body will greatly affect quantity of gas effusion. Otherwise, the quantity of gas effusion also direct correlates with gas pressure and permeability factor distribution of coal bed before coalface. In general condition, gas content factor of certain area before coal face is considered as invariant, but depressurization bell and concentrative stress bell of coal body caused by effusion will change gas pressure and distribution of permeability factor of coal bed.

4.2. Radius of Depressurization Area around Bore

It is generally considered that radius of depressurization area around bore equals to the distance from center of bore to the spot its stress increasing to stress of primary rock $\sigma_0$ For approximatively solving radius of depressurization area around bore, B.BHudouter replaces rounded bore with square bore inscribing round and calculates, then gains the formula:

$$
R_M = r_0 + \frac{d}{2\sqrt{2}f_r K_p} \ln \frac{\sigma_0}{\sigma_c}
$$

(8)

Where,
- $M$—radius of depressurization area around bore, m;
- $r_0$—radius of bore, m;
- $\delta$—diameter of bore, m;
- $\sigma_0$—stress of primary rock of coal body around bore before boring, MPa;
- $\sigma_c$—uniaxial compressive strength of coal, MPa;
- $f_r$—friction coefficient of shifted and unshifted coal body, generally adopt 0.4;
- $K_p = \frac{1 + \sin \varphi}{1 - \sin \varphi}$;
- $\varphi$—angle of internal friction of coal.

4.3. Variation Rule of Permeability Factor in Depressurization Area around Bore

Study of predecessor manifests that permeability factor of coal body on the edge of bore wall is greatly bigger than original permeability factor before bored because of boring influence, and permeability factor of coal body basically equals to original permeability factor outside depressurization area and its edge due
to tiny variation. Permeability factor of coal body in depressurization area is approximatively regarded as varying in terms of negative exponent \[9]. The computational formula is

\[
\begin{align*}
\lambda &= \lambda_1 e^{-\beta r} & (r_0 \leq r \leq R_M) \\
\lambda &= \lambda_0 & (R_M \geq r)
\end{align*}
\]

(9)

Where,

- \(\lambda_1\) — permeability factor of coal body on the edge of bore wall, \(\text{m}^2/(\text{MPa} \cdot \text{d})\);
- \(\lambda_0\) — original permeability factor of coal bed, \(\text{m}^2/(\text{MPa} \cdot \text{d})\);
- \(\beta_a\) — permeability growth factor in depressurization area around bore, 1/m.

Furthermore, average equivalent permeability factor can replace variation of permeability factor for simplicity in depressurization area around bore \[10\]. Average equivalent permeability factor is commonly 3-10 times original permeability factor.

5. Stress Distribution around Bore and Computer Simulation of Gas Flow Field

(a) From Fig.2 and Fig.3 it can be seen that, stress concentration come into being around drillbore after they are made, and it makes coal wall around drill bore crash by forming pressure relief area, and stress concentration strip is moving in. Because stress distribution is unequal in radial of drillbore which cause gas permeability is different, gas permeability coefficient of coal bed increase in crushed zone around
drill bore. The emission of gas in drill bore not only release gas expansion energy, but also release wall rock transmogrification energy, and make stress peak value transfer into deep, which is advantageous to eliminate outburst hazard.

(b) Fig.4 shows that drilling gas drainage area is increasing gradually to time, but increasing slower until tend to a relatively stable area after a while, namely gas drainage radius of drilling is not infinitly enlarged. So it is very crucial to define gas available radius when drainage gas.

6. Conclusions

A. Stress concentration around bore is showed on chart 1. Coal wall around bore breaks up and came into depressurization area for stress concentration, so stress concentration bells move inside, and bring on inhomogeneous stress distribution along radial of bore. This causes different permeability. The permeability factor of breakup bells around bore increase.

B. Discharge of gas in bore not only releases dilatational energy of gas, but also releases deformation energy of wall rock, and transfers stress maximum inside. It is advantage to eliminate burst risk.

C. Gas pumping area increases by time prolonging. But it increases slowly up to some a relative stability field. Namely gas pumping radius of bore is not infinite increcent. So it is crucial to determine available pumping radius of gas when we pump gas.

References


