Research and Application of Fracturing Comprehensive Evaluation Model for Steeply Dipping Coal Seam

To cite this article: Xiang Jun Xie et al 2018 IOP Conf. Ser.: Mater. Sci. Eng. 392 062092

View the article online for updates and enhancements.

Related content

- 3D Discrete element approach to the problem on abutment pressure in a gently dipping coal seam
  S V Klishin and A F Revuzhenko

- Research on mining of medium thick coal seam under pedal condition based on fuzzy evaluation
  Fan Yang, Zhongteng Zhang and Weizhen Liu

- Study on gas permeability coefficient measurement of coal seam by radial flow method
  Shuchuan Zhang
Research and Application of Fracturing Comprehensive Evaluation Model for Steeply Dipping Coal Seam

Xiang Jun Xie\textsuperscript{1}, Dali Guo\textsuperscript{2*}, Bo Wei\textsuperscript{1}, Jun Zhang\textsuperscript{1} and Chen Zhao\textsuperscript{1}

\textsuperscript{1}156 Prospecting Team of Xinjiang Bureau of Coalfield Geology, Urumqi 830009, Xinjiang, China
\textsuperscript{2}School of Science, Southwest Petroleum University, Chengdu 610500, Sichuan, China

*Corresponding author.
E-mail: swpu_science@foxmail.com.

Abstract. Hydraulic fracturing (HF) is widely used to enhance the production of oil and gas. The accurate evaluation of HF treatments could interpret several parameters, which provides better guidance for HF construction in other wells in the same block. The steeply dipping coal seam has the characteristics of low coal rank, large thickness, large dip angle and good reservoir property. The results of the evaluation are always with diversity and indeterminacy. Therefore, a comprehensive evaluation model is presented on the basis of uncertainty theory and other fracturing evaluation models. The parameters about HF can be obtained by solving this model. This model was applied on steeply dipping coal seams in Xinjiang, China. The results of fracture geometry showed the validity of this model.

1. Introduction
To understand the effect of hydraulic fracturing (HF) contributes to optimize HF treatment and increase wells production.

Several technologies have been studied to evaluate the effect of HF, such as temperature test of wells, numerical simulation, microseismic measurement and so on. These techniques have promoted the progress of fracturing technology and have played a real role in improving the fracturing effect. But the results are different in different ways. How to choose a more accurate evaluation method is a problem that needs to be discussed.

Given the fuzziness and grey characteristic of some evaluation results, a comprehensive evaluation method on the basis of uncertainty theory is a good solution to the problem. Many changes occur in the formation during HF, including the geometry of the fracture induced by HF, permeability of the reservoir and so on. Grasping the geometric dimension of fractures is the key to develop the countermeasures.

At present, there is few effect evaluations of HF for steeply dipping coal seam. The steeply dipping coal seam has the characteristics of low coal rank, large thickness, large dip angle and good reservoir property. Accurate post-pressure evaluation will have a significant impact on the production of coal bed methane.

Therefore, this study focuses on research and application of fracturing comprehensive evaluation model for steeply dipping coal seam. This paper is organized as follows: First, the uncertainty theory is presented. Second, a comprehensive evaluation model based on the uncertainty theory and other evaluation methods is established and solved. Finally, the model is applied on the steeply dipping coal seam in Xinjiang, China.
2. Uncertainty theory

Based on the three exist evaluation methods, the uncertainty theory is introduced to evaluate the fracture geometry by establishing a comprehensive evaluation model.

2.1. Faith degree

The faith degree is represented by a real number in the range 0 through 1. It indicates the degree of trust in a technology or expert. Assume a series of methods or experts is $A_1, A_2, \cdots, A_n$. The corresponding faith degree is $\alpha_1, \alpha_2, \cdots, \alpha_n$. Then the faith degree of experts can be noted as $\alpha = p(\alpha_1, \alpha_2, \cdots, \alpha_n)$. Thus,

$$p(\alpha_1, \alpha_2, \cdots, \alpha_n) = 1 - (1 - \alpha_1)(1 - \alpha_2)\cdots(1 - \alpha_n) \tag{1}$$

2.2. Unascertained rational number

For a random closed interval $[a, b]$, $a = x_1 < x_2 < \cdots < x_n = b$, if there is a function

$$\phi(x) = \begin{cases} a_i & x = x_i (i = 1, 2, \cdots, n) \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

and

$$\sum_{i=1}^{n} \alpha_i = \alpha, 0 < \alpha \leq 1 \tag{3}$$

Then $[a, b]$ and $\phi(x)$ constitute an order unascertained rational number. The $a$ , $[a, b]$ and $\phi(x)$ are called total confidence, value interval and faith distribution density function, respectively.

2.3. Blind number

Suppose $g(I)$ is an interval grey number set, $\alpha_i \in g(I)$, $a_i \in [0, 1]$, $i=1, 2, \cdots, n$. $\phi(x)$ is the grey function which is defined on $g(I)$, and

$$\varphi(x) = \begin{cases} \alpha_i & x = a_i (i = 1, 2, \cdots, n) \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

If $i \neq j$, then $a_i \neq a_j$, and $\sum_{i=1}^{n} \alpha_i = \alpha \leq 1$. The function $\phi(x)$ is called a blind number. $\alpha_i$, $\alpha$ and $n$ are faith degree of $\phi(x)$, total faith degree of $\phi(x)$ and the order of $\phi(x)$, respectively.

2.4. Operational rule

Suppose $f(x)$ and $g(x)$ are blind numbers,

$$f(x) = \begin{cases} f(x_i) & x = x_i (i = 1, 2, \cdots, k) \\ 0 & \text{otherwise} \end{cases} \tag{5}$$

$$g(y) = \begin{cases} g(y_j) & x = x_j (j = 1, 2, \cdots, m) \\ 0 & \text{otherwise} \end{cases} \tag{6}$$

then

$$\Phi_1 = \begin{bmatrix} x_1 * y_1 & x_1 * y_2 & \cdots & L & x_1 * y_m \\ x_2 * y_1 & x_2 * y_2 & \cdots & L & x_2 * y_m \\ \vdots & \vdots & \ddots & \cdots & \vdots \\ x_k * y_1 & x_k * y_2 & \cdots & L & x_k * y_m \end{bmatrix} = (x_j * y_j)_{1 \times m} \tag{7}$$
\[ \Phi_1 \] is the possible value * matrix of \( f(x) \) and \( g(y) \). Where, * is an expression of add, subtract, multiply, divide and other operators.

\[
\Phi_2 = \begin{bmatrix}
    f(x_1) * g(y_1) & f(x_1) * g(y_2) & \ldots & f(x_1) * g(y_n) \\
    f(x_2) * g(y_1) & f(x_2) * g(y_2) & \ldots & f(x_2) * g(y_n) \\
    \vdots & \vdots & \ddots & \vdots \\
    f(x_m) * g(y_1) & f(x_m) * g(y_2) & \ldots & f(x_m) * g(y_n)
\end{bmatrix} = (f(x_i) * g(y_j))_{i,m}
\] (8)

\( \Phi_2 \) is faith degree product matrix of \( f(x) \) and \( g(y) \).
The operation rule is as follows,

1. To arrange all the elements in the possible value * matrix into a sequence, and if there is the same element to record only once, then set as \( \bar{x}_1, \bar{x}_2, \ldots, \bar{x}_n \).

2. The elements of \( \Phi_2 \) corresponding to \( \bar{x}_i (i = 1, 2, \ldots, n) \) are arranged in another sequence, which is set as \( \alpha_1, \alpha_2, \ldots, \alpha_n \). When \( \bar{x}_i \) means the S same elements of \( \Phi_1 \), the \( \alpha_i \) means the sum of the S same elements of \( \Phi_2 \). Let

\[
\psi(x) = \begin{cases} 
\alpha_i & x = \bar{x}_i (i = 1, 2, \ldots, n) \\
0 & \text{otherwise}
\end{cases}
\] (9)

Then \( \psi(x) \) is called * operation of \( f(x) \) and \( g(y) \), which is written as \( \psi(x) = f(x) * g(y) \).

3. Comprehensive Evaluation Model
A comprehensive evaluation model for the length of HF fracture is established based on the uncertainty theory. Similarly, this comprehensive evaluation method can be used to establish models for the comprehensive evaluation of the fracture width and other parameters.

3.1. Establishment
There is grey and fuzzy information in the results of some evaluation methods. In order to distinguish the faith degree of the technology itself, the relative faith degree of the actual application of each evaluation result is called reliability. The faith degree and reliability can be obtained from the feedback information of field applications with expert grading method.

There are a variety of evaluation methods used to evaluate the length of HF fracture, including pressure decline analysis, numerical simulation, microseismic measurement and so on. Suppose there are three fracture length results calculated by three evaluation methods, \( L_1, L_2 \) and \( L_3 \). The faith degree of the three evaluation methods is \( \alpha_1, \alpha_2 \) and \( \alpha_3 \), respectively. And the reliability of the three evaluation methods is \( \beta_1, \beta_2 \) and \( \beta_3 \), respectively. Therefore, the comprehensive evaluation model for the length of HF fracture is

\[
L(x) = \frac{\alpha_1}{\alpha_1 + \alpha_2 + \alpha_3} L_1(x) + \frac{\alpha_2}{\alpha_1 + \alpha_2 + \alpha_3} L_2(x) + \frac{\alpha_3}{\alpha_1 + \alpha_2 + \alpha_3} L_3(x)
\] (10)

where, \( L_1(x) = \begin{cases} 
\beta_1 & x = l_1 \\
0 & \text{otherwise}
\end{cases} \), \( L_2(x) = \begin{cases} 
\beta_2 & x = l_2 \\
0 & \text{otherwise}
\end{cases} \) and \( L_3(x) = \begin{cases} 
\beta_3 & x = l_3 \\
0 & \text{otherwise}
\end{cases} \).

3.2. Solution
Based on the model and the operational rule of blind number, the results of \( L_1(x) \) and \( L_2(x) \) execute blind number operation with \( L_3(x) \). After this order reduction operation, a series of interval functions
will be obtained. In this series, the scattered intervals can be merged into one interval, which is called merge operation. Finally, an unascertained function is obtained, which satisfies

$$\hat{\lambda}(x) = \begin{cases} \gamma_i & x = x_i (i = 1, 2, \cdots, n) \\ 0 & \text{otherwise} \end{cases}$$

(11)

The partition of the interval is in accordance with the size of $\gamma_i$. The result is the corresponding interval number.

4. Application and analysis

The comprehensive evaluation model is applied on the steeply dipping coal seam in Xinjiang, China. The target layer denotes as X. The coal seam is a kind of humus coal, which has low thermal evolution. The parameters of target layer X are shown as Table 1.

| Parameters                          | Value          |
|-------------------------------------|----------------|
| Average reflectance of vitrinite (%)| 0.09           |
| Thickness (m)                       | 4.16-14.93     |
| Average thickness (m)               | 10.52          |
| Average gas content (m$^3$/t)       | 6.9-9.08       |
| Density (g/cm$^3$)                  | 1.3            |
| Porosity (%)                        | 3.7            |

Table 1. Parameters of target layer X.

The exist evaluation models have been used are pressure decline analysis and 3D numerical simulation proposed by Guo et al. and microseismic measurement. The calculated results of half-length of vertical fracture by four methods are shown as figure 1. The calculated results of width of vertical fracture by three methods are shown as figure 2.

Figure 1. Half-length of vertical fracture for wells in Xth layer with four methods.
Figure 2. Width of vertical fracture for wells in $X^{th}$ layer with three methods.

There are several shapes of fractures in the formation due to geological conditions and HF treatments. Other wells in $X^{th}$ layer have generated horizontal fractures. The calculated results of radius of horizontal fracture by four methods are shown as figure 3. The calculated results of width of horizontal fracture by three methods are shown as figure 4.

Figure 3. Radius of horizontal fracture for wells in $X^{th}$ layer with four methods.
Figure 4. Width of horizontal fracture for wells in Xth layer with three methods.

For Xth layer, the average half-length of vertical fracture was 185.76 m, and the average width was 18.91 mm. And the average radius and average width of horizontal fracture was 53.59 m and 15.79 mm, respectively.

5. Conclusions
(1) The comprehensive evaluation model proposed in this paper could provide objective scientific evaluation results for HF treatment. This has solved the problem caused by fuzzy information in other evaluation method.

(2) The comprehensive evaluation model not only applies to calculate fracture geometry but also other parameters about the changes in formation, such as conductivity of fracture, fracture closure pressure and so on.

(3) The application of the comprehensive evaluation model on the steeply dipping coal seam in Xinjiang was valid. That contributed to improve the production of coalbed methane.

Acknowledgments
This work is financially supported by the geological exploration fund project of Xinjiang Uygur Autonomous Region (No. N14-4-XJ01).

References
[1] Bian X, Jiang T, Jia C, Wang H, Li S and Yuan S, et al. 2016 A new post-frac evaluation method for shale gas wells based on fracturing curves. Natural Gas Industry B, 3(2), 146-151.
[2] Shu-Xin Y U and Cheng X G 2017 Evaluation technology and application of segmented productivity test to horizontal well after multiple layer fracturing. Well Testing.
[3] Wu C, Zhang X, Wang M, Zhou L and Jiang W 2018 Physical simulation study on the hydraulic fracture propagation of coalbed methane well. Journal of Applied Geophysics.
[4] Gulrajani S N, Mack M G and Elbel J 1998 Pressure history inversion for interpretation of fracture treatments. Spe Production & Facilities, 13(4), 235-250.
[5] Guangyuan W 1990 Unascertained Information and Its Mathematical Treatment. Journal of Harbin University of Civil Engineering and Architecture, 23(4):1-8.
[6] Nolte K G 1986 A general analysis of fracturing pressure decline with application to three models. Spe Formation Evaluation, 1(6), 571-583.
[7] Guo D, Zhao J, Guo J and Zeng X 2001 Three-dimensional model and mathematical fitting method of pressure test data after fracturing. *Natural Gas Industry*, 21(5), 49-52.

[8] Guo D, Wu G, Liu X and Zhao J 2003 Analyzing method of pressure decline to identify fracture parameters. *Natural Gas Industry*, 23(4), 83-85.

[9] Guo D, Zhang S, Li T, Pu X, Zhao Y and Ma B 2018 Mechanical mechanisms of t-shaped fractures, including pressure decline and simulated 3d models of fracture propagation. *Journal of Natural Gas Science & Engineering*, 50, 1–10.