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

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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 angel 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 applicated 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 angel 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.

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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

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

and

$$\sum_{i=1}^{n} \alpha_1 = \alpha, 0 < \alpha \leq 1 \tag{3}$$

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 $\mathrm{i} \neq \mathrm{j}$, 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. α_i, α 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,

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

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

then

$$\Phi_1 = \begin{bmatrix} x_1 * y_1 & x_1 * y_2 & \cdots & x_1 * y_m \\ x_2 * y_1 & x_2 * y_2 & \cdots & x_2 * y_m \\ \vdots & \vdots & & \vdots \\ x_k * y_1 & x_k * y_2 & \cdots & x_k * y_m \end{bmatrix} = (x_i * y_j)_{k*m} \tag{7}$$

Φ_1 is the possible value * matrix of $f(x)$ and $g(y)$. Where, * is an expression of add, subtract, multiply, divide and other operators.

$$\Phi_2 = \begin{bmatrix} f(x_1)*g(y_1) & f(x_1)*g(y_2) & \cdots & f(x_1)*g(y_m) \\ f(x_2)*g(y_1) & f(x_2)*g(y_2) & \cdots & f(x_2)*g(y_m) \\ \vdots & \vdots & & \vdots \\ f(x_k)*g(y_1) & f(x_k)*g(y_2) & \cdots & f(x_k)*g(y_m) \end{bmatrix} = (f(x_i)*g(y_j))_{k*m} \quad (8)$$

Φ_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 $\bar{x}_1, \bar{x}_2, \cdots, \bar{x}_n$.

(2) The elements of Φ_2 corresponding to $\bar{x}_i (i = 1, 2, \cdots, n)$ are arranged in another sequence, which is set as $\alpha_1, \alpha_2, \cdots, \alpha_n$. When $\bar{x}_i$ means the S same elements of Φ_1, the α_i means the sum of the S same elements of Φ_2. Let

$$\psi(x) = \begin{cases} a_i & x = \bar{x}_i (i = 1, 2, \cdots, n) \\ 0 & otherwise \end{cases} \quad (9)$$

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 α_1, α_2 and α_3, respectively. And the reliability of the three evaluation methods is β_1, β_2 and β_3, respectively. Therefore, the comprehensive evaluation model for the length of HF fracture is

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

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

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

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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

$$\lambda(x)=\begin{cases}\gamma_i & x=x_i(i=1,2,\cdots,n)\\ 0 & otherwise\end{cases} \tag{11}$$

The partition of the interval is in accordance with the size of γ_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.

Table 1. Parameters of target layer X.

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

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.

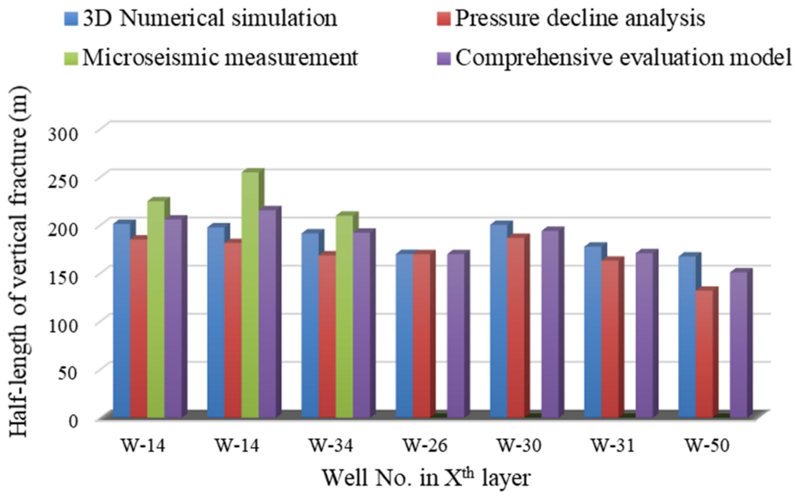

Figure 1. Half-length of vertical fracture for wells in X^{th} layer with four methods.

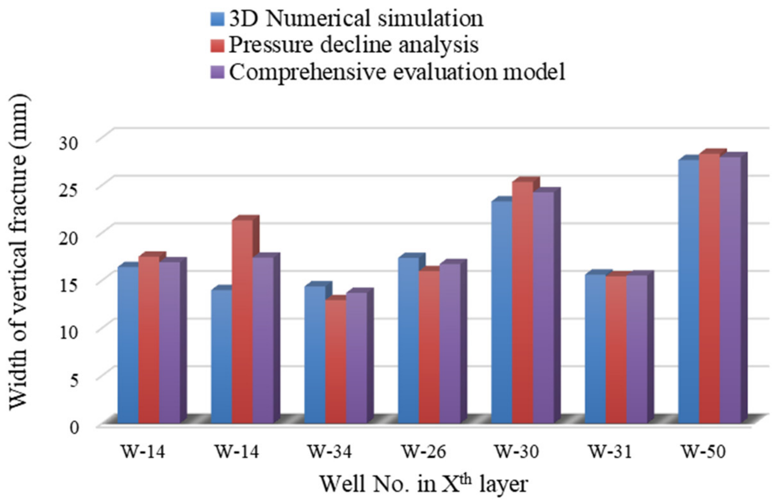

Figure 2. Width of vertical fracture for wells in X^th layer with three methods.

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.

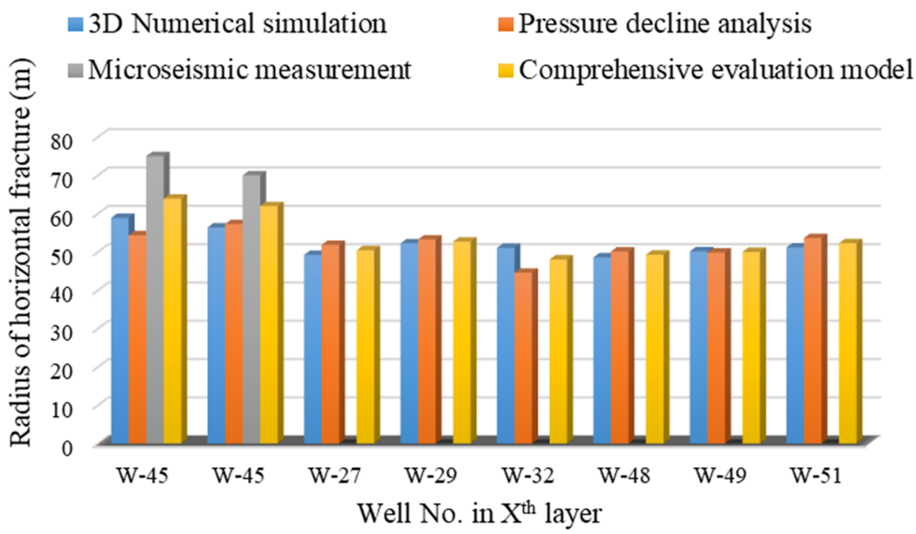

Figure 3. Radius of horizontal fracture for wells in X^th layer with four methods.

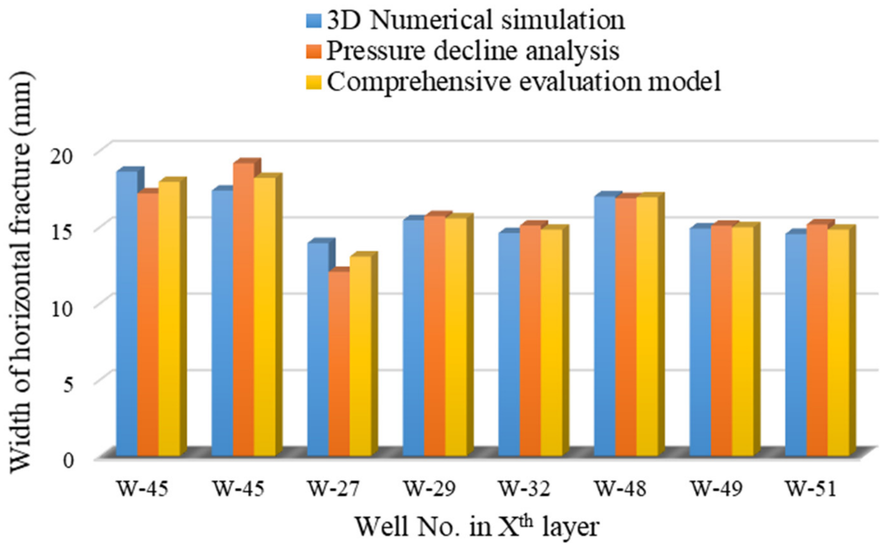

Figure 4. Width of horizontal fracture for wells in X^{th} layer with three methods.

For X^{th} layer, the average half-length of vertical fracture was 185.76 m, and the average width was 18.91mm. 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

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