



ELSEVIER

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

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

Necessity of porosity correction before simulation and re-understanding of the effects of gas adsorption on production in shale gas reservoirs

Jing Wang^{a,b,*}, Huiqing Liu^a, Wei Yu^b, Fei Cao^b, Kamy Sepehrnoori^b

^a MOE Key Laboratory of Petroleum Engineering in China University of Petroleum, Beijing 102249, China

^b Department of Petroleum & Geosystems Engineering, The University of Texas at Austin, Austin 78712, USA

ARTICLE INFO

Article history:

Received 11 July 2014

Received in revised form

25 August 2015

Accepted 21 December 2015

Available online 23 December 2015

Keywords:

Shale gas reservoir

Adsorbed gas

Porosity correction

Barnett Shale

Numerical simulation

ABSTRACT

Shale gas contains free gas and adsorbed gas in matrix pores. The size of matrix pore is on the order of nanometer, large specific surface area makes the adsorbed gas occupy a large part of the total void volume. However, most widely used simulators ignore the volume reduction of free gas due to adsorbed gas, resulting in the OGIP errors. In order to make the simulation results be more reasonable and accurate, firstly, we derived the correction formulas of bulk porosity, free gas saturation and connate water saturation used for converting measured data into simulation model. Then, the matrix porosity, gas saturation and connate water saturation are corrected to match the original gas in place (OGIP) and the production data of Barnett Shale. Finally, the effects of gas adsorption on gas production in Barnett Shale with porosity correction are studied. The results show that porosity correction is significantly necessary before inputting the measured parameters into a simulator. In Barnett Shale, the adsorbed gas takes up 1/4 of the total void volume, if this partial volume is ignored, the free gas storage capacity and OGIP will be overestimated by 52.49% and 25.5%, respectively. The cumulative gas production will be much higher without porosity correction due to the artificial increasing of the free gas volume in the model which should be occupied by adsorbed gas in reality. The adsorption effect of shale gas is adverse to the development of shale gas. Only a little fraction of the adsorbed gas contributes to gas production in the late-stage. For Barnett Shale, the recovery factor of free gas is about three times of adsorbed gas; the gas recovery factor in the near-wellbore region is about two times of the gas recovery factor in the whole reservoir.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

Shale gas has received great attention in recent years around the world due to its large reserves. The future energy landscape will see natural gas play an increasing role for energy supply, particularly in light of the substantial quantities of unconventional gas reserves now being exploited in the United States and plans to exploit similar unconventional resources in many other countries (Khosrokhavar et al., 2014a, 2014b). At the end of 2012, shale gas accounted for 24% of US gas demand, and it is expected to account for 49% of total gas production in the United States by 2035 (Khosrokhavar et al., 2014a, 2014b; Weijermars 2014). Although shale gas can obtain subsidies in the form of tax credits, the only real incentive for shale gas development has been and continues

to be price signals. If gas prices stay depressed below the commonly assumed hurdle rate, then a decline in shale gas output may turn out to be more realistic (Geny 2010; Weijermars 2014). In addition, shale gas production are influenced and restricted by many factors, technology innovation, government policy, private sector entrepreneurship, land and mineral rights ownership, market structure, geology, water availability, and natural gas pipeline infrastructure (Khosrokhavar et al., 2014a, 2014b).

Shale is different from conventional gas reservoirs; the gas storage space in shale involves both nano-sized pores and natural micro-fractures. Permeability is extremely low on the order of nano-darcy. In order to increase the well productivity, two key technologies comprised of horizontal drilling with multi-stage hydraulic fracturing have been widely used (Zhu et al. 2009; Waters et al. 2009; Ma et al., 2013; Yu et al., 2014; Guo et al. 2014; Yu et al., 2015).

Shale gas reservoirs are organic-rich formations, varying from one shale to another, even within formation itself, they serve as both reservoir and source rock. Gas in shale involves free gas in

* Corresponding author at: MOE Key Laboratory of Petroleum Engineering in China University of Petroleum, Beijing 102249, China.

E-mail address: wangjing8510@163.com (J. Wang).

Nomenclature

b_{CH_4}	Langmuir adsorption constant of CH_4 , 1/psi	V_{ga}	Volume of adsorbed gas in petrophysical model, scf
B_{ga}	Adsorbed gas formation volume factor	V_{gf}	Volume of free gas in petrophysical model, scf
B_{gfs}	Free gas formation volume factor	V_{wc}	Volume of connate water in petrophysical model, scf
D	Reservoir depth, ft	V_{gf}'	Volume of free gas in simulation model, scf
g	Gravitational acceleration, $g=9.8\text{ m/s}^2$	V_{ga}'	Volume of adsorbed gas in simulation model, scf
G_a	Adsorbed gas storage capacity, scf/ton	V_L	Langmuir volume, scf/ton
G_f	Free gas storage capacity, scf/ton	V_m	Mole volume of CH_4 , scf/mole
K_m	Permeability of matrix, md	V_{scgf}	Volume of free gas at standard condition, scf
\hat{M}	Apparent natural gas molecular weight, lbm/lbmole	V_{scgf}	Volume of adsorbed gas at standard condition, scf
m	Gas adsorption mass per unit volume formation, g/cm^3	V_{wc}'	Volumes of connate water in simulation model, scf
p_m	Matrix pressure, psi	ρ_b	Bulk density, g/cm^3
p_g	Gas pressure, psi	ρ_{ga}	Adsorbed gas density, g/cm^3
p_L	Langmuir pressure, psi	ρ_{gf}	Free gas density, g/cm^3
q_g	Sink/source term per unit volume of formation, $ft^3/(s \cdot ft^3)$	ϕ_f	Free gas porosity in petrophysical model
S_{gf}'	Free gas saturation in simulation model	ϕ_f'	Free gas porosity in simulation model
S_w	Water saturation in petrophysical model	ϕ_m	Matrix porosity
S_w'	Water saturation in simulation model	ϕ_{wc}	Connate water porosity in petrophysical model
t	Time, s	ϕ_{wc}'	Connate water porosity in simulation model
		ϕ_t	Total porosity in petrophysical model
		ϕ_t'	Total porosity in simulation model
		μ_g	Gas viscosity, mPa·s
		ω_{CH_4}	Mole of adsorbed CH_4 per unit mass of rock, gmole/lb
		$\omega_{CH_4, max}$	Maximum mole of adsorbed CH_4 per unit mass of rock, gmole/lb

natural micro-fractures and matrix pores and adsorbed gas on the surfaces of matrix pores (Jenkins and Boyer, 2008). Comparing with conventional tight gas reservoirs, shale gas reservoirs should produce a certain amount of gas from desorption that could not be overlooked (Weniger et al., 2010; Mengal and Wattenbarger, 2011). Because the content of organic matter and clay minerals is much higher in shale, the specific surface area of pores is very large, which induces the content of adsorbed gas to be 20–85% (Curtis, 2002). Therefore, people think that gas desorption could be a major production mechanism and might have a significant contribution to ultimate gas recovery.

For a shale gas reservoir, the total gas porosity involves both free gas porosity and adsorbed gas porosity. Because the helium sorption on the sample is considered to be negligible, it is usually used to determine the void volume of shale (Buscha et al., 2008; Khosrokhavar et al., 2014a, 2014b). Hence, the measured porosity is the total porosity. Unfortunately, in most of widely used commercial simulators, such as CMG and Eclipse (Eclipse, 2010; CMG, 2011), the mass balance equation of gas in matrix is written as follows:

$$\nabla \cdot \left[\frac{K_m \rho_{gf}}{\mu_g} (\nabla p_g - \rho_{gf} g \nabla D) \right] + \rho_{gf} q_g = \frac{\partial}{\partial t} (\rho_{gf} \phi_m) + \frac{\partial \hat{m}}{\partial t}. \quad (1)$$

In the above equation, the adsorbed term is treated as the way of polymer, surfactant in chemical flooding. This part does not take up a true pore volume, and the free gas takes up the total void volume. Consequently, the free gas porosity is much larger than the actual value. Hence, the OGIP used in the models is larger than the actual value. As a result, large errors might be produced using these models.

Accurate determination of the OGIP is a precondition for conducting a reservoir simulation study. Bustin et al. (2008) presented that the OGIP, porosity and water saturation determinations developed for conventional reservoirs may lead to substantial errors. Ambrose et al. (2012) compared the old petrophysical model and new petrophysical model of shale rocks and used molecular dynamic simulation to study the distribution and density of free gas and adsorbed gas in shale rocks, the results indicated the old OGIP

calculations may lead to a large error. But these opinions have not been sufficiently paid attention. Many simulators or models have been used to simulate the development of shale gas reservoirs (Zhang et al., 2009; Cipolla et al., 2010; Dahaghi, 2010; Mongalvy et al., 2011; Ye et al., 2014), in these models, total gas porosity is still used as the free gas porosity, and adsorbed gas takes up a virtue volume. As a result, an unreasonable conclusion that gas adsorption is favorable to shale gas development is presented.

In this work, Barnett Shale is used as an example for our study. First, correction formulas for the bulk porosity, free gas saturation and connate water saturation used for simulation are derived. Then, using the new parameters converted from measured data by above correction formulas as the input parameters for CMG simulator to establish reservoir models, and both OGIP and production rates of Barnett Shale are matched and the influences of gas adsorption on gas production are discussed based on the results. Then, the variation of free gas and adsorbed gas in the producing process are studied. The results are very significant to a conduct simulation study for shale gas reservoir and understand the influences of gas adsorption on gas production.

2. Adsorption and geomechanics effects in Barnett Shale

2.1. Gas adsorption

Gas adsorption is an important feature of shale gas reservoirs, which might contribute significantly to the total gas recovery. Langmuir isotherm is widely used to describe gas adsorption/desorption physical process (Langmuir, 1918). In the Computer Modeling Group's (CMG, 2011) GEM simulator, the amount of gas adsorbed on the solid surface for multi-component is modeled using the extended Langmuir isotherm, which was presented by Arri et al. (1992) and Hall et al. (1994). For single-component shale gas reservoir, the equation is a special case, which is shown below:

$$\omega_{CH_4} = \omega_{CH_4, max} \frac{b_{CH_4} p_m}{1 + b_{CH_4} p_m}. \quad (2)$$

Download English Version:

<https://daneshyari.com/en/article/1754620>

Download Persian Version:

<https://daneshyari.com/article/1754620>

[Daneshyari.com](https://daneshyari.com)