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Research Article

# Introduction to the appropriate-stimulation degree of hydraulic fracture networks in shale gas reservoirs

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**Abstract**

Due to the limitation of actual shale gas reservoir conditions and fracturing technologies, artificial fracture networks are different greatly even in the same or similar stimulated reservoir volume. Deviations and even faults occur in evaluation and cognition if only the stimulated reservoir volume (SRV) is used to characterize and evaluate the effect of stimulation. In this paper, the spatial distribution of artificial fractures and natural fractures and the internal pressure state and degree of reserve recovery of stimulated shale gas reservoirs were studied by means of artificial fracture propagation numerical simulation and production numerical simulation. And three concepts were proposed, i.e., shale gas fracture network, ideal fracture network and appropriate-stimulation degree of fracture network. The study results indicate that, at the end of reservoir development, target zones can be classified into three types (i.e., relatively appropriate stimulation zone, transitional stimulation zone, and uncompleted stimulation zone) according to the recovery degree and production time of stimulated reservoirs; and that the final morphologic parameter of fracture networks and the reservoir characteristic are two main factors affecting the appropriate-stimulation degree of fracture networks. As for a specific gas reservoir, the orientation, length, conduction, height and spatial location of its fracture network are the main factors influencing its appropriate-stimulation degree if the well trajectory is set. The proposal of the theory on the appropriate-stimulation degree of hydraulic fracture networks in shale gas reservoir enriches the theoretical system of shale reservoir stimulation technology, and it can be used as the reference for characterizing the fracture systems in other unconventional reservoirs, such as tight oil and gas reservoirs.


*Keywords:* Shale gas; Reservoir stimulation; Ideal fracture network; Appropriate-stimulation degree of fracture network; Completed stimulation zone; Transitional stimulation zone; Uncompleted stimulation zone

## 1. Introduction

When fracturing optimization design and performance evaluation are conducted, the results of numerical simulation indicate that, given the same stimulated reservoir volume (SRV), artificial fracture conductivity and contacting area between artificial fracture and reservoir, individual well production, oil recovery and distribution of residual oil/gas are different if fracture distribution state is different. Post-fracturing assessment is often based on micro-seismic events, while practical application shows that the performances after fracturing vary greatly even with similar physical properties of reservoir and micro-seismic event volume. This is because there are different distribution states of artificial fractures formed in fracturing. Since the final development effect depends on hydraulic fracture distribution state, it is essential to quantify fracture distribution state in fracturing design and post-fracturing evaluation.

Yin et al. [1] adopted the fractal method to characterize fracture development degree. Cipolla et al. [2–5] proposed

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injection pressure drawdown test to analyze fracture development degree in 2008, production matching method combined with numerical simulations and micro-seismic monitoring in 2009 and fracture complexity index in 2010. Xu et al. [6] analyzed fracture state by applying micro-seismic technology and mechanic fracture propagation analyzing software. Wang et al. [7] proposed that parameters such as equivalent fracture amount, equivalent fracture width and equivalent leak-off coefficient can be used to characterize complex fractures. All these methods, either quantitative or qualitative, only describe fracture itself and their results cannot reflect the matching between fracture system and reservoir. Deviations and even faults occur in evaluation and cognition if only SRV or the intuitive sense of fracture morphology is used to characterize and evaluate the effect of stimulation.

In order to quantify the matching between artificial fracture and reservoir, the authors proposed the concept of appropriate-stimulation degree of fracture network in shale gas reservoir. Relatively appropriate stimulation zone, transitional stimulation zone and uncompleted stimulation zone were also put forward on the basis of recovery degree and non-dimensional production time (a specific time in a gas well life cycle divided by the total life cycle). And two types of factors influencing appropriate-stimulation degree of fracture network were analyzed.

## 2. Definition and connotation of fracture network appropriate-stimulation degree

### 2.1. Background

After stimulation, artificial fractures and their connected natural fractures in shale gas reservoirs cut rocks in SRV into independent units with different shapes and sizes. Artificial hydraulic fracture simulation is carried out through artificial fracture propagation numerical simulation and production numerical simulation. Results show that the shape and size of units are different in varied process and reservoir conditions, thus the seepage state and production performance are different (Fig. 1). Meanwhile, results of a large amount of micro-seismic show that production varies greatly even with similar physical properties of matrix and the same SRV because the number of influencing factors is large [8−11]. For example, there are two wells with the same borehole length and operation parameters in platform Y and both SRV of them is $0.7 \times 10^8$ m$^3$. However, their production after stimulation is significantly different (Figs. 2 and 3).

In this paper, fracture network appropriate-stimulation degree was proposed to characterize the state of fracture network during hydraulic fracturing process and evaluate stimulation performance.

### 2.2. Fracture networks and ideal fracture networks

The following concepts are clarified before fracture network appropriate-stimulation degree is defined.

Fracture network of shale gas reservoir (or fracture network): a fracture system consisting of artificial fractures and natural fractures which connect with artificial fractures (Fig. 4).

An ideal fracture network: all points in fracture network matrix connecting a well almost reach a limited pressure at a specific time (Fig. 5-a). This definition has two meanings. First, an ideal fracture network is an ideal stimulation state without considering economic rationality and the possibility of engineering implementation. Second, all points in fracture network matrix have synchronous pressure drop. This means that the permeability of an ideal fracture network has improved greatly so that the average pressure in every matrix unit declines synchronously and reaches a certain value.

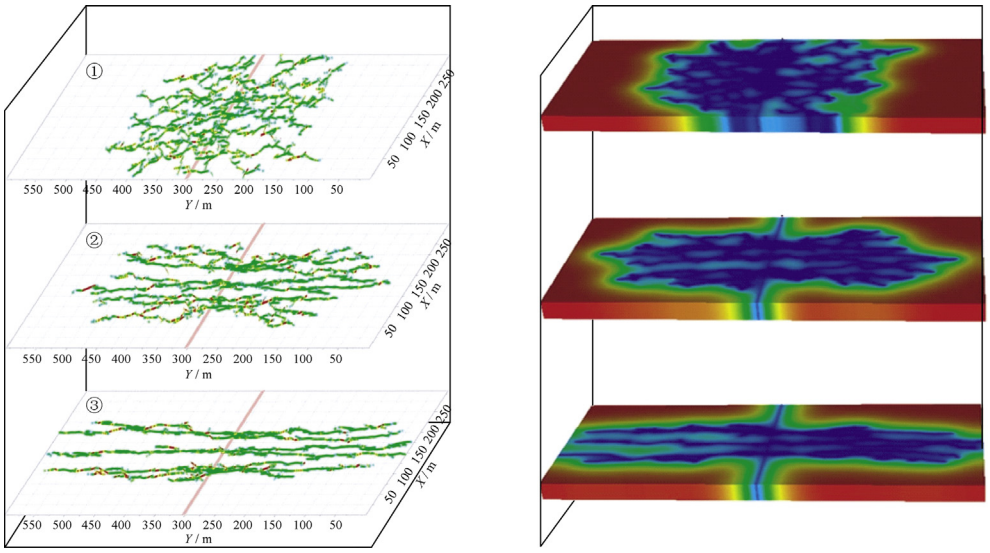


Fig. 1. Pressure distribution of different gas reservoirs with various fracture morphologies but at the same development condition at the end of one-decade production (the matrix permeability is 100 nD).

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