Research on the Initiation Mechanism of Artificial Fracture in the Fractured Reservoir

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Abstract
The low permeability reservoir which has a significant proportion of oil and gas reserves is the focus on mining in the future. Hydraulic fracturing technology is a major means in achieving such reservoir exploitation. In this paper, the initiation mechanism of artificial fracture in the fractured reservoir is studied. Also, the crack condition is given. Then, the influence factors of initiation mechanism of artificial fracture are analyzed and the theoretical models are further verified through the field application. The results show that: for fixed size cracks, the integrating factor decreases with the increasing of the crack spacing; for fixed crack spacing, the integrating factor increases with the increasing of the crack size; for the same d/a, the larger the size of crack is, the more easily crack extends. By studying on the initiation mechanism of artificial fracture of fractured reservoir, provide theoretical basis for hydraulic fracturing technology being applied in low permeability fractured reservoir. So that the efficient development of special oil and gas reservoirs can be achieved.

Key words: Fractured reservoir; Artificial fracture; Initiation mechanism; Field application

INTRODUCTION
Low permeability reservoirs are widely distributed in each main basin and have a significant proportion of oil and gas reserves. It is an important foundation for oil and gas production growth quite a long time in the future[1]. Due to rock is well compacted and its compactness is strong in low permeability reservoir, the brittleness is enhanced. What’s more, in the role of stress field, the complex and crisscrossed natural fracture system is often produced, which is mainly embodied in low permeability fractured reservoir[2]. In order to improve the production and economic benefit of the reservoir, hydraulic fracturing technology is usually adopted in mining. Thus the research on artificial fractures is the key part of current study[3-4].

There are some scholars have studied on the artificial fracture[5]. Caibo et al.[6] have established a new mathematical model of fracture face skin with segmentation characteristic using fracture mechanics and fluid coupling method. Xu Jianguo et al.[7] have established the mechanical model of horizon wellbore and the computational model of fracture initiation angle and have analyzed artificial fracture initiation law by analyzing the force condition and stress distribution of horizon wellbore. An analysis has been carried out on the relationships between artificial fractures and earth stress and natural fractures by Wan Xiaolong et al.[8], so that the coupled relationship between artificial and natural fractures is studied. Duan Hui et al.[9] have studied the characteristics of artificial fracture for fissure-cavern carbonate reservoirs. But in the present research results, the study on initiation mechanism of artificial fracture is not common[10].
In this paper, the initiation mechanism of artificial fracture in the fractured reservoir is studied and the crack condition is given. Also, the influence factors of initiation mechanism of artificial fracture are analyzed and the theoretical models are further verified through the field application. It can provide theoretical basis for hydraulic fracturing technology being applied in low permeability fractured reservoir.

1. INITIATION MECHANISM OF ARTIFICIAL FRACTURE

There are a large number of micro cracks in fractured reservoir. In hydraulic fracturing operations, vertical artificial cracks along the shear direction of natural fracture and horizontal artificial cracks along the opening direction of natural fracture will be produced which are interconnected to form a seam network.

1.1 Shear Initiation along the Natural Fracture

The tangential stress $\sigma_\theta$ of rock of borehole wall is,

$$
\sigma_\theta = (1-2\cos \theta)\sigma_H + (1+2\cos \theta)\sigma_S
- \frac{\alpha (1-2\nu)}{1-\nu} (P_i - P_p).
$$

(1)

The vertical stress $\sigma_z$ of rock of borehole wall is,

$$
\sigma_z = \sigma_v - 2\nu(\sigma_H - \sigma_S) \cos 2\theta
+ \frac{\alpha (1-2\nu)}{(1-\nu)} (P_i - P_p).
$$

(2)

Considering the natural fracture is non-filled, the criterion of shear initiation along the natural fracture is,

$$
\beta \mu \frac{2 \mu_w \sigma_\theta}{(1 - \mu_w \cot \beta) \sin 2 \beta} = \sigma_N - \sigma_\theta.
$$

(3)

Take Equations (1) and (2) into Equation (3), the corresponding fracture pressure $P_f$ will be got,

$$
P_f = \frac{m_1 m_2 - k_2 m_1 + k_1 k_2 P_p}{1 + k_1 - k_2}.
$$

(4)

Where, $\theta$ is polar angle, $\beta$ is the angle between structural plane and the maximum main stress, $\sigma_H$ and $\sigma_S$ are the horizontal principal stress, MPa; $\sigma_v$ is the circumferential stress, MPa; $P_i$ is the fluid column pressure, MPa; $P_p$ is the pore pressure, MPa; $\alpha$ is the Biot coefficient; $\mu_w$ is the internal friction coefficient. $m_1 = (1 - 2\cos \theta)\sigma_H + (1 + 2\cos \theta)\sigma_S$; $m_2 = \sigma_v - 2\nu(\sigma_H - \sigma_S) \cos 2\theta$; $k_2 = 2\mu_w / (1 - \mu_w \cot \beta) \sin 2 \beta$.

1.2 Opening Initiation Along the Natural Fracture

In the process of hydraulic fracturing of fractured reservoir, another way of initiation of artificial fracture is that the natural fracture on the wall cracks first. The condition of the initiation occurrence is,

$$
P_f' \geq \sigma_N - \alpha P_p.
$$

(5)

Where, $\sigma_N$ is the normal stress of natural fracture surface, MPa.

There are multiple small cracks on the borehole which will converge to seam in hydraulic fracturing. The simplify distribution model of crack on the borehole is built, as seen in Figure 1. The crack system contains evenly spaced, periodic and same size cracks with an infinite number.

The stress intensity factor $K_i$ on the tip of crack is,

$$
K_i = \gamma P_m \sqrt{a} = \gamma (P_i - \sigma_N + a P_p) \sqrt{a}.
$$

(6)

Where, $\gamma$ is the shape factor, $\gamma = \frac{2d}{\sqrt{a}} \tan \frac{\alpha}{2d}$ and $a$ is the half length of crack, m.

According to the $K$ criterion, the critical pressure of crack system instability is,

$$
P_f' = \sigma_N - aP_p + \frac{K_h}{\gamma \sqrt{a}}.
$$

(7)

Where, $\sqrt{a}$ is integrating factor which has nothing to do with the stress factor and it is represented by $\Gamma$.

![Figure 1](attachment:image1.png)

The Distribution Model of Collinear Crack System

2. ANALYSIS OF INFLUENCE FACTORS

Draw the change curves between $\Gamma$ and $a$, and $\Gamma$ and Figure 3.

![Figure 3](attachment:image3.png)

The Relation Curves Between $\Gamma$ and $a$ in Different $d$
3. VALIDATION OF THEORETICAL MODEL

In order to validate the prediction model of crack initiation given in this paper is correct, the fracturing well which has been completed in Daqing oilfield is selected to predict. Then evaluate whether the initiation model is accurate by comparing the field construction data.

In the block, the minimum horizontal principal stress is $\sigma_h = 43.76$ MPa, the maximum horizontal principal stress is $\sigma_H = 48$ MPa, the direction of maximum horizontal geostress is $117^\circ$, the vertical principal stress is $\sigma_v = 55$ MPa, the pore pressure is $P_p = 19.1$ MPa, the Boit coefficient is $\alpha = 0.81$ and the tensile strength is $S_t = 3.5$ MPa. Take X well as an example. The dip of crack is $70^\circ$ which is consistent with the direction of maximum horizontal stress and the internal friction coefficient of crack plane is $\mu_w = 0.23$.

It can be obtained by calculating that the crack pressure of vertical artificial cracks along the shear direction of natural fracture is $P_{\tau f} = 63.51$ MPa and the crack pressure of horizontal artificial cracks along the opening direction of natural fracture is $P_{t f} = 45.61$ MPa. So the X well is opening initiation along the natural fracture and its crack pressure $P_f$ is 45.61 MPa.

Figure 4
The Relation Curves Between $\Gamma$ and $d/a$ in Different $a$

As can be seen from Figure 3 and Figure 4, for fixed size cracks, the integrating factor decreases with the increasing of the crack spacing and for fixed crack spacing, the integrating factor increases with the increasing of the crack size. Besides, for the same $d/a$, the larger the size of crack is, the more easily crack extends. Therefore, it can be concluded that the greater the size of single crack is and the smaller the gap between cracks is, the more easily cracks gather into a seam.

Figure 5
The Fracturing Construction Materials of X Well. Red Ordinate Represents the Pressure, Mpa. Blue Ordinate Represents the Displacement, m$^3$/min; Yellow Ordinate Represents the CO$_2$ DISplacement, m$^3$/min; Green Ordinate Represents the Crosslinking Agent Displacement, m$^3$/min; Pink Ordinate Represents the Density of Sand, kg/m$^3$.

Figure 5 is the fracturing construction materials of X well. It can be seen that the crack pressure is 45.5 MPa in the hydraulic fracturing operation which is very close to the predicted pressure. Therefore, the prediction model of crack initiation built is feasible.

CONCLUSION

(a) Two ways of crack initiation of artificial fracture in fractured reservoir are given, which are shear initiation along the natural fracture and opening initiation along the natural fracture. Also, the corresponding calculation models of crack pressure are presented.

(b) It can be concluded that the greater the size of single crack is and the smaller the gap between cracks is, the more easily cracks gather into a seam.

(c) The feasibility of prediction models of crack initiation of fractured reservoir are validated by field application.
REFERENCES


