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Flow in multi-scale discrete fracture networks with stress sensitivity

Bin Liang [a], Hanqiao Jiang [a], Junjian Li [a, *], Changcheng Gong [a], Ruyi Jiang [b], Yanli Pei [a], Shiming Wei [a]

[a] *Key Laboratory for Petroleum Engineering of the Ministry of Education, China University of Petroleum, Beijing 102249, PR China*
[b] *Department of Science and Technology Management, China National Petroleum Corporation, Beijing 100007, PR China*

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ABSTRACT

For hydraulic fracturing in the shale reservoir, the existence of natural fractures has a great impact on the propagation of hydraulic fractures and the flow capacity of porous media. Our previous study mainly discussed the effect of different fracture parameters (i.e., orientation, aperture) on the fracture network permeability based on discrete fracture model and finite elements analyses (Liang et al., 2016). To further account for the in-situ condition, we now investigate the effect of stress sensitivity, i.e. the stress difference between hydraulic fractures and natural fractures, on flow behavior in multi-scale discrete fracture networks. A series of sensitivity experiments on both naturally and artificially fractured cores with the existence of proppants were carried out. Fracture models at different scale were established based on the corresponding mathematical fitting models, to study the effect of stress sensitivity on the seepage process. Results show that with the increase of confining pressure, the permeability of natural fractures decreases exponentially while the permeability of hydraulic fractures decreases more slowly following the cubic polynomial law. The stress sensitivity of natural fractures has more influence on the flow dynamics than that of hydraulic fractures, and this difference is subject to the fracture orientation, fracture length, and intersection relationship. When the fracture orientation is parallel to pressure gradient or the fracture can serve as part of the main channel, the stress sensitivity has great impact on the productivity of the fracture network. The drainage area around the hydraulic fractures are almost the same irrespective of the stress, but the drainage area of natural fractures changes significantly when considering stress sensitivity. Therefore, it is necessary to incorporate the stress effect on the flow conductivity of hydraulic and natural fractures while modeling complex fractured reservoirs.

1. Introduction

With the growing challenge of conventional reservoir exploitation, producing gas or oil from shale reservoir has gradually become the focus of current energy industry (Wang and Krupnick, 2013). Unlike conventional reservoirs, fluid transport in naturally fractured reservoirs (NFR) is a complex process (Liang et al., 2016; Ren et al., 2015). Most NFR are comprised of natural fractures with arbitrary orientations, various apertures and different fracture patterns. NFR unfolds an upper degree of heterogeneity and diversity caused by discrete fractures compared to conventional porous media. The complexity of discrete fracture geometry and connectivity of site-specific fractured matrix make it hard to characterize the flow behavior in NFR (Farayola et al., 2013). The seepage capacity of natural fractures is strong, so the mass transfer processes needs to be studied clearly. Traditional continuum model is insufficient to simulate such discrete fracture models because of its inability of depicting the mazy features of natural fractures. Therefore, multiphase simulation of the NFR with the complex fracture network is a challenging task in reservoir engineering (Reichenberger, 2003).

The modeling of flow performance in discrete fracture media has been kept ongoing. Modeling the flow behavior of NFR can be roughly divided into three categories: dual porosity continuum models (DCM), discrete fracture network models (DFN) and discrete fracture models (DFM) (Sahimi, 2012). For the DCM, there are two mass balance equations describing fracture and matrix system, respectively (Warren and Root, 1963). Initially, flow through fractured porous media is simulated by using DCM. This approach suffers from some critical limitations despite of its

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* Corresponding author. College of petroleum engineering, China University of Petroleum, Beijing city Changping District Road No. 18, PR China.
E-mail address: junjian@cup.edu.cn (J. Li).

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simulation efficiency. Firstly, DCM cannot capture the complex structure of discrete fracture network, which may dominate the whole seepage process. Another disadvantage lies in the inaccurate evaluation of the transfer mechanism between matrix and fractures (Karimi-Fard et al., 2003). Unlike DCM, the DFN can address the mass transfer mechanism between matrix and fractures (Mi et al., 2014a). However, the DFN still has some limitations. The model takes the intersection of cracks as the basic research nodes, this brings the difficulty to describe the flow behavior in the matrix away from the research nodes.

Compared with DFN, research nodes exist in both the matrix and the cracks in DFM. This modeling method can precisely capture the complexity feature of a discrete fracture medium. DFM model uses grid nodes to represent flow relationship between fracture-fracture, fracture-matrix and matrix-matrix. It is necessary to generate unstructured grids adjusted to the distribution of discontinuous fractures, as shown in Fig. 1. The DFM has obtained considerable development in the last decade (Feuga and Peaudecerf, 1990; Gong et al., 2008).

Besides discrete fracture modeling methods, the difference between the stress-sensitive conductivity of hydraulic and natural fractures also has a great influence on flow simulation in shale porous media. Hydraulic fracturing is a common technique for the tight reservoir development, which will generate a complex fracture system composed of both natural and hydraulic fractures. Obvious conductivity differences can be detected between the natural fractures and hydraulic fractures, and the pressure sensitivity of natural fractures is rather strong (Jianzheng, 2002; Ren et al., 2016). For hydraulic fractures, the conductivity capacity will be greatly improved due to the existence of proppants (Davies and Kuiper, 1988), as show in Fig. 2.

The proppants provide effective resistance to ensure the effective conductivity of hydraulic fractures. Many mathematical models have been proposed to characterize stress-sensitive conductivity, but they are subject to numerous assumptions (Gao et al., 2012). There are also some experimental studies on the stress sensitivity of fracture conductivity (Phueakphum and Fuenkajorn, 2014).

The purpose of this paper is to study the flow conductivity of hydraulic fractures and natural fractures under stress effect in multi-scale discrete fracture networks with stress sensitivity. For better understanding the flow dynamics, three discrete fracture models with different scale (disjoint fracture scale, fracture network scale and reservoir scale) have been established considering the pressure sensitivity. The whole paper is organized as following; firstly, experiments on the pressure sensitivity of permeability are conducted on both artificially-fractured and naturally-fractured cores. Permeability fitting models of the hydraulic and natural fracture are then obtained. Based on the conductivity models, discrete fracture models are established by using DFM and the finite element method. The simulation results are finally presented in three aspects: pressure distribution, streamline analysis, and velocity field.

2. Model definition and introduction

The discrete fracture model consists of two parts, the matrix and the facture network. Flow in matrix follows Darcy's law while flow in fracture belongs to modified Darcy's law. The whole flow process includes flow from matrix to matrix, matrix to fracture, fracture to matrix, and fracture to fracture. These flow processes will be presented in the following results. The whole flow area is divided into a series of flow units. The flow area is gridded by non-structured mesh using triangulation algorithm, and the center of each grid is regarded as a research node. The crack is equivalent to an internal boundary with a unique tangential method algorithm to define it. This can describe the crack behavior without a large number of dense and tiny grid elements. Unstructured mesh can efficiently split the matrix and fracture elements, which can provide a guarantee for the accurate calculation of mass transfer between any two mobile units. Based on these grids, the finite element method is used to implement the simulation process.

2.1. DFM description

The basic model is 2D. The first set of mode is a square with constant pressure at left and right sides. The second set of models is a square with a production well and an injection well with constant pressure at the two diagonal corners. The flow in the model is single phase flow. The parameters of the model are in Table 1.

Fig. 3 consists of pressure distribution, streamline distribution, and velocity field distribution. Considering the pressure distribution map, it is obvious that the existence of cracks will make the pressure contour complicated. Through the pressure contour we can find in which direction pressure drop is the most, and how the cracks affect the pressure distribution. Streamline describe the velocity direction of different fluid particles in the flow field, the

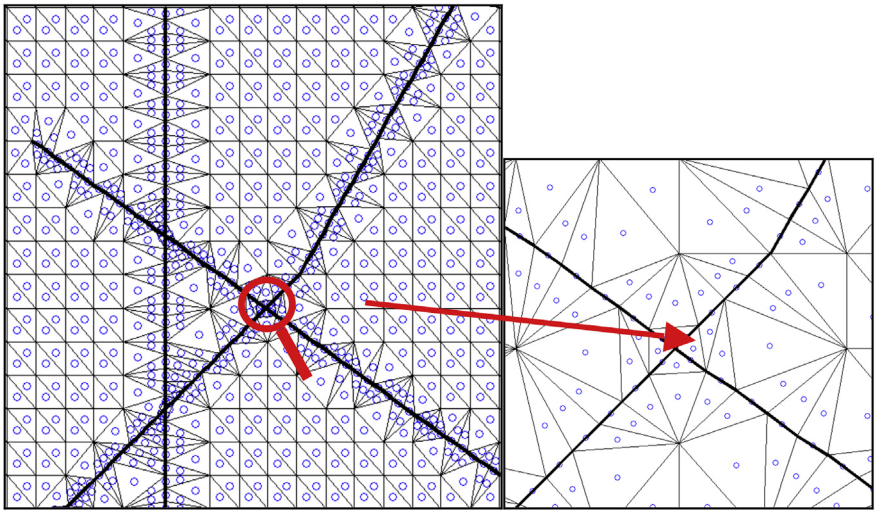

Fig. 1. The unstructured grid and the node of DFM (Liang et al., 2016).