Journal of Natural Gas Science and Engineering 28 (2016) 1–14

Contents lists available at ScienceDirect

Journal of Natural Gas Science and Engineering

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

Desorption area and pressure-drop region of wells in a homogeneous coalbed

Yizhao Wan [a], Yuewu Liu [a, *], Weiping Ouyang [b], Wenchao Liu [a], Guofeng Han [a]

[a] *Institute of Mechanics, Chinese Academy of Sciences, Beijing 100190, China*
[b] *Changqing Downhole Technology Company, Chuangqing Drilling Engineering Co., Ltd, CNPC, Xi'an 710018, China*

ARTICLE INFO

Article history:
Received 15 July 2015
Received in revised form
10 November 2015
Accepted 12 November 2015
Available online 1 December 2015

Keywords:
CBM
Desorption area
Finite element method
Contour

ABSTRACT

The coalbed methane (CBM) desorption area is highly important in the placement of wells to produce an adequate working system. This paper develops a homogeneous seepage model of CBM that incorporates desorption and uses a finite-element method to obtain the pressure field in complex boundary cases influenced by adjacent wells. The pressure field is presented in a 2D and pseudo-3D form that visually demonstrates the shape of the pressure profile and the pressure expansion. A method of combined numerical computation and contour drawing technology is used to determine the CBM desorption area and pressure drop region. By analyzing the main factors that affect the CBM desorption region, we demonstrate that a higher value of critical desorption pressure yields a larger desorption area of the seam. The effect of the permeability is different from the value of the critical desorption. This effect is determined by the critical desorption pressure level and the intersection of pressure profiles with different permeabilities. Permeability anisotropy leads to a desorption area with an elliptical shape. We also demonstrate that a greater flux of methane will result in a greater desorption region, and the effects of the distance between wells and the desorption area are closely related to the permeability. The developed model is applied in a field case to predict the desorption area.

1. Introduction

CBM is an unconventional type of natural gas. As a new type of clean energy, the development and utilization of CBM can not only directly produce economic benefits but also is important for the reducing in coal mine disasters and improving the environmental quality of the atmosphere. China is rich in coalbed methane resources. A new resource evaluation study shows that CBM resources in China occupy 36.8 × 10^{12} m^3 (Shao et al., 2015; Wang et al., 2014), ranking third in the world. In recent years, with the construction of new gas pipelines including the West–East Gas Pipeline project and an output of natural gas exceeding 50 billion m^3, China has become one of the world's greatest producers of gas and is gradually adjusting its energy structure. However, there are still significant gaps between China's energy structure and those of developed countries. The development and utilization of coalbed methane plays an important role in promoting the improvement of the energy structure (Ni et al., 2007).

Currently, research on coalbed methane geology and exploration drilling technology has become more thorough (Zhao, 1999; Weeks, 2005; Perry and Lee, 2007; Myers, 2009). In addition, certain achievements in coalbed methane development have been obtained. Coalbed methane exists in an adsorption state in the coal seam. Exploitation of coalbed methane is typically performed using the drainage buck mode. This mode has three stages (Yang et al., 2009; Meng et al., 2014a). The first stage is the drainage decompression portion. With the extraction of water, the coal seam pressure is gradually decreased. The second stage occurs when the pressure drops below the critical desorption pressure of the coal seam, and methane desorbs from the coal particles and flows to the wellbore through the fractures. In this stage, the gas flux is low. In the third stage, with the discharge of water and reduction in pressure, a large amount of coalbed methane desorption occurs in the coal seam, and gas production increases.

Domestic and foreign scholars have proposed many models for the recovery of CBM and its mechanism of transport. These models can be classified into three types:

---

* Corresponding author.
E-mail address: liuyuewulxs@126.com (Y. Liu).

http://dx.doi.org/10.1016/j.jngse.2015.11.026

(a) Empirical models. This type of model uses simple mathematical formulas to describe the experimental phenomenon. The typical models include the Lidime and McFail models (King and Ertekin, 1989).

(b) Equilibrium adsorption models. This type of model assumes that the coal is a single porosity media. The gas enters into the fractures once it desorbs from the coal matrix; therefore, the gas density is dependent on the fracture pressure and independent of time. The free and adsorbed gas in the coal pore is in a continuous equilibrium state. The typical models include the Mckee and Bumb models (Bumb and Mckee, 1986).

(c) Non-equilibrium adsorption models. This type of model assumes that the coal is a dual porosity media consisting of micro-pores and fractures. These models take into account the desorption, seepage and diffusion process from micro-pores to the fractures. The diffusion process is a non-equilibrium process that is characterized by Fick's law. These types of models can be classified into transient models, which are based on Fick's second law, and pseudo-steady models, which are based on Fick's first law. The representative transient models include the Smith (Smith and Williams, 1984) and Kolesar (Kolesar et al., 1990a, 1990b) models, and the pseudo-steady models include the Ertekin (Ertekin and Sung, 1989; Anbarci and Ertekin, 1990) and Comet models.

These models are derivative from Langmuir isothermal adsorption (Meng et al., 2014b) or other adsorption theories and Fick diffusion laws (Liu et al., 2014). So there are a lot of undetermined parameters needed to be evaluated from experiments in the lab. It is time consuming and the parameters from lab are not very accurate because the experimental conditions in the lad are quite different from the subsurface.

In the process of coalbed methane production, determination of the methane desorption zone, which can be used to determine adequate well spacing and routine production, is a very important issue. Several analytical models have been developed to predict the desorption area of CBM (Seidle, 1993; Spivey and Semmelbeck, 1995; Xu et al., 2013). These models are simple to run but are only appropriate for reservoirs with a circular shape and neglect the interference of adjacent wells. Therefore, the application of analytical models is limited by these factors. Another approach for predicting the desorption area consists of implementing numerical reservoir simulations using numerical simulators (Luo et al., 2000; Gentzis and Bolen, 2008). This method is capable of simulating reservoirs with complex boundary shapes and multiple wells. However, large amounts of data are required to run the simulation. Data such as the relative permeability curves are often unknown.

In this paper, we develop a numerical method to predict desorption area and pressure-drop region. This model assumes that the desorption of coalbed methane and the pressure have a linear relationship. The model calculates desorption by including the critical desorption pressure and a coefficient, which is a source term added to the conventional control equation. In this new model, only two parameters are needed to be determined and this procedure can be easily accomplished by well testing. We used the finite-element method to solve the model in the complex boundary and well interference cases. The pressure contour is used to determine the desorption area and pressure-drop region under different critical desorption pressures. We discuss the effect of the critical desorption pressure, permeability, permeability anisotropy, wellbore rate and well spacing on the desorption area and pressure-drop region. A field example is also presented by applying this new method to a platform with four wells.

2. Physical and mathematical model

2.1. Assumptions

(a) The coal seam is homogeneous and anisotropic.

(b) The methane gas is a weakly compressible Newtonian fluid with a laminar state in accordance with Darcy's law. The reservoir is bounded by the constant pressure boundary, and gas is produced in vertical wells.

(c) When the pressure falls below the critical desorption pressure, the coalbed methane begins to desorb from the coal, and desorption becomes instantaneous.

(d) The temperature of the reservoir is constant, and the effects of gravity and other physical chemistry effects are neglected.

2.2. Mathematical model

2.2.1. Governing equations

To describe the CBM desorption characteristics, we assume that the gas volume desorbed from coal seam depends linearly on the difference between critical desorption pressure and pore pressure. And the desorption occurs only if the pore pressure is smaller than the critical desorption pressure. Then, the desorption gas volume is

$$q_d = [\alpha_1 + \alpha_2(m_c - m)]\varepsilon(m_c - m) \tag{1}$$

where α_1 and α_2 are two desorption coefficients.

Then, the continuum equation accounting for the sources terms of desorption is

$$\frac{\partial(\phi\rho_g)}{\partial t} + \nabla\cdot(\rho_g V) = \rho_{sc} q_d \tag{2}$$

The flow in coalbed is dominated by Darcy's law

$$V = -\frac{K}{\mu}\nabla p \tag{3}$$

Combing Eq. (2), Eq. (3) and the equation of state for actual gas, the governing equation for gas flow accounting for desorption is

$$\frac{K}{\phi}\nabla\cdot\left(\frac{p\nabla p}{\mu Z}\right) + \rho_{sc} q_d = \frac{\partial}{\partial t}\left(\frac{p}{Z}\right) \tag{4}$$

Pressure is replaced by pseudo pressure, and we assume the coal seam is anisotropy in two dimensions. Eq. (4) is given by

$$\sqrt{\frac{K_x}{K_y}}\frac{\partial^2 m}{\partial x^2} + \sqrt{\frac{K_y}{K_x}}\frac{\partial^2 m}{\partial y^2} + \frac{\mu_i Z_i}{\sqrt{K_x K_y} p_i}\frac{p_{sc} T}{T_{sc}}[\alpha_1 + \alpha_2(m_c - m)]\varepsilon(m_c - m) = \frac{\phi c_g}{\sqrt{K_x K_y}}\frac{\partial m}{\partial t} \tag{5}$$

The dimensionless form of Eq. (5) is

$$\sqrt{K_{xy}}\frac{\partial^2 p_D}{\partial {x_D}^2} + \frac{1}{\sqrt{K_{xy}}}\frac{\partial^2 p_D}{\partial {y_D}^2} + \alpha_{1D} + \alpha_{2D}(p_D - p_{CD}) = \frac{1}{C_D e^{2S}}\frac{\partial p_D}{\partial T_D} \tag{6}$$

where α_{1D} and α_{2D} are two dimensionless desorption coefficients which are given by