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The Evolution Law of Parameters and Inversion Model in Coalbed Methane Wellbore Pre-Extraction Process: Research and Applications

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This study investigated the key parameters of coalbed methane (CBM) pre-extraction processes, using a mathematical model of coupled fluid-solid behavior. It developed a backward calculated model to estimate the residual CBM pressure and content in the coal seam from borehole extraction data. It revealed the spatiotemporal migration rule and distribution patterns of CBM and identified outburst-prone areas. The study improves the understanding of CBM behavior and suggestions for improved safety and disaster prevention in coal production.

1. INTRODUCTION

Coalbed methane (CBM), a significant hazard in Chinese coal mines, accounts for 80% of major accidents. Despite its risks, CBM offers potential as a clean energy source. For mines with high CBM content, simultaneous extraction of coal and CBM is crucial for resource utilization and disaster management. Pre-extraction reduces CBM risks, but existing methods have limitations. In this study, a novel approach leveraging pre-draining boreholes and smart mining technologies is proposed. By integrating monitoring data and fluid-solid coupling models, we backward calculate key CBM parameters, enhancing precision and real-time monitoring during extraction, allowing the monitoring and mitigation of hazards.

2. METHODOLOGY

2.1 Fluid-solid coupling model of CBM-containing coal

By integrating principles from poroelasticity, hydrodynamics, and rock mechanics, stress-strain equations (Equation 1) for CBM-containing coal, dynamic models for porosity and permeability variation (Equations 2, 3), models for fracture ratio and permeability variation (Equations 4, 5), CBM diffusion and flow (Equations 6, 7), and extraction negative pressure decay (Equation 8) were formulated. These equations constitute the basis for investigating dynamic aspects of CBM in coal seams, serving as theoretical foundations for CBM exploration and development, as shown in **Fig.1**. Changes in porosity and fracture ratio are influenced by adsorption-desorption strain, wet strain, and CBM stress deformation. Through numerical simulations, this approach enhances the accuracy of predicting coal seam mechanics and CBM dynamics, providing reliable support for dynamic parameter backward calculation in CBM extraction from coal seams.

$$
\left\{
\begin{array}{l}
1.\,Gu_{i,ij}+\dfrac{G}{1-2\upsilon}u_{i,ij}-\theta_p(\Delta\bar{p})_{,i}+\theta_M(s_w-s_{w0})_{,i}-\theta_s(\varepsilon_s)_{,i}-\alpha\bar{p}_{,i}+F_i=0\\
2.\,\phi_m=1-\dfrac{1-\phi_{m0}}{\exp\left(-K_Y\Delta\sigma^{eff}\right)}\left[1-\dfrac{(\bar{p}-\bar{p}_0)}{K_m}+\beta_M(s_w-s_{w0})+\alpha_{sg}V_{sg}\right]\\
3.\,k_m=k_{m0}\left\{\dfrac{1}{\phi_{m0}}-\dfrac{1-\phi_{m0}}{\phi_{m0}\cdot\exp\left(-K_Y\Delta\sigma^{eff}\right)}\left[1-\dfrac{(\bar{p}-\bar{p}_0)}{K_m}+\beta_M(s_w-s_{w0})+\alpha_{sg}V_{sg}\right]\right\}^3\\
4.\,\phi_f=\phi_{f0}\exp\left[-\dfrac{1}{K_f}\Delta\sigma_f^{eff}+\dfrac{1}{K_m}\Delta\sigma_m^{eff}-\alpha_{sg}V_{sg}-\beta_M(s_w-s_{w0})\right]\\
5.\,k_f=k_{f0}\exp\left[-\dfrac{3}{K_f}\Delta\sigma_f^{eff}+\dfrac{3}{K_m}\Delta\sigma_m^{eff}-3\alpha_{sg}V_{sg}-3\beta_M(s_w-s_{w0})\right]\\
6.\,\dfrac{\partial}{\partial t}\left\{
\begin{array}{l}
\dfrac{V_Lp_m}{p_m+p_L}\exp\left[-\dfrac{c_2}{1+c_1p_m}(T-T_t)\right]\rho_s\dfrac{M_g}{RT}p_n+\\
\left[\begin{array}{l}
1-\dfrac{1-\phi_{m0}}{\exp\left(-K_Y\Delta\sigma^{eff}\right)}\times\\
\left(\begin{array}{l}
1-\dfrac{(\bar{p}-\bar{p}_0)}{K_m}+\beta_M(s_w-s_{w0})+\\
\alpha_{sg}\dfrac{V_Lp_m}{p_m+p_L}\exp\left(-\dfrac{c_2}{1+c_1p_m}(T-T_t)\right)
\end{array}\right)
\end{array}\right]\dfrac{M_g}{RT}p_m
\end{array}
\right\}=-\dfrac{M_g}{\tau RT}(p_m-p_{fg})\\
7.\,\dfrac{\partial\left(p_f\varphi_f\right)}{\partial t}-\nabla\left(p_f\dfrac{k_f}{\mu_g}\nabla p_f\right)=\dfrac{(p_m-p_{fg})}{\tau}\\
8.\,p(x)=s_1e^{-s_2x}
\end{array}
\right.
$$

Fig.1 Fluid-solid coupling model

2.2 Simulation experiment of CBM extraction

Dimensional analysis and physical similarity criterion were used to relate CBM flow rate to various parameters in pre-drainage. Dimensionless parameters, π1 and π2, describing CBM extraction patterns, were derived. A formula was developed using these parameters to retro-calculate CBM pressure based on observed extraction rates, facilitating analysis of extraction effectiveness in coal seams. An experimental setup ensured similarity between the prototype and the model, with a schematic diagram and image highlighting conditions for maintaining similarity, as shown in **Fig.2**.

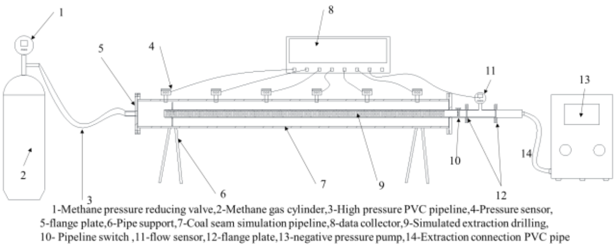


Fig. 2 Experimental system structure diagram

2.3 Backward calculation model for CBM parameters

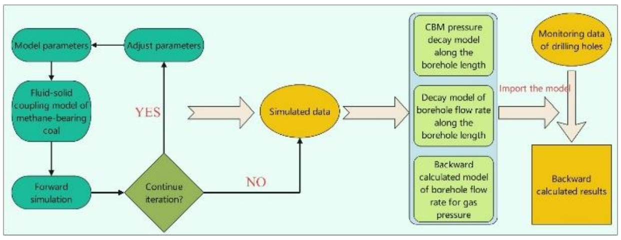
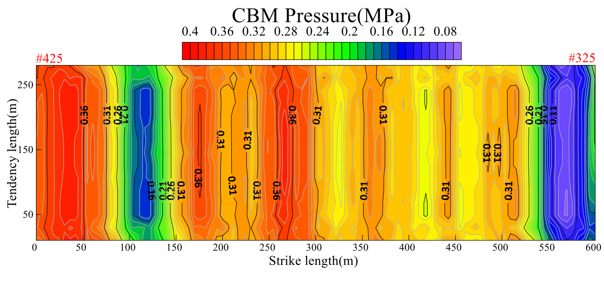


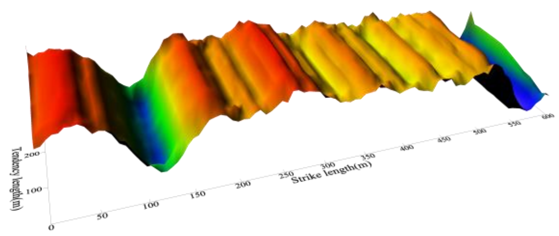
Fig.3 CBM parameters backward calculation workflow

Based on the previous discussion, an inversion model for calculating key parameters of CBM in the coal seam from monitoring data can be established as shown in **Fig.3**. We divide the process of backward calculation of key parameters during the CBM extraction process in the coal seam from monitoring data into five parts: basic parameter collection, forward calculation, model fitting, data acquisition, and backward calculation.

3. RESULTS AND DISCUSSION



(a) 2D View



(b) 3D View

Fig. 4 CBM pressure distribution cloud map

The method of coalbed gas pressure inversion based on drilling and extraction flow was applied to the experimental working face. A sophisticated monitoring system was installed to collect coalbed gas data from pre-extraction boreholes, which were then input into the reverse calculation model to obtain distribution maps of coalbed gas pressure and content. The graphical representation illustrates the spatial distribution pattern of gas pressure, highlighting the heterogeneity within the coal seam. Additionally, an analysis of potential hazards associated with the spatial variability of the coal seam was conducted, as shown in **Fig.4**.

4. CONCLUSION

This study provides a novel approach for capturing residual CBM parameters during the CBM extraction process. Prevention and control workers in coal mines can use this approach to calculate and tailor strategies for different working faces based on practical considerations. Additionally, the calculated results can be leveraged for further research on adjusting CBM extraction strategies to enhance efficiency.

PARTIAL REFERENCE

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