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A systematic study of fracture parameters effect on fracture network permeability based on discrete-fracture model employing Finite Element Analyses

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ABSTRACT

Due to the discontinuity of porous media, naturally fractured reservoirs are different from traditional reservoirs. Accurate description of seepage law and quantitative study of the influence of fracture parameters on flow capabilities have always been a complicated and challenging task. In this paper, the influence of various fracture parameters (i.e. fracture orientation, fracture length, fracture aperture, intersection relationship and their comprehensive influence) on permeability is studied quantitatively and systematically based on the discrete fracture model (DFM) and Finite Element Analyses. A series of fracture models are established to get a comprehensive understanding of the inherent rules and the permeability of each model is calculated. For further insight of the fracture seepage law, the article also conducts research on pressure distribution, streamline distribution and velocity field distribution. Results show that fractures parallel to mainstream line have bigger contribution to seepage process, the sensitivity interval of fracture aperture, in this paper, is 0.1mm-0.01 mm, and longer fracture will generate higher permeability while super long fracture approaching the injector and the producer should be avoided. For the discrete fracture network, if the intersecting cracks cannot serve as part of the mainstream channels, this intersection is almost meaningless. The sensitivity analysis can provide a guidance for modeling DFM as well as probing into the complex flow characteristics in naturally fractured reservoirs and other complex fractured reservoirs.

1. Introduction

Over 40 percent of oil and gas reservoirs throughout the world are naturally fractured reservoirs. With the rapid energy demand growth and severe production pressure from conventional reservoirs, producing gas or oil from shale formation has played an increasingly important role in the world energy industry (Wang and Krupnick, 2013). Some of the world's major oil distribution areas such as Middle East, North America, South America, and South East Asia are naturally fractured reservoirs (Farayola et al., 2011). Unlike conventional reservoirs, fluid transports in naturally fractured reservoirs (NFR) is a complex process. 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 models is insufficient to simulate such discrete fracture models due to its inability of depicting the mazy features of natural fractures. Thus reasonable simulation of the NFR is a challenging task in reservoir engineering (Reichenberger, 2003).

The modeling of flow performance in discrete fracture media has been kept ongoing. Research to simulate the flow behavior of NFR can be roughly divided into three levels: dual porosity continuum models (DCM), discrete fracture network models (DFN) and discrete fracture models (DFM) (Sahimi, 2012). For the DCM described as Fig. 1, there are two mass balance equations describing fracture and matrix system respectively as investigated by Warren and Root (Warren and Root, 1963). Flow through fractured porous media is originally simulated using DCM. This approach suffers

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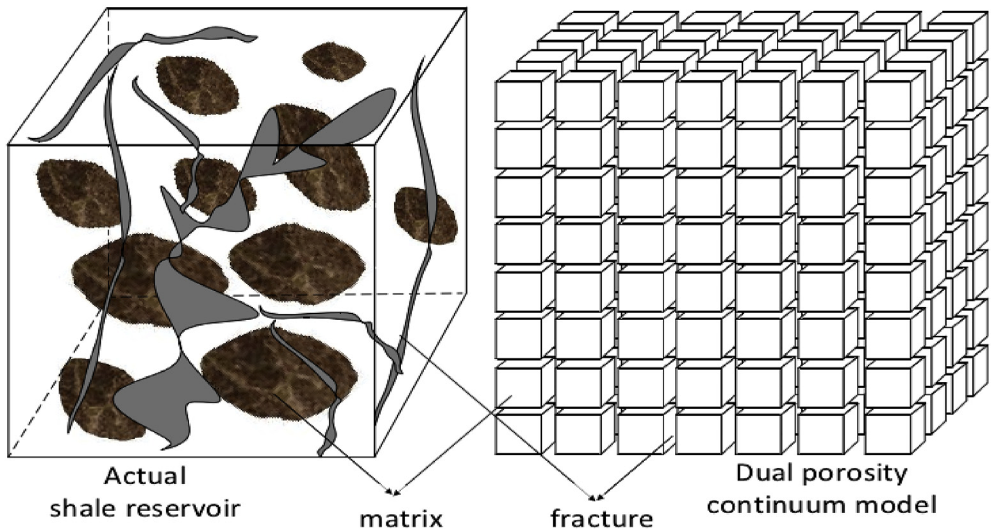

Fig. 1. Idealization of the heterogeneous porous medium as dual porosity model (Guo et al., 2014).

from some critical limitations despite of its 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,b). However, the DFN still has some limitations. As shown in Fig. 2, the model takes the intersection of cracks as the basic research node, but this will cause 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. It is another modeling method that 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. 3. This will affect the simulation speed and increase the simulation cost. Just because of this, the model has not been industrialized although the DFM has obtained considerable development in the last decade(Feuga and Peaudecerf, 1990; Gong et al., 2008).

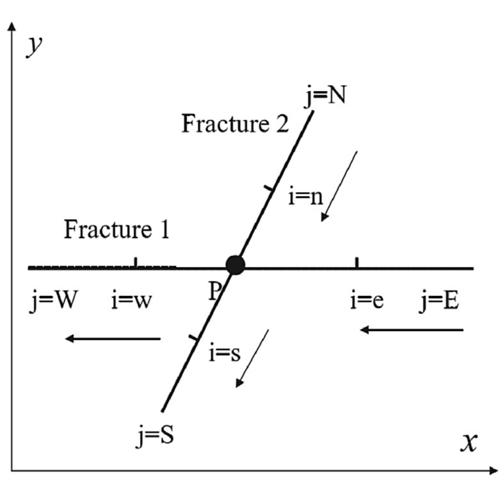

Fig. 2. Simplified fracture element schematic.

There has been some research on the application of the finite-element method to handle single or multiphase flow (Kim and Deo, 2000). Reddy stated that the finite element method is an powerful computer oriented method to solve engineering problems (Reddy and Gartling, 2010). A major application advantage of the methodology in reservoir simulation is that the geometrical domain can be discretized with the maximum use of mesh points.

The motivation of this article is to systematically study the influence of fracture parameters on the seepage capability of the discrete fracture medium, of which one dominant characterization is the permeability. Taking the advantages of DFM and the finite element method, this work simulates fluid flow in discrete fracture reservoirs using the finite element analysis software, COMSOL Multiphysics 5.0. This paper establishes multi group models and the influence of each parameter on the flow capacity of DFM is studied. To make the results more comprehensive and persuasive, simulation results are carried out by the permeability analysis, pressure distribution analysis, streamline analysis, and velocity field analysis.

2. Model definition and introduction

The discrete fracture model consists of two parts, the matrix and the facture network. Matrix flow follows Darcy's law, the flow in fracture belongs to modified Darcy's law. Flow processes include 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 characterized as a non-structured mesh by triangulation algorithm, and the center of each grid is a the 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.