Fuel 130 (2014) 296–305

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Evaluation of the pre-drained coal seam gas quality

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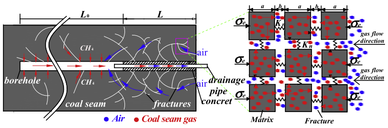
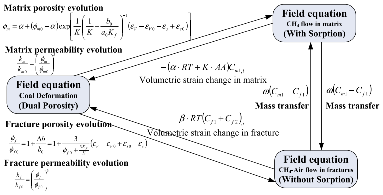
HIGHLIGHTS

- A gas–air compositional model is applied to better understand pre-drained gas processes.
- Model superiority and reliability are verified by model comparisons and history data matching.
- Gas-drained quality associated with internal and external factors is quantitatively evaluated.

GRAPHICAL ABSTRACT



(a) Concept model of air-leakage in coal seam borehole



(b) Evaluation model of the pre-drained coal seam gas quality

ARTICLE INFO

Article history:
Received 10 March 2014
Received in revised form 15 April 2014
Accepted 16 April 2014
Available online 29 April 2014

Keywords:
Coal seam gas
Coal-gas interactions
Gas-drained quality
Compositional flow

ABSTRACT

Coal seam degasification through underground drilling and its efficiency are directly related to the safety of underground coal mining. The major problem of underground coal seam gas drainage is the rapid decay of gas concentration, which may lead to a low utilization ratio and many hazards, such as environmental pollution, spontaneous combustion of coal, gas combustion and gas explosion. Although coal-gas interactions have been comprehensively investigated, fewer studies consider the low-quality phenomenon (low gas flow and concentration) in the process of gas extraction due to the air leakage of the borehole.

In this study, a fully coupled coal deformation and compositional flow model, which represents the important non-linear responses of the gas-drained quality due to the effective stress changes, was implemented into a finite element (FE) model to demonstrate the superiority and reliability of the model through a comparison with another theoretical models and a historical data matching. Subsequently, the susceptibilities of gas-drained quality associated with the intrinsic and extrinsic factors, incorporating the gas sorption, the porosity–fracture characteristics of coal, the sealing depth and the leakage flux, are quantified through a series of simulations. The simulation results revealed that (1) increasing/decreasing the CH_4 Langmuir volume/pressure sorption parameter can improve the gas-drained quality, and (2) the leakage fracture characteristics around the borehole are the main factors affecting the gas-drained quality, and thus, increasing the coal permeability or extending sealing depth does not necessarily improve the

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http://dx.doi.org/10.1016/j.fuel.2014.04.051
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gas-drained quality under the condition of serious leakage. This FE model and its simulation results can improve the understanding of the coal-gas interactions of underground gas drainage, providing a scientific basis for the evaluation of the gas-drained quality, the design and optimization of drainage systems, etc.

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1. Introduction

Advances in our understanding of coal-gas interactions have changed the manner in which we treat coalbed methane (CBM): from mitigating its dangers as a mining hazard to developing its potential as an unconventional gas resource recovered [1]. A coal seam is characterized by a typical dual-porosity and dual-permeability system containing a micro-porous matrix surrounded by macro-porous cleats/fractures; the coal matrix represents the main reservoir for the gas (of the order of 98%), and the cleat/fracture system provides an essential and effective flow path for the flow of gas [2]. Coal seam degasification and its efficiency are directly related to the safety of coal mining, and the recovery of methane can be an energy resource [3,4]. In China, coal seam gas is commonly drained in the pre-mining phase through underground drilling (the amount of gas drainage was 14.1 billion m^3 in 2012, among which underground drained gas accounted for 80.9%), which is determined by the actual reservoir conditions of coal seams. However, there is serious air leakage around a drainage borehole due to the coal-rock excavation process (Fig. 1), resulting in the gas drainage concentration of 80%. Chinese in-seam boreholes decreases to a low level (6–20%) in a short time, the average pre-pumping rate of the coal seam gas is less than 23%, and the utilization rate of the underground drained gas is only 33.3% [5]. Furthermore, low-concentration gas may also lead to many hazards, such as the spontaneous combustion of coal, gas combustion and gas explosion [6]. In addition, coal seam gas, as a carbon-hydrogen gas, once released into the atmosphere, contributes to global warming and environmental pollution and also represents a waste of clean energy.

Low-concentration gas extraction triggers a series of coal-gas interactions, including coal deformation, compositional gas flow and the dynamic evolution of dual-porosity and dual-permeability. Balla (1989) developed a mathematical model to simulate gas flow in a coal seam borehole, including gas sorption and permeability change [7]. Zhao and Valliappan (1995) derived the governing equations of gas migration in coal seams, which considered the effect of coal deformation, two-phase flow and mass/gas transfer in the porous media [8]. Valliappan and Wohua (1996) presented a coupled model between gas flow and coal deformation for gas migration in coal seams [9]. Young (1998) used the non-equilibrium and pseudo-steady state formulations to simulate CBM production performance by incorporating the stress-induced changes in fracture porosity and permeability and the matrix shrinkage due to the release of adsorbed gas [10]. By assuming that an individual fracture reacts as an elastic body upon a change in the normal stress component, Gilman and Beckie (2000) proposed a simplified mathematical model of methane movement in a coal seam [11]. Guo et al. (2004) numerically investigated the effects of non-Darcy flow and coal deformation through their explicit algorithm, which coupled gas flow and the porosity and permeability changes of coal seams [12]. Unsal et al. (2010) proposed a numerical model for multiphase flow in fractured reservoirs using a fracture-only model with transfer functions. In their model, fracture geometry is modeled explicitly, while fluid movement between fracture and matrix is accommodated using empirical transfer functions [13]. Considering coal to be a triple-porosity system, the implementation of a bi-disperse pore-diffusion model in a coalbed reservoir simulator was discussed by Shi and Durucan (2005) [14], who assumed that the gas adsorption occurs only in the micropores, whereas the macropores, as well as tortuous paths for gas transport between the micropores and cleats, provide storage for the free gas. Zhu et al. (2007) proposed a coupled model for solid deformation and gas flow, in which the Klinkenberg effect is considered [15]. Wei et al. (2007) presented an alternative model to address multi-component gas diffusion and flow in bulk coals, focusing on the CH_4–CO_2 counter-diffusion associated with CO_2-ECBM [16]. Zhang et al. (2008) conducted another study on coupled gas flow and coal deformation processes that incorporated the newly developed permeability model, which considered the controlling factors of the volume occupied by the free-phase gas, the volume occupied by the adsorbed phase gas, the coal mechanical deformation induced pore volume change, and the sorption induced coal pore volume change [17]. Connell (2009) performed a coupled numerical model to investigate the applicability of these geomechanical assumptions for coal seam gas drainage [18]. Subsequently, this work was extended to CO_2-ECBM [19]. Similarly, Wang et al. (2009) proposed a deformation-flow coupled model to address CO_2-ECBM. Although permeability was considered to be a function of the effective stress, the influence of the sorption-induced strain on the permeability was not coupled [20]. Based on the work of Zhang et al. (2008) [17], equivalent poroelastic models were developed to simulate the interactions of multiple processes triggered by the injection or production of a single gas [21,22]. Chen et al. (2010) extended these single poroelastic models to include the flow and transport of gas mixtures (CO_2 and CH_4) [23]. Wu et al. (2010) developed a dual poroelastic model (coal matrix and fracture) for a single gas under variable stress conditions. The model allows for the exploration of the full range of mechanical boundary conditions from invariant stress to

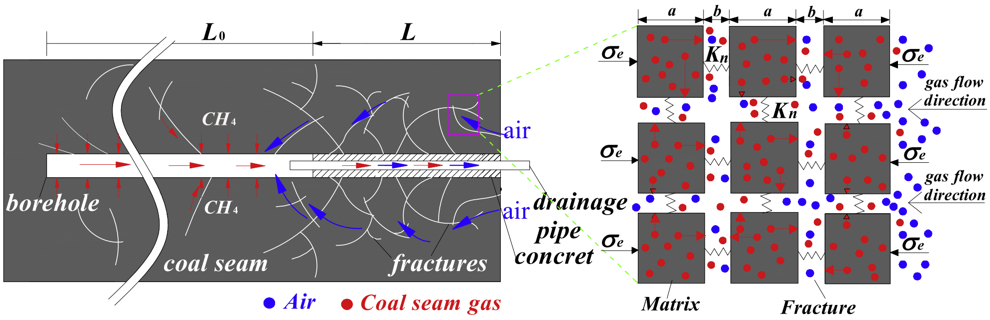

Fig. 1. Schematic diagram of air-leakage in coal seam borehole (L is the sealing borehole depth, L_0 is the effective drainage length, K_n is the fracture stiffness, σ_e is the effective stress, and a and b represent the cubic matrix length and the fracture aperture, respectively).

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