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Invited review

A review of stimulated reservoir volume characterization for multiple fractured horizontal well in unconventional reservoirs

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Abstract: Unconventional resource exploration has boosted U.S. oil and gas production, which is successfully by horizontal well drilling and hydraulic fracturing. The horizontal well with multiple transverse fractures has proven to be effective stimulation approach could increase reservoir contact significantly. Unlike the single fracture planes in typical low permeability sands, fractures in shales tends to generate more complex, branching networks. The concept of stimulated reservoir volume was developed to quantitative measure of multistage fracture interact with natural fractures in unconventional reservoir. However, the simple fracture modeling of the past do not suitable for the complex scenarios simulation. This paper reviews the mainstream characterization method of stimulated reservoir volume in shale reservoirs, including microseismic interpretation, rate transient analysis method, analytical and semi-analytical method and numerical method. Finally, the systematic evaluation of application conditions with respect to each method and further research directions for characterization method are proposed.

Keywords: Multiple fractured horizontal well, stimulated reservoir volume, unconventional reservoirs, characterization method.

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1. Introduction

With conventional resources depletion recent years, unconventional oil and gas reservoir development has received more and more attentions. The concept of “ Unconventional” mostly reflect the technology, knowledge and also the experience at present (Lolon et al., 2009; Mayerhofer et al., 2006), which could change into the “Conventional” reservoir with the rapid development of the science and technology. The important development technology of unconventional reservoirs, such as shale gas is hydraulic fracturing with stimulated reservoir volume, which could stimulate the formation and increase the reservoir contact significantly (Mayerhofer et al., 2010). Moridis et al. (2010) divided the complex fracture network system into four types of media in unconventional reservoir, the fracture in different region have large differences either in fracture geometry or in the fracture properties. Suliman et al. (2013) divided the stimulated reservoir volume into three part based on the density of microsesimic and reservoir conductivity. In view of this background, finding appropriate method to characterize stimulation reservoir volume (SRV) will play a key role in order to accurate predict well performance of a shale gas and to optimize the design of the hydraulic fracturing technology.

The present review describes the analytical and numerical method of SRV characterization and to identify key weaknesses where further research is needed. It summarizes recent literature in order to improve the understanding of the fundamentals underlying the SRV characterization in hydraulic fracturing operations for shale gas reservoir.

2. Definition of stimulated reservoir volume

The definition of SRV technology has broad sense and narrow sense, the concept of generalized SRV including layered fracturing technology and horizontal well hydraulic fracturing technology. The main purpose of former technology

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is to increase produce degree in longitudinal profile, the latter technology is to improve reservoir flow capacity and reservoir drainage area. This technology using large amount of low viscosity fracturing fluid, as well as diversion materials and technology to achieve complex fracture network, reduce the fluid flow distance between matrix and fractures, significantly improve the overall permeability of reservoir, and finally stimulated the reservoir in three dimensional. This technology not only can greatly improve the single well production wells production, but also can maximize reservoir producing extent and recovery factor.

The present review describes different method and its application focusing on stimulated reservoir volume characterization. It summarizes recent literature in order to improve the understanding of the fundamentals underlying the complex hydraulic fractures in hydraulic fracturing for shale gas production and, finally, the different options available for flow simulation and production prediction in the future are explored.

3. Characterization of stimulated reservoir volume

3.1 Microseismic method

Microseismic monitoring is widely used in petroleum industry to image the hydraulic fracture network within SRV. Microseismic images can provide information of the artificial fracture height, azimuth, height, length and complexity caused by interaction with natural fractures. With this technology, the recorded seismic information during hydraulic stimulation can be analyzed to characterize the failure mechanism and the rock deformation location. It was developed as a method to get information about the fractures activation and the nature of improvement of permeability (Maxwell et al., 2002; Fisher et al., 2004; Rutledge et al., 2004). For example, various complex microseismicity patterns located in the Barnett Shale are analyzed to be the reactivation of existing fractures instead to induce new ones (Cipolla et al., 2008).

If the wavefield sampling is sufficient and data quality is satisfying, the mechanism of generating microseismic can be interpreted to characterize the SRV. This is more accurate when multiple orientations of existing fracture were reactivated. The orientations of fracture failure planes can be characterized by interpreting the source mechanism (Eisner et al., 2010). The studies of different researchers indicate a correlation between the SRV that emits seismic signal while stimulation and the ultimate recovery factor of the well (Fisher et al., 2004; Mayerhofer et al., 2006). The correlation is attributed to bigger networks simulated around a well which has a large microseismic area, resulting in higher permeable flow path connected to the horizontal well and therefore a higher production potential.

Different approaches were proposed to interpret the obtained information from microseismic imaging. The basic approach it to commonly refer the volume of microseismic response cloud as SRV, under the premise that each of the reservoir cell contribute to production (Mayerhofer et al., 2010). However, this analysis approach disregards some of the critical fracture characteristics, like connectivity between different fractures and the conductivity distribution of the fracture system. To couple more physical behavior, a geomechanical model was proposed to simulate the propagation of complex fracture network of SRV (Mayerhofer et al., 2010; Rogers et al., 2010). To form a network of induced hydraulic fractures, a background natural fracture system is considered to assist induced fractures propagation. The sophisticated fracture network need to be validated by history matching of the production history. Instead, a discrete fracture network (DFN) can be directly modeled by considering the seismic moment and focal mechanism of every microseismic event. To develop the DFN, fracture planes are located at microseismic events, and the aperture and are of the fractures are evaluated based on the magnitude of the events (Kanamori, 1977). The fracture orientation can be determined by analyzing source attributes characterization (Williams-Stroud and Eisner, 2010). The DFN modeled from analyzing focal mechanism also need to be calibrated with production data to reduce the degree of uncertainty.

Although DFN approach is more accurate compared with dual porosity models in capturing complex fracture system, it suffers from expensive computational cost. DFN method use very small size of cells to discretize the volume near fractures, which lead to more cells and larger computational load. The substantial run time is more challenging for the subsequent production history matching. Li and Lee (2008) developed embedded discrete fracture model (EDFM) to discretize the fracture into structured cubical cells. Since fractures are modeled explicitly within the grid, the grids of matrix domain remain structured without any refinement. With this feature, EDFM can be simply used in reservoir simulator to be more computationally efficient in calculating fluid transport within SRV.

3.1.1 Microseismic-constrained DFN model

Williams-Stroud (2008) developed the approach of applying microseismic event to calibrate the discrete fracture network model of SRV, and then implement it into conventional reservoir simulation.

The microseismic events were identified, measured, and located, and then the energy of event is measured by generating a tomographic image of location. There are several factors that influence the detectability of events; the strongest influence is the ratio of signal to noise (S/N) for a specific location. Lower confidence is applied to the events with lower S/N. if S/N is big enough, the inversion of source mechanism is applied to the seismic data to characterize the failure-plane orientation and slip for almost all the detected seismic traces. Figure 1 (Williams-Stroud et al., 2013) represents the result of final processed events of a well. Events showed in the image are colored with respect to fracture stage and sized with respect to different relative energy. The signal with the lowest S/N for this set had a value of 2.75. In three of the eight stages, a diffuse and well-defined trend, is parallel to a north-northeast azimuth. Stage 1 also shows a south-southeast azimuth trend of events.

A geocellular model is filled with microseismic events, the location and density of the fractures are calibrated by location and relative energy. But the energy of the microseismic events cannot be high enough to determine their source mechanisms. Probabilistic method is employed to construct fractures of SRV. Instead of assigning fractures directly to analyze hypocenters, the microseismic events in geocellular model can be used as a probability to identify the likelihood of fracture generated within a specific cell. It is reasonable to use the stacked amplitude values in the P32 parameter describing fracture surface area for each rock volume (Dershowitz and Einstein, 1988). Since the calibration of microseismic energy with respect to fracture size is not available, fracture size is evaluated by arbitrarily selecting between maximum and minimum lengths, which follows a power-law distribution (Vermilye and Scholz, 1995).

The orientation of the fractures constructed in the DFN within SRV are constrained by resistivity image log interpretation of wells nearby, regional fault orientation and lineament analysis. The regional geologic lineaments and faults are similar to the spatial trend generated by the locations of microseismic event. Characterization of the different modeled fracture sets is performed by fluctuating of the maximum and minimum fracture length of the fracture and changing the fracture length distribution. For the developed DFN model, an equivalent permeability value is implemented with the approach proposed by Oda (1985). It need to have the value of fracture aperture to use Oda (1985) calculation, which can be achieved by image logs or core analysis. The equivalent permeability is input into dual porosity model to simulate the fluid flow behavior. Fig. 2 shows two generated fracture network.

3.1.2 Microseismic-constrained embedded discrete fracture model

The EDFM was originally developed to resolve the limitations of DFN and dual continuum model and to take advantage of the method's synergy. Moinfar et al. (2014) improved the model to enhance its capability in modeling dip-angled and arbitrary orientated fractures. This EDFM has been implemented in many reservoir simulators recently and the application has been illustrated (Mayerhofer et al., 2006).

In EDFM, fracture planes are delineated explicitly within the matrix grid and are discretized through boundaries of cells. A discrete modeling method can be used to characterize the complexity inherent in the fracture system. Structured cells are employed to discretize the rock matrix domain to achieve a simple representation of reservoir geometry and to make the setting of model parameters simple. Fig. 3 presents a schematic view of a EDFM involving three fractured planes. As Fig. 3 indicates, different fracture planes could have arbitrary dip angles and orientations, and it also could include non-aligned orientations with respect to the major coordinate axes. The induced fractures are discretized into unstructured grid because of the intersection of the matrix blocks and planes of fractures. It indicates three potential intersections of matrix blocks and fracture planes, and the unstructured segments are created correspondingly. Each attachment of the whole fracture segments can regenerate the full fracture planes. The matrix domain is still structured since the fracture network is regarded as explicit in the fracture model. The detailed description of discretization process of the induced fracture planes and the modification of the conductivity are not belonging to the scope of this paper.

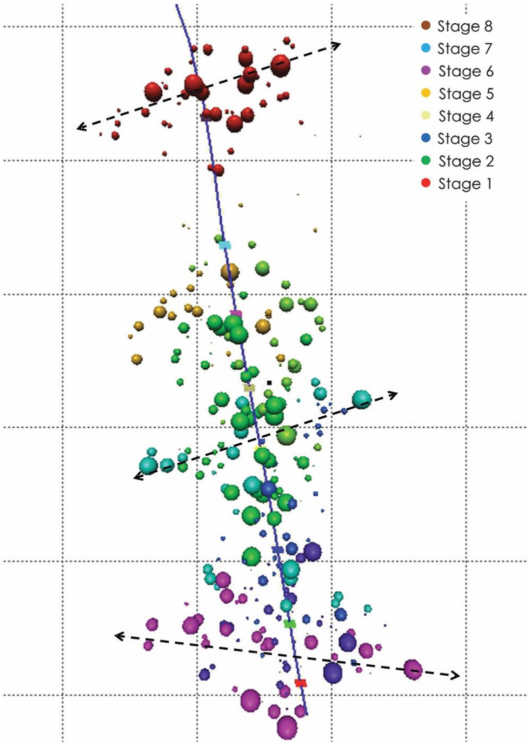

Fig. 1. Microseismic processing results. Spheres show located microearthquake hypocenters. Events are colored by stage and sized by energy. Dashed arrows show the orientations diffuse trends defined by the event locations (Williams-Stroud et al., 2013).

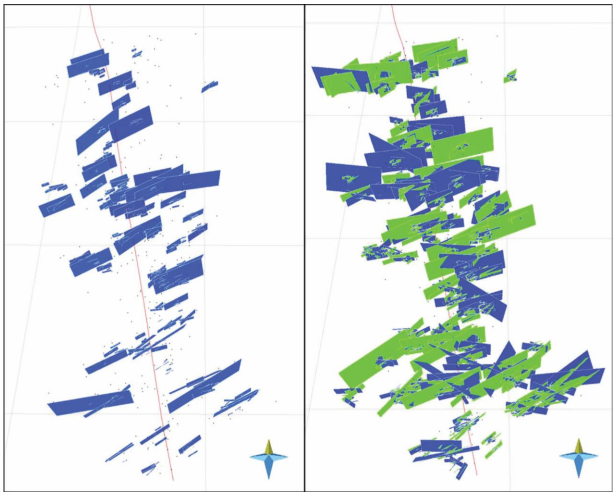

Fig. 2. DFN realizations constrained by microseismic events. The DFN on the left has one fracture set with a strong preferred orientation. The DFN on the right has two fracture sets, one with a strong preferred orientation and the second fracture set with a higher degree of orientation scatter (Williams-Stroud et al., 2013).

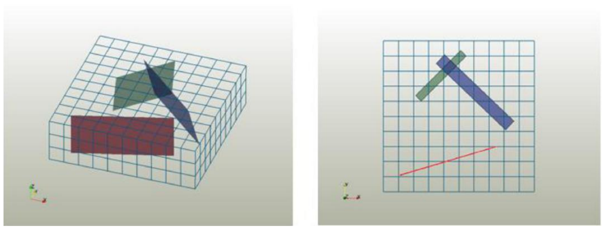

Fig. 3. Schematic representation of reservoir model using EDFM: oblique view (left), and top view (right) (Shakiba and Sepehrnoori, 2015).

Microseismic monitoring is applied to translate the seismic data into discrete fracture network model to simulate the reservoir depletion. The seismic event distribution is examined to capture the complexity and size of the fracture system. Supposing the ratio of length to width is high, then the configuration can be categorized as a planar geometry. Under this circumstance, the microseismic event distribution can be used to quantifying the height and half-length of the hydraulic fracture. On the other hand, supposing the microseismic cloud length to width ratio is low, it can be described as complex fracture network (Cipolla et al., 2008). The primary factors developing complex networks are low stress anisotropy and interaction between natural fractures and hydraulic fractures (Fisher et al., 2004; Gale et al., 2007). It is complex to fit to planar fracture to such a microseismic cloud, and it may provide misleading interpretation. Although the volume of the recorded seismic events seems to provide efficient estimate of spatial extent of SRV, it provides little information about the fracture connectivity. With this circumstance, it is essential to consider the complexity and geometry of the fracture network to ensure a reliable forecast of production.

The collected microseismic data can be directly applied to build a EDFM, with the premise that the signal to noise ratio is high enough to ensure the high-quality of the data. The source mechanism need to be inverted into the focal mechanism and a fracture is located at the hypocenter. By analyzing the focal mechanism, the fracture orientation can be determined. The corresponding fracture surface area can be evaluated from size of the microseismic event. For small magnitude events, a stochastic method can be employed to evaluate the orientation and size of the fracture planes, which provide a pseudo-deterministic fracture network (Detring and Williams-Stroud, 2013).

3.2 Rate transient analysis method

Advanced analytical method employed to quantitative production analysis is categorized as rate transient analysis (RTA) method, which is analogous to pressure transient analysis method (Clarkson, 2013). RTA cam be employed to evaluate the following information about the SRV and unstimulated reservoir volume (USRV):

1. Origional gas in place and ultimate recovery-by analyzing the boundary dominated flow regime.

2. Permeability of both SRV and USRV, hydraulic fracture half-length and fracture conductivity-through analyzing transient flow regime.

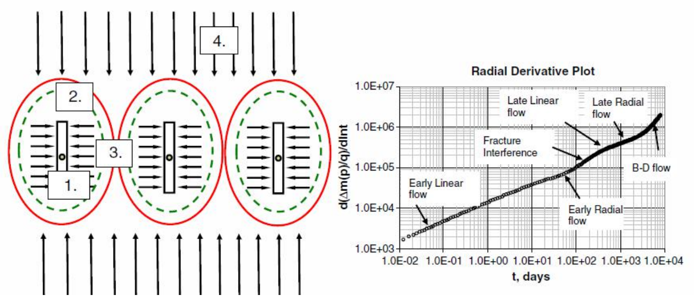

Fig. 4. Left side: flow-regimes sequences for a multi-fractured horizontal well with planar infinite conductivity fractures, completed in a tight gas reservoir. Arrows represent streamlines. Right side: flow-regimes identification of a simulated multi-fractured horizontal well completed in a tight gas reservoir (Clarkson, 2013).

Rate transient analysis method need to use both bottom hole pressure and production rates for the analysis to account for different operating conditions of the well. RTA start with identifying the flow regimes, which are correspond to different flow patterns and geometry of the reservoir, which could be analyzed for hydraulic fracture and reservoir properties. For short term, the flow patterns are affected by flow to the wellbore or hydraulic fracture network within SRV for the stimulated wells. The most common approach to determine flow regimes for rate transient analysis is to employ a pressure derivative or rate normalized pressure derivative versus material balance time or superposition time on a log-log plot (Fig. 4). Flow regime 1 is linear flow; flow regime 2 is elliptical flow; flow-regime 3 is fracture interference; and flow-regime 4 is late compound linear flow.

Brown et al. (2011) propose the tri-linear flow model for multi-fractured horizontal well (MFHW). It is common to regard the inner reservoir as stimulated reservoir and to characterize the permeability of the whole SRV as an equivalent permeability. The impact of distance of investigation calculation on rate transient analysis was proposed by Behmanesh et al. (2015), which can be used to characterize the SRV. It proposed a new way to calculate distance of investigation (DOI) with the theory of maximum rate of pressure response. DOI is the effective distance traveled by pressure transient with respect to production well (Zheng, 2016). The DOI derived with the condition of constant pressure and constant rate are:

$$y_{inv} = 0.113\sqrt{\left(\frac{k}{\phi\mu c_t}\right)_i t} \tag{1}$$

$$y_{inv} = 0.194\sqrt{\left(\frac{k}{\phi\mu c_t}\right)_i t} \tag{2}$$

Yuan et al. (2016) proposed a microscopic tank model to capture the dynamic drainage volume for different production time. In ultra-low unconventional reservoir, transient linear flow regime can last for months to years, which make the major contribution to hydrocarbon production. For transient

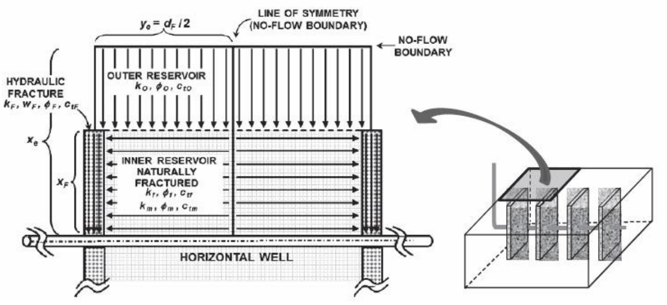

Fig. 5. Trilinear flow model (Brown et al., 2011).

linear flow regime, with the pressure disturbance created at the production well propagating throughout the reservoir, the drainage volume will expand. The expanding of drainage volume is regarded as a moving boundary problem. Dynamic material balance approach is used to calculate the average value of pressure, saturation for each production time within the dynamic drainage volume.

Since the inner reservoir volume is regarded as SRV, the procedures for analyzing transient linear flow of oil and gas proposed by Zheng (2016) is as follows.

1. Draw the plot rate normalized pressure vs. material balance time to identify the flow regime. Find out the time when DOI reaches the midline of two adjacent hydraulic fractures, and calculate the permeability of SRV.

2. Guess a fracture length and input it into macroscopic "tank model", then calculate the relationship between average saturation and average pressure.

3. Draw the plot, RNP vs. square-root of material-balance-time, and find out the slope m.

4. Supposing that the correction factor equals to 1 at beginning, the fracture length can be calculated by $x_f = 39.83/h_f m_L \sqrt{(k\phi\mu_0 c_t)_t}$, which is an approximate value since the correction factor is not real.

5. Input the new fracture length calculated last step into macroscopic tank model, and find out the average pressure and average saturation for each time interval.

6. Draw the plot $\triangle m/q_o(t)/f(p)$ vs. $\sqrt{t}$, and find out the new slope m of early time points (DDV does not reach outer reservoir).

7. Input m into step 4 to iterate until the error of fracture length within required discrepancy.

Employing the analyzation approach, fracture half-length and equivalent permeability of SRV can be evaluated. Thought different definition of DOI can also be implemented in the integrated analysis approach to characterize the SRV, the DOI calculated based on the theory of unit impulse method is most accurate to evaluate the equivalent permeability of SRV (Behmanesh et al., 2015).

3.3 Analytical and semi-analytical method

With technical innovation in the past decades, massive stimulation has been broadly applied into the field and proved effectively, especially the application of MFHW achieves the commercial exploitation. However, modeling fluid flow in the complex fracture networks remains challenging.

In many cases, a fracture propagation can create a branch pattern and a complex fracture networks around the hydraulic fractures, which were defined as SRV. The high conductivity of SRV makes liquids flow into the well easily and benefits the well production. Most of shale gas reservoirs in Eagle ford, Barnett and Marcellus have obtained high production due to SRV.

The numerical approach could realize apparent permeability to characterize shale gas flow, but it has some drawbacks, such as the complex computational process, relationships of parameters and difficult application, so the simplifications of the flow models have to be considered.

Linear flow models can describe the complex flow of MFHW in unconventional reservoirs. Ozkan et al. (2009) and Brown et al. (2011) presented the tri-linear model and studied the performance of MFHW in unconventional oil and gas reservoirs, assuming that the SRV between the hydraulic fractures are described as dual-porosity mediums and linear flow existed in hydraulic fractures and formation. Sang et al. (2014) introduced the adsorption and desorption process into the tri-linear model to predict the production of MFHW in shale gas reservoirs. Stalgorova and Mattar (2012) and Wang et al. (2017) improved the tri-linear model to a five-linear model by simplifying stimulated reservoir volume in a region with limited width. Aybar et al. (2014) revised the trilinear model considering the effect of stress on natural fracture permeability in SRV to study the performance in unconventional reservoirs. Zhang et al. (2015) then presented a numerical five-region model with multi-nonlinearity to study the production of shale gas. To account for heterogeneity of complex fracture network inside the SRV, Wang et al. (2015a, 2015b) and Fan and Ettehadtavakkol (2017) introducing the fractal dimension to quantitatively describe the complex fracture density inside the SRV in Barnett shale reservoir.

The linear flow models have been used widely at present, but some radial flow and transition flow regimes of MFHW are ignored in PTA.

Some work has focused on the semi-analytical models derived by using the point source function to describe the SRV and study the complete pressure responses of MFHW. Zhao et al. (2014a) derived a model for a vertically fractured well in coal seam reservoirs with SRV considering adsorption and Fick' diffusion, which were used to develop the source functions into well-test-analysis. Zhao et al. (2014b) extended the unconventional multiple hydraulic fractured horizontal well in a composite model to describe the SRV and analyzed the effects of related parameters on pressure and production performance. Jiang and Younis (2015) developed the single-porosity model into rate transient analysis for multistage fractured horizontal wells in tight oil considering a circular SRV. Zhao et al. (2015) derived the Laplace point source function in anisotropic reservoirs to further analyze the transient pressure of partially penetrated fractured wells. Zhang et al. (2015) presented a composited model for MFHW to model the shale gas flow in fractured shale reservoirs. In their work, the formation properties of the circular SRV and USRV are different, and the stress-sensitivity effect of the SRV was taken into account. In addition to the circular SRV, the elliptical SRV is also applied to analyze the performance of MFHW in tight gas reservoirs. The radial flow model is applicable to homogeneous reservoirs and requires a long period, which cannot describe a complete transient performance for a fractured well or an anisotropic reservoir. The elliptical flow appears surrounding a hydraulic fracture in an anisotropic formation or in an area with an elliptical boundary. Therefore, it is essential to conduct research on the transient performances of fractured wells in shale reservoirs.

Currently, much research about elliptical flow in porous media focused on the single hydraulic fracture. Prats et al. (1962) studied the flow performances of compressible and incompressible fluids for a vertically fractured well in a closed elliptical reservoir. Meanwhile, they presented a solution for long times at a constant rate and an equivalently effective well radius. Russell and Truitt (1964) studied the transient pressure behavior in vertically fractured reservoirs. However, Gringarten et al. (1974) found that the model presented by Russell and Truitt was not suitable for short-term analysis and presented the analytical solutions for both closed and infinite reservoirs with the infinite conductivity fractures. Kucuk and Brigham (1979) studied the transient elliptical flow in an elliptical or anisotropic-radial reservoir. Riley et al. (1991) analyzed the behavior of a vertically fractured well with infinite conductivity in elliptical flow. Blasingame et al. (2007) obtained a series of decline-type curves for a system consisting of a hydraulic fracture using an analytical model. Considering both the full and partially penetrating infinite conductivity fractures, Igbokoyi and Tiab (2008), and Igbokoyi and Tiab (2010) presented the pressure transient analysis in an elliptically fractured reservoir. Actually, the hydraulically fracturing technology can stimulate an area around the fractures with different reservoir properties from the initial formation, so the results of the above research have not been applied to well testing. Therefore, some scholars (Obut and Ertekin, 1987; Stanislav et al., 1992) focused on studying the behavior of the elliptical reservoir with SRV. Xu et al. (2015) developed the elliptical tri-porosity model (Zhang et al., 2011) into the tight oil reservoir with an elliptical SRV.

3.4 Numerical method

There are mainly four classes of numerical methods that are used to model fluid flow and transport in fracture-matrix system: continuum medium model, discrete fracture model (DFM), EDFM.

The continuum approaches including dual porosity, dual permeability (DPDK) or multiple porosity models. The typical continuous medium model is dual porosity model proposed by Warren and Root (1963), which uses two sets of separated continuous medium to describe fracture-matrix system (As shown in Fig. 6). The communication between fracture and matrix is accomplished by exchange function related to matrix shape factor. It is appropriate for reservoirs with uniform distribution connected fractures and has limitation to model large-scale fracture that dominates the flow (e.g., hydraulic fractures). DPDK model was proposed by Rossen (1977) and Kazemi et al. (1976). Both dual porosity and dual permeability have been implemented in most commercial reservoir simulators. However, the traditional dual porosity and dual permeability in unconventional reservoirs could lead to large inaccuracy because it will take long time to reach pseudo-steady state in the ultra-permeability matrix. Recently, multiple porosity systems (Yan et al., 2013; Sheng et al., 2015) were used to better model fluid flow mechanisms in different pore types such as kerogen, inorganic minerals, and natural fractures. However, this method is based on the assumption that the fracture is very well connected and evenly distributed. It is not possible to solve the problem in the presence of large-scale fractures and dominant fluid flow paths.

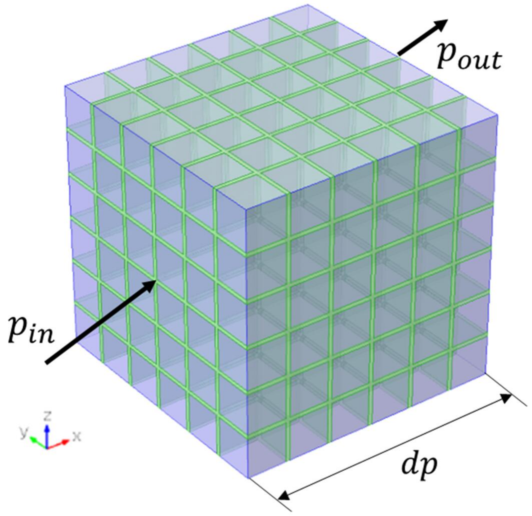

Fig. 6. Dual porosity model.

Compared with continuum medium model, DFM, in which the fractures are represented explicitly, is a better approach to model realistic, complex, and non-ideal fracture geometries and to account for the effects of individual fractures on fluid flow explicitly. Moreover, the transfer flow between matrix and fracture is more accurate and straightforward because it depends directly on the fracture geometry. For DFM, the key step is to generate unstructured grids for complex fractured networks. In essence, the discretization problem is transformed into a grid problem. In order to accurately meet the fracture geometry, unstructured PEBI (perpendicular bisector) or Voronoi grid was introduced to the petroleum industry by Heinemann et al. (1989). The PEBI grids are widely used to model complex fracture networks. In order to accurately model fracture geometry and fracture aperture, Karimi-Fard et al. (2003) introduced a low-dimensional method to represent each fracture mesh block of a 2D line segment with “zero” aperture. This method has been widely used by many researchers (Branets et al., 2009; Romain et al., 2011; Moog, 2013; Fung et al., 2014; Jiang and Younis, 2015). Recently, Hoteit and Firoozabadi (2006) developed a compositional DFM using mixed finite-element and discontinuous Galerkin methods to

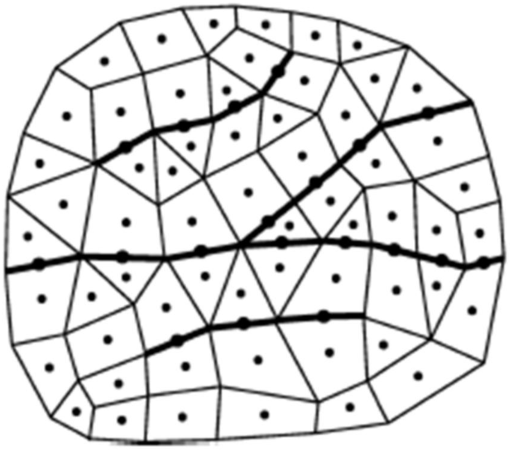

Fig. 7. Hysical model for DFM models.

resolve the mass conservation error for multiphase flows. Balasubramanian (2007) developed a compositional DFM using the control-volume finite-element method. Furthermore, Monteagudo and Firoozabadi (2004), Reichenberger et al. (2006), Matthai et al. (2007), Monteagudo and Firoozabadi (2007), Geiger-Boschung et al. (2009), and Marcondes et al. (2010) applied control-volume finite-element methods to develop numerical simulators for multiphase flow in discrete fractured media. The DFM has a great progress in reservoir with complex fractures. However, as the geometries of discrete fracture networks become more and more complex, unstructured grid generation is becoming increasingly difficult to deal with Sun (2016).

The EDFM (Li and Lee, 2008; Moinfar et al., 2014) is a new method proposed to efficiently handle the complex fractures. The EDFM is an efficient approach to handle the complex fracture geometries through discretizing the fractures into segments with matrix cell boundaries (Li and Lee, 2008; Moinfar et al., 2014; De Araujo Cavalcante Filho et al., 2015). In addition, virtual cells are added for these fracture segments. The Non-Neighboring Connections are used for these cells to account for fluid transport associated with fractures, including the flow between matrix and fractures, flow inside an individual fracture, and flow between intersecting fractures (Zhang et al., 2017).

4. Conclusions

Effective development of unconventional reservoirs in the future still need to develop the following techniques and methods.

1) The combination of multiple methods to describe the complex fracture network and the SRV. According to the comprehensive introduction of several mainstream methods, different methods have their advantages and applicable range, so comprehensive characterization of next technical research should be focused on a variety of methods, such as micro seismic monitoring and unstable seepage characteristics analysis comprehensive characterization, etc.
2) Accurate characterization of effective SRV or effective proppant volume. The method of SRV estimate exist many problems, by combining the geology characteristic of fracture network, detailed research on the effective stimulated reservoir volume parameters is beneficial for hydraulic fracture optimization and accurately predict the well performance.
3) Coupling mutil-physical mechanism of unconventional resource, such as shale oil and gas flow in porous media, adsorption and desorption, etc.
4) The novel fracture simulation method. Existing fracture simulation methods have their limitations and shortcomings, how to exploit its strong points and avoid exposing its weaknesses of all these models, to find better method is the trend in the future.

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