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Journal of Natural Gas Geoscience xx (2018) 1–9

http://www.keaipublishing.com/jnggs

Original research paper

Study on the optimization of fracturing parameters and interpretation of CBM fractured wells

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Received 30 January 2018; revised 1 March 2018

Available online ■ ■ ■

Abstract

Due to complex seepage mechanism and weak reservoir property, CBM requires being exploited by hydraulic fracturing. In order to comprehend the influencing laws of fracturing parameters' on productivity, recovery efficiency, and well network thoroughly, this paper establishes a non-linear gas-water percolation model of fractured wells. Stress deformations, fluid–structure interaction, CBM desorption, and diffusion research are done. On top of the above, injection pressure-drop well test method is adopted to evaluate fracturing effects. The result demonstrates that the reservoir porosity initially declines and subsequently rises. Permeability is non-linearly affected by threshold pressure gradient. Well space optimization involves fracture orientation, fracture penetration ratio, and fracture conductivity impacts. The rectangle and rhombus well pattern selection refers to reservoir anisotropy critical ratio. The injection pressure-drop test interpretation should be improved further due to the changes in wellbore liquid level. This study is of great significance to improve fracturing evaluation and parameters optimization.

Keywords: CBM reservoir; Fluid-mechanical coupling analysis; Fracturing parameters optimization; Well test interpretation

1. Introduction

Coalbed is an unconventional self-generating and self-preserving reservoir. In regards to reservoir mechanism, much research has been performed on the genetic type of coalbed methane gas [1–4], Langmuir desorption and absorption, gas-bearing properties, dewatering gas production, and so on. There are abundant studies on fracturing fluid damage, proppant optimization, fracture crack law, and more for reservoir stimulation [5–7]. However, there is barely any in-depth research on the influences of fracture parameters on coalbed development efficiency [8–10]. Owing to the pressure declining desorption, initial diffusion, subsequent gas flow rule, and poor physical properties, most coalbed methane wells continually needs to be exploited by means of fracturing [11,12]. The fracture extends along the orientation of the maximum principal stress. The pressure passes quickly along the fracture direction, while the pressure propagation along the vertical direction depends mainly on the physical properties of the coalbed matrix. Thus, the fracture direction affects the selection of well space and pattern [13–16]. In terms of fracture performance interpretation, the liquid level changes during injection testing and the selection of testing section could affect the interpretation results. It is only by

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Peer review under responsibility of Editorial office of *Journal of Natural Gas Geoscience*.

https://doi.org/10.1016/j.jnggs.2018.04.001

Please cite this article in press as: Q. Feng, et al., Study on the optimization of fracturing parameters and interpretation of CBM fractured wells, Journal of Natural Gas Geoscience (2018), https://doi.org/10.1016/j.jnggs.2018.04.001

Nomenclature

$\Delta\varepsilon$	Deformation of coal matrix, %
y_i	Gas mole fraction of gas component i of coalbed methane, %
a_i	Langmuir volume of component i, m^3/t
b_i	Langmuir adsorption constant of component i, MPa^{-1}
R	Gas constant, $MPa\cdot m^3/(kmol\cdot K)$
ρ_c	Coal density, t/m^3
T	Absolute temperature of reservoir, K
E	Young modulus of coalbed, MPa
V_0	Molar volume of gas,10^{-3}/mol
C_m	Compressibility of coalbed, MPa^{-1}
P_0	Original formation pressure, MPa
P	Pressure of coalbed Matrix, MPa
φ	Reservoir porosity under current formation condition, %
φ_0	Reservoir porosity under original formation condition, %
K	Reservoir porosity under current formation condition, mD
K_0	Reservoir porosity under original formation condition, mD
G_d	Desorption amount of coalbed methane, m^3
a	The separated production ratio of coal ash, %
W_c	Moisture content of coalbed, %
V_L	Langmuir volume, m^3/t
P_L	Langmuir pressure, MPa
q_D	Diffusion amount of dissolved gas, m^3/s
C_{mw}	Concentration of dissolved gas in matrix, m^3/m^3
C_{fw}	Concentration of dissolved gas in cleat, m^3/m^3
D_g	Diffusioncoefficient of dissolved gas in water, m^2/s
V_m	Pore volume of matrix, m^3
η	Shape factor of matrix particle, m^{-2}
P_m	Pressure of matrix system, MPa
P_f	Pressure of fracture system, MPa
q_{mfg}	Channeling fluid rate between coal matrix and cleat, m^3/s
F_G	Geometric form factor
V_E	Gas concentration on the surface of matrix unit, m^3/m^3
τ	Desorption time of coalbed methane, s
$\overline{V}_m$	Average gas concentration in matrix unit, m^3/m^3
P_{fg}	Pressure of gas phase in cleat system, MPa
P_{mg}	Pressure of gas phase in matrix system, MPa
φ_m	Porosity of matrix system, %
φ_f	Porosity of cleat system, %
x	Pore structure factor
σ_{gw}	Interface tension of gas and water, N·m
μ_g	Gas viscosity, mPa·s
B_g	Volume coefficient of gas phase
q_{vg}	Gas production, $m^3/(m^3\cdot s)$
q_{vw}	Water production, $m^3/(m^3\cdot s)$
S_g	Gas saturation, %
K_c	Permeability of cleat system, mD
K_{rg}	Relative permeability of gas phase, mD
K_{rw}	Relative permeability of water phase, mD
λ_g	Starting pressure gradient of gas phase, MPa/m
λ_w	Starting pressure gradient of water phase, MPa/m
K_f	Permeability of fractures, mD
w	Fracture width, m
X_f	Fracture half length, m
F_{ratio}	Fracture penetration ratio, fraction
F_c	$K_f\cdot w$, fracture conductivity,D·m
h	Reservoir thickness, m
C_t	Total compressibility, MPa^{-1}
σ_t^V	Vertical tensile strength, MPa
σ_t^H	Horizontal tensile strength, MPa
K_x	Permeability of principle fracture direction
K_y	Permeability of vertical principle fracture direction
C_L	Wellbore storage coefficient, m^3/MPa
V_w	Wellbore fluid volume, m^3
C_w	Water compressibility, MPa^{-1}
C_2	Wellbore storage coefficient of variable fluid level, m^3/MPa
V_a	Wellbore volume of unit length, m^3
ρ_w	Fluid density, g/cm^3

avoiding the effects aforementioned could we improve the accuracy of the fracture performance evaluation. As a result, fracturing parameters optimization and interpretation are analyzed in this paper.

2. Fluid-solid coupling analysis of CBM fracturing wells

2.1. Variable physical properties of coalbed

Solid coal, liquid water, and gas all create a single system in a coalbed reservoir, which maintains the coalbed pressure and phase equilibrium. As a self-generating and self-storage reservoir, coal cleats are well developed [17,18], stress deformation occurs under the effects of matrix desorption and shrinkage. The total deformation is defined as follows:

$$\Delta\varepsilon=\sum_{i=1}^{n}\frac{a_i b_i y_i \rho_c RT}{EV_0\sum_{i=1}^{n}b_i y_i}\left[\ln\left(1+p_0\sum_{i=1}^{n}b_i y_i\right)-\ln\left(1+p\sum_{i=1}^{n}b_i y_i\right)\right]+C_m(p-p_0) \tag{1}$$

The principal changes in reservoir property are brought by the gradual increase of the output of reservoir fluid,