International Journal of Mining Science and Technology 22 (2012) 859–862

Contents lists available at SciVerse ScienceDirect

International Journal of Mining Science and Technology

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

Variation in gas drainage rate from a coal seam during mining

Li Gang [a,b,*], Qi Qingxin [b,c], Li Hongyan [b,c], Fan Xisheng [b,c]

[a] SDIC Coal Company, Beijing 100034, China
[b] State Key Laboratory of Coal Mining and Clean Utilization, China Coal Research Institute, Beijing 100013, China
[c] Mine Safety Technology Branch, China Coal Research Institute, Beijing 100013, China

ARTICLE INFO

Article history:
Received 10 March 2012
Received in revised form 14 April 2012
Accepted 15 May 2012
Available online 24 January 2013

Keywords:
Mining process
Gas drainage
Double media with pores and cracks
Permeability

ABSTRACT

Gas flow patterns during draining of gas from a coal seam during mining are discussed. The coal seam is treated as a dual medium with both pores and cracks. The seepage, diffusion, and desorption processes are treated using a gas flow equation that describes flow around drill holes. MATLAB is used to solve the differential equations. The permeability tracer test results from a mined coal seam are used to study the variation in gas drainage from a coal seam during mining. The results show that mining can increase the permeability of a coal seam, which then increases the gas drainage. There are inflection points in this variation over time. A close relationship between this variation and the rate of change in coal seam permeability is observed.

1. Introduction

Over the past years gas has been the main cause of disasters during coal production and the "first killer" that endangers miners' lives. This is a kind of unconventional gas with a high calorific value. Recently the increased depth of mining has made gas problems more serious. This greatly restricts safe production from the coal mine. Eliminating the damage and hidden trouble from mine gas, and simultaneously getting a cheap energy supply, has made gas drainage a more important problem in China. Real conditions in our country have led to the formation of a gas drainage mode incorporating the ground and the mine, being mainly under the coal mine [1]. Ensuring safe mining requires most gassy and outburst prone mines to perform a thorough pre-drainage before mining of the working face begins. This is converted to contiguous drainage when the coal seam is mined. Because the gassy coal mined in China has low permeability seam pre-drainage is always ineffective. Increasing seam penetration is required to ensure the effectiveness of gas pre-drainage. Many laboratory studies have shown that there are obvious changes in coal seam permeability when the coal is under stress. Some scholars have also analyzed the relationship between ground stress, effective stress, and the dielectric permeability of coal and rock [2–6]. In addition, field studies have shown that coal seam fissures develop that lead to further connections that could, in turn, lead to greater coal seam permeability [7,8]. Therefore, it is necessary to study and the gas flow of gas drained from drill holes in a coal seam under mining conditions, which information can provide new ideas for achieving efficient gas drainage.

2. Gas flow equation for gas drained through drill holes from a coal seam: the seam as pores and cracks

A gas flow law in a coal seam for drill hole drainage was described in previous studies from a fluid mechanics point of view. The coal seam was considered a uniformly distributed, virtual continuous medium over a large scale. The gas flow theory was based on Darcy's law, which was applied to the parametric design of gas drainage drill holes [9,10]. However, the real situation underground shows that in fact only free gas can be involved in seepage. Most of the original coal seam gas is absorbed, which is different from free gas. When only considering seepage of gas the physical nature of a gas flow process would be unable to give the correct response [11]. Therefore, considering the seepage and desorption diffusion of coal seam gas requires that the coal seam seem to be considered a two phase medium with both pores, the first phase, and cracks, the second. The mathematical model appropriate for this actual physical process is described below.

The basic assumptions are:

(1) The surface of the holes and cracks is where gas is adsorbed. The cracks are the place where free gas resides.

* Corresponding author. Tel.: +86 10 88006497.
E-mail address: snow7981@163.com (G. Li).

2095-2686/$ - see front matter © 2012 Published by Elsevier B.V. on behalf of China University of Mining & Technology.
http://dx.doi.org/10.1016/j.ijmst.2012.11.008

(2) There are both diffusion and seepage fields. The diffusion process is Fickian and the seepage process follow Darcy's law. There is gas exchange between the two fields. For two flow fields the amount of exchange implies a negative source on one side and an equivalent positive source on the other.
(3) The influence of coal seam deformation is not considered.

These are important assumptions. Other assumptions made are similar to those described in reference [9]. These are the basic conditions of gas flow theory.

A closed surface with a fixed space is arbitrarily taken as one unit cell in the coal seam. The basic principles of fluid mechanics allow the mathematical and mechanical model of gas flow to be established. The amount of gas flowing through the unit cell surface during unit time is

$$\oiint_S \rho \vec{V} \cdot \mathrm{d}\vec{s}$$

where ρ is the density of the gas; $\vec{V}$ the velocity vector; and $\mathrm{d}\vec{s}$ the infinitesimal area, the integral is over the closed surface, S. The rate of change of free gas over time in the unit cell is

$$\frac{\partial}{\partial t} \iiint_\Omega \rho \mathrm{d}\omega$$

for

$$\rho = \chi \rho_{g0} \frac{p}{p_a}$$

where χ is the porosity, m^3/m^3; ρ_{g0} the density of the gas under standard conditions, kg/m^3; p_a the standard atmospheric pressure, equal to 1×10^5 Pa; $\mathrm{d}\omega$ the infinitesimal volume; and Ω the unit.

The conservation of mass and Stokes theorem allow us to write:

$$\left(\chi \rho_{g0}/p_a\right) \frac{\partial p}{\partial t} + \nabla \cdot \left(\rho \overrightarrow{V}\right) = q \tag{1}$$

According to Darcy's law:

$$\overrightarrow{V} = -\frac{K}{\mu} \nabla p \tag{2}$$

where K is the permeability of the coal seam, m^2; μ the dynamic viscosity of the gas, Pa s; and ∇p the pressure gradient of the gas.

If Eq. (2) is substituted into Eq. (1), after some transformation Eq. (3) may be written:

$$\left(\chi \rho_{g0}/p_a\right) \frac{\partial p}{\partial t} = \frac{K}{\mu} (\nabla \rho \cdot \nabla p + \rho \Delta p) + q \tag{3}$$

Eq. (3) is the coal seam gas flow equation for a coal seam considered as a double medium with both pores and cracks. This equation shows that the outflow of gas from a unit cell plus the amount of desorbed gas equals the variation in gas concentration within the unit cell over unit time.

Consider the radial flow of free gas into a drill hole. If the radius of one drill hole is given as R_1 then the initial and boundary conditions are:

$$t = 0 \quad p = p_0 \tag{4}$$

$$\begin{cases} p = p_1 \quad (r = R_1, t > 0) \\ p = p_0, \frac{\partial p}{\partial t} = 0 \quad (r \to \infty, t > 0) \end{cases} \tag{5}$$

where p_0 is the original coal seam gas pressure, MPa; r the radial distance in cylindrical coordinates giving the distance between a target location and the hole center, m; and p_1 the pressure in the drill hole, MPa.

Eq. (3) contains the internal source, q is difficult to define because of complications with desorption and diffusion processes of the coal seam gas in the coal mine. In short, it is difficult to obtain an analytical formula for q. Reference [11] derives, through a large number of desorption experiments, an empirical estimate of q:

$$q = AB \frac{\rho_c p_a}{RT} ab \left(\frac{p_0}{1 + bp_0} - \frac{p}{1 + bp} \right) \exp(-At) \tag{6}$$

where AB is a test coefficient; ab the adsorption constant of coal, can be measured by gas desorption tests; R the molar gas constant; T the absolute temperature of the gas, K; and ρ_c the bulk density of the coal, kg/m^3.

Eq. (3) is a highly complex, nonlinear heat conduction type partial differential equation. Obtaining even an approximate analytical solution is so difficult that numerical methods must be used to solve it. The finite difference method allows the solution of Eq. (3) and coal seam gas pressure distributions over space and time can be estimated. Then changes in coal seam gas pressure over time at any position can be found. This allows both gas drainage quantity and gas drainage rate to be calculated.

Fig. 1 shows an estimate for the variation in gas drainage over time for a drill hole depth of 80 m and a drill hole diameter of 90 mm, with a coal seam permeability of 2.62×10^{-3} μm^2. A drainage time of 30 d gives a total drainage quantity from one drill hole of 25.4247 m^3.

3. Variation of gas drainage from a coal seam during mining

Eq. (3) contains the coal seam permeability, K, as a constant that reflects the pre-gas-drainage stage. At that point the coal seam permeability may be considered unchanged because the coal seam is not influenced by mining.

However, the coal seam permeability changes because of mining. Some studies have shown that coal seam permeability after mining shows a cyclical variation as the work face advances [8]. This is shown in Fig. 2. At first, between 20 and 40 m from the face, the coal seam permeability slowly increases. These changes are over a long period of time but the variation is not very large. After a period of slow growth the permeability suddenly increases by a factor of several times, which then reaches a peak. During the observation period the fist permeability peak appears at a distance of 7.9 m from the work face. The value was 18.23×10^{-3} μm^2 and this exceeds the lowest value by 6.04 times. After peaking the permeability drops rapidly to a local minimum but then increases again to a large number. This growth lasts only a short time before the work face has advanced to the current position.

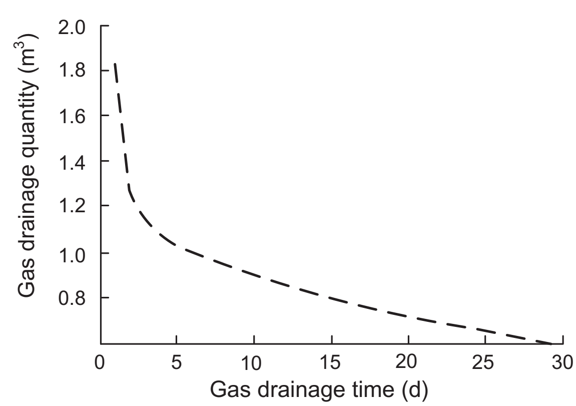

Fig. 1. Gas drainage from one drill hole an un-mined coal seam.