Stimulated Reservoir Volume Estimation and Analysis of Hydraulic Fracturing in Shale Gas Reservoir

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Abstract

Hydraulic fracturing in horizontal well is the key technology for the commercial exploitation of shale gas reservoir. Stimulated reservoir volume (SRV) is an important indicator to evaluate the fracturing performance. However, estimating the SRV has been a long-standing challenge due to its complex forming mechanism. Most current SRV estimation methods are either expensive or time-consuming. This paper developed a 3D mathematical model to estimate the SRV by simulating the four main processes during shale fracturing—multiple hydraulic fractures propagation, formation stress variation, reservoir pressure lifting and natural fractures failure. In this model, hydraulic fractures propagation is calculated by pseudo-three-dimensional model, coupling with formation stress model; formation stress and reservoir pressure are obtained by displacement discontinuity method and Green’s function approach, respectively; natural fracture failure criterion is derived from Warpinski’s theory. This model not only considers the stress interference effect of multiple fractures, but also subdivides the SRV into shear-SRV and tensile-SRV according to the failure type of natural fractures network. This model was first implemented to a pilot well in the FL gas field in southwest China to estimate a SRV that matches well with the on-site monitoring microseismic signals. Then, this model was applied to FL gas field on a large scale to evaluate the overall fracturing effects. Finally, a sensitivity study was conducted to analyze the impact of engineering parameters on the SRV. This research explores an efficient method to estimate the SRV without high cost or complicated process and provides the theoretical basis and guidelines for pre-fracturing design and post-fracturing evaluation in shale gas reservoir.

Keywords
Shale gas · Hydraulic fracturing · Stimulated reservoir volume · Mathematical modeling · Field application

List of symbols

- \((A_{n})_{ij}\) Plane-strain, elastic-influence coefficient matrix representing the normal stress at element \(i\) induced by normal-displacement discontinuity at element \(j; i, j \in \{1, 2, \ldots, N\}\)
- \((A_{nt})_{ij}\) Plane-strain, elastic-influence coefficient matrix representing the normal stress at element \(i\) induced by shear-displacement discontinuity at element \(j; i, j \in \{1, 2, \ldots, N\}\)
- \((A_{ntt})_{ij}\) Plane-strain, elastic-influence coefficient matrix representing the shear stress at element \(i\) induced by normal-displacement discontinuity at element \(j; i, j \in \{1, 2, \ldots, N\}\)
- \((A_{tt})_{ij}\) Plane-strain, elastic-influence coefficient matrix representing the shear stress at element \(i\) induced by shear-displacement discontinuity at element \(j; i, j \in \{1, 2, \ldots, N\}\)
- \(c_{L}\) Filtration coefficient \((\text{m/s}^{0.5})\)
- \(E\) Young’s modulus of formation rock \((\text{Pa})\)
- \(F_{i}\) Derivatives functions, \(i \in \{3, 4, 5, 6\}\)
- \(G\) Formation shear modulus \((\text{Pa})\)
- \(h_{f}\) Fracture height \((\text{m})\)
- \(h_{r}\) Thickness of reservoir \((\text{m})\)
- \(h_{rD}\) Dimensionless thickness of reservoir
- \(K_{0}\) Zeroth-order Bessel function
- \(K_{f}\) Friction coefficient of natural fracture

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1 Introduction

In the last decade, as shale gas reservoir has been explored in many countries, global petroleum industry places great importance on this unconventional resource. However, with the ultra-low permeability and low porosity, vertical well drilling followed by conventional hydraulic fracturing is not well performed in the shale gas reservoir [1,2]. Because of the brittleness of shale rock, fortunately, a large number of natural fractures are existing in the reservoir, which can be effectively stimulated by multistage fracturing in horizontal wells [3–5]. This technique can dramatically increase shale gas production and improve the economic efficiency [6,7].

During multistage hydraulic fracturing, the horizontal well is segmented into several stages and pumps a large amount of slick water into reservoir at a high flow rate in each stage. It aims at creating hydraulic fractures and stimulating surrounding natural fractures [8]. Those hydraulic fractures and stimulated natural fractures are interwoven into an activated fractures network, in which the reservoir permeability is substantially increased, and consequently, the gas well production soars [9].

The activated fractures network is often referred to as “stimulated reservoir volume (SRV)” [10]. So far, numerous field data have shown a significant positive correlation between SRV and shale gas production [11,12]; therefore, estimating the SRV is becoming indispensable for prefracturing design and post-fracturing evaluation in shale gas reservoir. Currently, there are several ways to estimate SRV, which could be divided into two categories: direct measurement and numerical simulation. Direct measurement methods include microseismic monitoring [13,14] and tiltmeter measurement [15,16]; numerical simulation methods include wire-mesh modeling [17,18] and discrete fracture modeling (DFM) [19–23]. These estimation methods have different advantages and disadvantages: Microseismic monitoring is accurate but costs too much, tiltmeter measurement is cheap but sometimes inaccurate, especially for deep reservoir, wire-mesh modeling is convenient to use but somehow oversimplified, DFM is comprehensive but too complicated, its 3D simulation program usually runs in hours even days.