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The Current Status of SRV Fitting Methods based on Microseismic Event Points

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Abstract: Tight oil and gas reservoirs require hydraulic fracturing as a stimulation measure due to their low porosity and permeability characteristics, which enhances their economic benefits. Microseismic events are generated during hydraulic fracturing and monitored by geophones. The stimulated reservoir volume (SRV) is derived from the study of microseismic event point sets. Research by scholars both domestically and internationally has shown that SRV is significantly positively correlated with production. To effectively manage reservoir operations, it is necessary to reasonably calculate and evaluate the SRV induced by hydraulic fracturing. Currently, the methods used for SRV calculation are somewhat disorganized. This paper organizes these methods and introduces their basic principles.

Keywords: Microseismic Event Points; Fracture Volume; Binning Fitting Method; Triangulation Fitting Method.

1. Introduction

Scholars have developed numerous algorithms for studying SRV formed by hydraulic fracturing. In the early 21st century, foreign scholars such as Maxwell (Maxwell et al., 2002) and Fisher (Fisher et al., 2002) conducted detailed discussions on the implementation of inclinometer and microseismic monitoring technologies in Barnett shale slickwater fracturing. They purposefully studied the geometric shape of fractures generated during fracturing operations and their real-time changes. Through specific analyses, they concluded that complex fracture networks consisting of natural and artificial fractures were formed during the fracturing process. Analysis of a large number of hydraulic fracturing measures revealed that horizontal wells can achieve greater SRV compared to vertical wells, and SRV increases with the injection volume. Therefore, horizontal well development technology has become a core technique for shale gas development (Wu Qi et al., 2011). As research on SRV progresses, it has been found that SRV is significantly positively correlated with tight oil and gas production. Consequently, determining SRV provides a basis for formulating later-stage oil and gas production measures, which is crucial for stabilizing oil and gas production. Fisher et al. (Fisher et al., 2004) provided typical diagrams of shale vertical well network fractures in their 2004 seismic monitoring study and systematically summarized the fracture morphology and expansion characteristics during vertical well fracturing. They proposed using channel length and width to characterize the length and width of fracture expansion. Warpinski et al. (Warpinski et al., 2008) introduced the "fracture network algorithm" in 2008, which uses fracture network length, width, and height to characterize SRV. Bo Song et al. used half-length of fractures and fracture spacing to characterize SRV width, and horizontal well length to characterize SRV length. Traditional SRV calculation methods use cubic geometric shapes to fit SRV, ignoring the physical structure inherent to SRV itself. Consequently, the fitting results are overly optimistic and rough, and significantly larger than the actual SRV.

2. SRV Fitting Algorithms Based on Binning

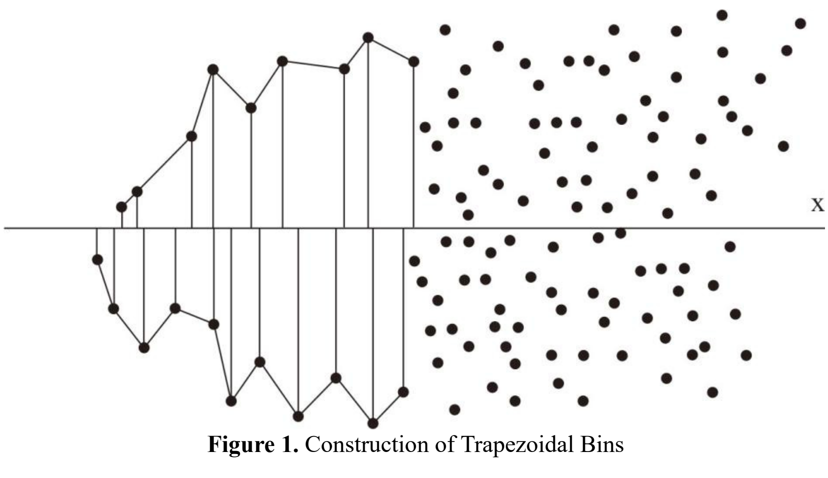

Figure 1. Construction of Trapezoidal Bins

Binning-based fitting algorithms include Trapezium-based Binning and Rectangle-based Binning (Gajraj et al., 2013). Both methods require first determining the orientation line based on the microseismic event point set, then determining the bin height based on the position of the bin relative to the orientation line. The primary difference between these methods lies in the shape of the bins constructed.

(1) Trapezium-based Binning

The first method is based on trapezoidal bins, as shown in Figure 4-1. First, define the x-direction as the orientation line direction. Then, starting from the microseismic event point closest to the origin, connect adjacent event points to form individual bins. Typically, these bins take on a trapezoidal shape. Notably, because this method constrains the bin height to the actual distance from the event point to the x-axis, minimizing the bin size, the calculated Stimulation Response Area (SRA) is more conservative than the Rectangle-based Binning method introduced below. The result is smaller and represents the most conservative method for calculating SRA.

(2) Rectangle-based Binning

The second method is based on rectangular bins, as shown in Figure 2. First, define the x-direction as the orientation line direction. Define the length of a single rectangular bin in the x-direction as the distance between two adjacent microseismic event points in the x-direction. Similar to the Trapezoidal Binning method, start from the microseismic event point closest to the origin. However, initialize the bin height as the distance from the first point to the x-axis. Using the previously defined x-direction bin width, scan along the x-direction to the next adjacent microseismic event point. If this point is farther from the orientation line, reset the bin height to this distance, thus obtaining a rectangular bin. This algorithm resets bin height repeatedly, incorporating nominal bin height size, and repeating these steps yields independent rectangular bins for adjacent event points. Unlike the simple linking of adjacent bins in the Trapezoidal Binning method, the Rectangle-based Binning method selects the point with the greatest distance from the x-axis between two adjacent microseismic event points to create a rectangular bin (Figure 2). The product of SRA obtained by this method and average height H yields SRV.

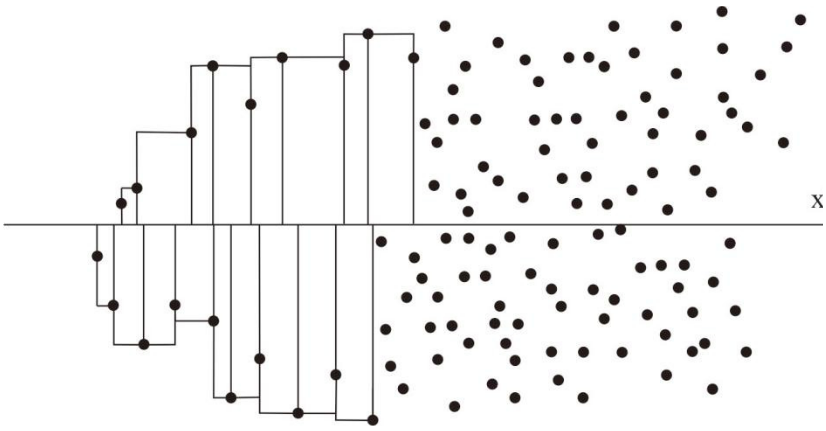

Figure 2. Construction of Rectangle-based Bins

3. Delaunay Triangulation Fitting Algorithm

In 1934, Russian mathematician Delaunay proposed the Delaunay triangulation algorithm, noting that triangles formed by Delaunay triangulation have the largest minimum internal angle among all possible triangles. In 1970, Miles established the foundation theory of Voronoi diagrams based on Voronoi and Dirichlet's work, proving that Delaunay triangulation is dual to Voronoi diagrams. Delaunay triangulation is a representative and characteristic optimized triangulation method that optimizes the uniformity of triangulated meshes.

Using a three-dimensional Delaunay triangulation algorithm to fit microseismic event point sets involves dividing a region Ω containing microseismic event points (using the convex hull of event points as Ω) into tetrahedrons. The volume sum of Delaunay tetrahedrons then yields the hydraulic fracturing volume SRV.

An easy-to-implement point-by-point insertion algorithm with good triangulation effects and low complexity is introduced below. The basic steps are as follows:

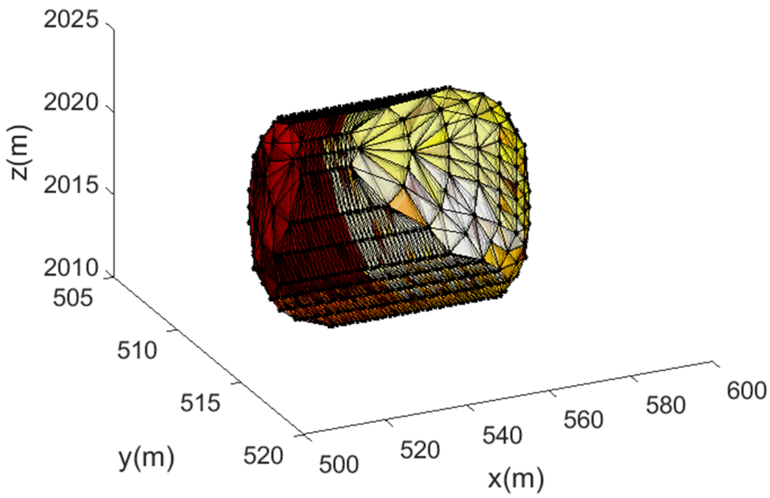

Figure 3. SRV Interpretation Using Triangulation

1) Establish an initial tetrahedron containing microseismic event points and store it in a linked list L;

2) Sort the point set by X value size and insert points sequentially;

3) Find all tetrahedrons enclosed by an outer sphere containing the current insertion point and delete these tetrahedrons to form a cavity, recording its boundary surfaces;

4) Connect triangles on the cavity boundary surface with the current insertion point to form new tetrahedrons and add them to linked list L;

5) Repeat these steps to sequentially insert all microseismic event points;

6) For each tetrahedron in the tetrahedron collection, if any vertex coincides with a super-tetrahedron, delete that tetrahedron from linked list L;

4. Ellipsoid Fitting Algorithm

According to porous media seepage theory, pressure diffusion laws result in elliptical flow regions around fractures in homogeneous formations. Therefore, ellipsoidal fitting is also used to calculate SRV. Additionally, since quantitatively describing the geometric structure characteristics of SRV is necessary, ellipsoidal fitting of microseismic event point sets provides a visualized physical geometric structure for SRV.

The Minimum Volume Enclosing Ellipsoid (MVEE) is an ellipsoid with minimal volume covering all given point sets (Sun et al., 2004). The MVEE problem has been studied in various fields such as multivariate positioning and divergence estimation (Croux et al., 2000, 2002), robust multivariate statistics and singular value processing (Shawe-Taylor et al., 2002; Hardin et al., 2004), and clustering methods with linear transformation-invariant properties in data mining (Dolia et al., 2004).

General ellipsoidal fitting algorithms often exhibit poor stability, especially when fitting large numbers of microseismic points. Parameters in these methods frequently fail to meet requirements, preventing control over generated shapes as ellipsoids. To address these issues, this paper introduces an MVEE-based method that uses minimal volume ellipsoids covering all microseismic points. By constructing an expression for ellipsoid centers and applying an ascending method to optimize ellipsoidal fitting, this approach not only exhibits good stability but also allows adjusting the range of fitting points according to precision needs, thereby obtaining a more reasonable hydraulic fracturing SRV.

In an n-dimensional space, a set of m microseismic event points can be represented as $S=\{x_1, x_2, \cdots, x_m\}$. The Minimum Volume Enclosing Ellipsoid (MVEE) for S, denoted as MVEE(S), is defined as the ellipsoid with the smallest volume that contains all m points in set S.

Assuming that the affine hull of point set S spans an n-dimensional space ensures that any ellipsoid enclosing S has a positive volume. Here, an affine hull refers to the smallest affine set generated by a collection of points in a real linear space. Specifically, let A be a set in a real linear space X. The smallest affine set containing A is called its affine hull. It is both: 1) The intersection of all affine sets that contain A, and 2) The collection of all elements obtained by continuously connecting elements in A using straight lines.

In other words, given a set A, its affine hull represents all possible linear combinations of its elements under affine transformations (i.e., combinations where coefficients sum to 1). This ensures that MVEE(S) is well-defined and meaningful in n-dimensional space when applied to microseismic event points.

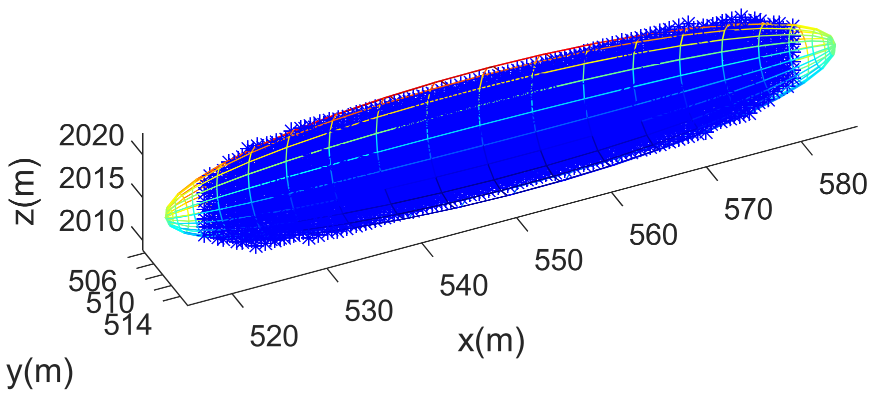

Figure 4. Interpretation of SRV Using Ellipsoid Fitting Method

5. Conclusion

Algorithms such as binning methods, three-dimensional Delaunay triangulation, and minimum volume enclosing ellipsoid (MVEE) can all be used to fit microseismic event point sets and calculate stimulated reservoir volume (SRV). Among these methods, both binning algorithms and three-dimensional Delaunay triangulation tend to produce SRV estimates significantly larger than the actual fracture volume, while MVEE provides results closer to real-world fracturing outcomes.

However, these methods not only clearly delineate microseismic activity regions from a mathematical perspective but also offer more detailed and quantitative geometric structures for SRV analysis. In practical applications, combining multiple fitting algorithms from those mentioned above can enhance evaluations of fracturing effectiveness and improve predictions of oil and gas production yields.

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