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An analytical model for desorption area in coal-bed methane production wells

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HIGHLIGHTS

- A simplified model was established to predict the expansion of desorption region.
- The method of "continuous succession of steady states" was used.
- The model was verified by numerical simulation and obtained excellent agreement.
- The new model is simpler and more practical than previous methods.
- The proposed model was applied on Hancheng CBM region and got reliable results.

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ABSTRACT

Production forecasting, well spacing, and well pattern optimization are key tasks in coal-bed methane field development plan. Desorption area around a production well is an important factor in well performance and reserve estimation. Analytical models are found to be simple and practical tools for drainage area calculation and well deliverability in conventional reservoirs. However, up to now, we have found no such analytical model for coal-bed methane wells with two-phase flow in which the gas desorption in coal is the controlling mechanism while the water is flowing in the cleat system.

In this paper, we present a mathematical model to predict how the size of desorption area is changing with pressure propagation during gas and water production. The pressure profiles at different production stages are determined using diffusivity equation which is solved using the known method of "continuous succession of steady states". For the case of two-phase flow of gas–water system, the pressure squared concept is used for linearization in middle and late times, while the pressure concept is used in early times when water flow is dominated. We have combined pressure from the solution of diffusivity equation with the material balance equation in order to develop our predictive model which is applicable for vertical wells for both cases of with or without hydraulic fractures.

This model is verified by numerical simulation and is in excellent agreement with the numerical solutions. Furthermore, the developed model is applied in one coal-bed methane well group in Hancheng field in China. It is found that desorption area is expanded outward in elliptical shape and the area can be calculated by the gas production data. The results show that two sample wells in the group have interfered with each other after producing for 525 days.

1. Introduction

In coal-bed methane reservoirs, gas is mainly stored in micropores of coal surface by the mechanism of adsorption in contrary with the conventional reservoirs which free gas is stored in rock porosity system [1–4]. To release the adsorbed gas from the coal surface and to produce it through the natural cleat system, the reservoir pressure should be reduced to a critical desorption pressure by dewatering operation. During this reservoir depressurizing, the desorption area expands outward with pressure propagation. To date, both analytical [5,6] and numerical approaches [7,8] have been used to predict the expansion of desorption area. However, it is found that the previous analytical models are not working accurately in the case of two-phase flow of gas–water system because not only the flow behavior in this case is more complex [3,9]; but also, the working condition of CBM well is frequently changing as a result of work-over, shut-in well, and so on. In the

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Nomenclature

A	the area of desorption area (m^2)	r	radius (m)
b	Langmuir isotherm constant (MPa^{-1})	r_d	desorption radius (m)
B_g	gas FVF (fraction)	r_w	wellbore radius (m)
B_w	water FVF (fraction)	S_g	gas saturation (fraction)
C_d	desorption compressibility, (MPa^{-1})	S_w	water saturation (fraction)
C_t^*	modified total compressibility (MPa^{-1})	T_{sc}	absolute temperature (K)
C_f	rock compressibility (MPa^{-1})	T	absolute temperature at standard conditions (K)
C_g	gas compressibility (MPa^{-1})	t	production time (days)
C_w	water compressibility (MPa^{-1})	V	the volume of desorption area (m^3)
G_p	cumulative production (m^3)	V_m	Langmuir pressure (m^3/m^3)
K	absolute permeability (md)	x, y	Cartesian coordinate (m)
K_{rg}	effective permeability to gas (dimensionless)	Z	compressibility factor (fraction)
K_{rw}	effective permeability to water (dimensionless)	Z_{sc}	compressibility factor at standard conditions (fraction)
L	fracture half-length (m)		
P	reservoir pressure (MPa)	*Greek symbols*	
P_{sc}	reservoir pressure at standard conditions (MPa)	μ_g	gas viscosity (MPa s)
P_d	critical desorption pressure (MPa)	μ_w	water viscosity (MPa s)
P_{wf}	well bottom hole pressure (MPa)	φ	cleat porosity (fraction)
P_L	Langmuir pressure (MPa)	ξ,η	elliptical coordinates (m)
q_d	quantity of desorption gas from matrix to cleat ($m^3/(m^3$ h))	λ_t	total mobility of gas and water (md/(MPa s))

case of numerical modeling, many different data set are required to run the simulation such as the geological model, coal and fluid properties [8,10] and petrophysical properties for example permeability, porosity, and relative permeability curves which are hard to obtain [11]. In contrary to numerical simulation, an analytical model does not need most of those data sets and it is simple and fast.

In this paper, we first present different mechanisms of pressure propagation and desorption area expansion during the production. Then, a simplified mathematical model is developed for the pressure distribution in CBM based on the characteristic of gas–water ratio. Furthermore, the pressure equations are solved using the method of continuous succession of steady states. Next, a mathematical model for desorption area in a coal-bed methane well is developed combined with material balance equation, which is appropriate for middle and high-rank coal. Then, it is shown that the developed new model is validated with numerical simulation. Finally, the predictive model has been applied in Hancheng CBM field in China and the results are discussed in detail. Some conclusions are presented in the last section.

2. Pressure propagation and desorption area expansion

It is necessary to review different flow mechanisms occurring in CBM reservoirs for the development of a mathematical modeling. Throughout the production from under-saturated CBM reservoirs, the following three stages are commonly taking place: (1) dewatering stage; (2) stable production stage; and (3) decline stage [3]. In all three stages, either single-phase or two-phase flows can occur depending on the relative permeability of each phase. During the early stage of depressurizing, since no gas has been desorbed, single phase water flows only. Once the pressure reaches the critical desorption pressure, the gas phase will change from adsorbed gas to free gas state. By the time the gas phase reaches the critical gas saturation, a two-phase gas–water flow will develop in the cleat system. As a result, the following characteristics for pressure propagation in each stage will occur:

(1) During the dewatering stage, since the flow behavior is only a single phase, the pressure propagates through the water in the cleat system. The pressure propagation will interfere with other neighboring wells at the flow boundary. After reaching to the boundary, the pressure drop in the drainage area will be proportional to the water production rate.

(2) During stable stage, since the reservoir pressure is reduced to the critical desorption pressure, and the gas begins to desorb and diffuse through the coal matrix to the cleat system, the desorption area begins to expand (Fig. 1). At this time, a single-phase water flow is changed to two-phase flow. In this case, the resulting flow resistance in two-phase system is obviously higher than single phase flow. However, on the other hand, the matrix system acts as a source supplying gas to the cleats; therefore, it slows down the trend of pressure drop. In overall, the expansion of desorption area is

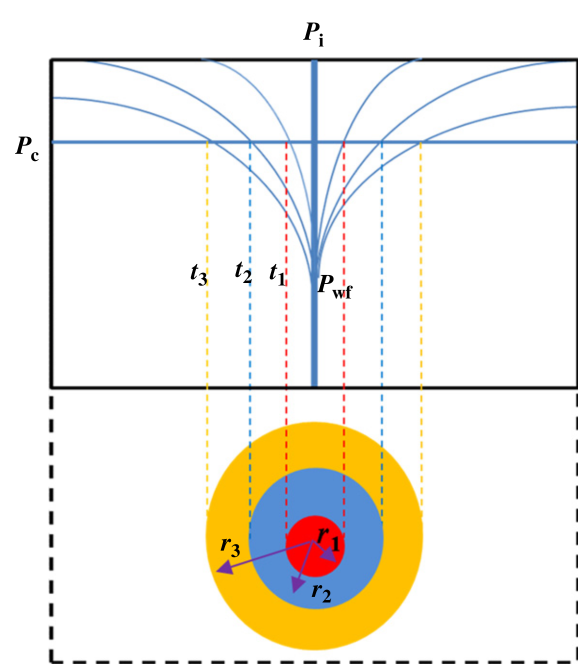

Fig. 1. The schematic of desorption area expansion in a CBM well.