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SIMULATION STUDY ON HORIZONTAL WELLS OF FRACTURING IN TIGHT OIL RESERVOIRS

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ABSTRACT

Tight reservoir has poor porosity and permeability, so it is necessary to use volume fracturing in horizontal wells to increase seepage area and communicate natural fractures, so as to realize high efficiency production. In order to comprehensively analyze influence factors of fracture network, and provide scientific geological model for the next production forecast, the method system of key parameters of natural fracture and fracture network is established, design the simulation model, which including the formation of the geological model, natural fracture simulation and fracture network simulation integrated software the 3 part, analyzes the influence of brittleness coefficient, horizontal stress difference, natural fracture, net pressure changes caused by fracturing fluid displacement and fracturing fluid volume parameters on fracture network size and communication. In depth analysis of these factors can provide reference for the field.

Keywords: Tight oil; volume fracturing; fracture; fractures simulation.

I. INTRODUCTION

A common method for the efficient development of tight oil reservoirs is horizontal well multi-stage fracturing, it can increase the contact space with the reservoir and expand the fluid-flow area . Due to the high content of brittle rocks, small rock particles and low porosity in tight reservoirs, natural fractures are generally developed under the same stress conditions. While the hydraulic fracturing expands the interface with the reservoir, it also communicates with natural fractures to obtain more fluid-flow channels. Therefore, the structure and key parameters of the horizontal- well fracturing network are closely related to the natural fractures, and the natural fractures' fluid-flow channels also play an important role in the production calculation and analysis.

Based on the above related research, predicting the natural fractures in the whole region, simulating the fracture network for single horizontal well hydraulic fracturing, forming an integrated software, thereby the Research of fracture network simulation on the basis of predecessor's work has a strong practical significance. Considering the horizontal well's fracture network in the tight reservoir is the results of mechanical response based on the natural fracture distribution, this paper designs a set of algorithms to simulate the distribution of the fracture network under multi-factors and evaluate the connection effect, which provides geological basis and analysis method for the tight resorvoir's production prediction.

II. NATURAL FRACTURE SIMULATION

Natural fractures are affected by various factors such as structure, stress, thickness, lithology, pressure, temperature, etc. There are many uncertainties in the simulation and parameter calculation, and there is no uniform method for the description and calculation of natural fractures. Therefore, in this paper, the empirical formula method is used to calculate the fracture parameters, and the random discrete fracture method is used to simulate the natural fracture network.

The relationship between fracture spacing and reservoir thickness, brittleness coefficient and formation depth is:

$$D_0 = 0.02h + \frac{H}{1000B_{RIT-T}} \quad (1)$$

$$b = 2\ln D_0 + 5 \quad (2)$$

D_0: crack spacing, m; h: single layer thickness of sandstone, m; B_{RIT-T} : brittleness coefficient; H: formation depth, m; b: crack opening, μm.

According to the calculation method for natural- fracture parameters proposed by E.M. Cemexoba et al. in 1969:

$$D_{lf} = \frac{1}{D_0} \quad (3)$$

$$K_f = CD_{lf}b^3 \times 10^{-12} \quad (4)$$

$$\phi_f = \frac{K_f}{8.5\times10^{-4}b^2} \quad (5)$$

D_{lf} : fracuture density, 1/m ; K_f : natural fracture's permeability, D ; C : proportion coefficient, 1.71×10^6 ; φ_f : natural fracture's porosity, %。

In the simulation, the natural fractures need to be randomly distributed in the reservoir. The method of the fracture sheet in the discrete fracture network model is adopted. The height of the fracture is the thickness of the reservoir. Monte-Carlo simulation method is adopted for the fracture location. The fracture parameters are calculated based on the calculated values. The natural fractures are simulated based on Exponential distribution [8].

III. HYDRAULIC FRACUTRE NETWORK SIMULATION

The hyraulic fracture network simulation includes three parts: the calculation of the fracture's key parameters, the calculation of the fracuture's extension parameters, and the simulation of the fracture network.

2.1 Calculation of fracture key parameters

The model used for the length of the hydraulic fracture network is mostly a numerical model. For the sake of computational convenience, in the simulation of a single-cluster fracture, the first assumption is still to propagate along the single-wing fracture, and the branch fracture is considered on the basis of total length, thereby selecting a simplified PKN. Model [9], the key parameters are calculated as follows:

$$L = 0.73[\frac{GQ^3}{(1-\upsilon)\mu h^3}]^{\frac{1}{5}} t^{\frac{4}{5}} \quad (6)$$

$$G = \frac{E}{2(1+\nu)} \quad (7)$$

$$w_{max} = 1.49(\frac{(1-\upsilon)Q^2\mu}{Gh})^{\frac{1}{5}} t^{\frac{1}{5}} \quad (8)$$

$$w = \frac{\pi}{4} w_{max} \quad (9)$$

L: imaginary fracuture half length, m; w_{max}: maximum fracture width, m; w: average hydraulic fracture width, m; Q: fracturing fluid displacement, m3/min; G: shear modulus , Pa; E: elastic modulus, Pa; v: Poisson's ratio; μ: viscosity of fracturing fluid, mPa.s; t: fracturing time, min;

After the proppant is added, the propped fracture width and the fracture conductivity [10] are:

$$w_z = \frac{V_s}{2Lh} \quad (10)$$

$$k_{f1} = 54\times10^6 w_z^{\ 2} \quad (11)$$

$$k_{f2} = k_{f1}w_z / d \quad (12)$$

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$$F = k_{f2} w_z \qquad (13)$$

Wz: propped fracture width, cm; Vs: the volume of the proppant pack, m^3; d: cluster space, m; K_{f1}: reservoir permeability, D; K_{f2}: fracture permeability, D; F: conductivity, D.cm;

2.2 fracture propagation parameter calculation

Fracture propagation is affected by brittleness coefficient, horizontal stress difference, natural fractures and fracture net pressure [11-18]. The designed algorithm is as follows.

2.2.1 Fracture initiation point confirmation

(1) Influence of brittleness coefficient

After experimental studies, when the reservoir brittleness coefficient is greater than 40, the hydraulic fracturing is easy to produce branches . Therefore, when the fracture network is simulated, multi-branch fractures can be realized by setting imaginary natural fractures. When the brittleness coefficient is greater than 40, the fracture randomly encounters an imaginary fracture within the length $L_{Rt} = \frac{40}{B_{RIT-T}} \times l$, thereby opening the imaginary fracture and creating a branch fracture.

(2) Influence of horizontal stress difference

Hozizontal stress difference is defined:

$$k_h = \frac{\sigma_H - \sigma_h}{\sigma_h}$$

σ_H: The maximum horizontal principal stress, MPa; σ_h :the minimum horizontal principal stress, MPa; k_h: the horizontal stress difference coefficient, non-dimensional.

In the study of paper[11], when the horizontal stress difference coefficient is less than 0.5, the branch fractures are easily generated. Therefore, in the simulation of fracturing, fractures are assumed to have natural fractures at random locations within $L_{Rk} = \frac{k_h}{0.2} \times l$.

Both the brittleness coefficient and the horizontal stress difference coefficient have a controlling effect on the branch fractures. Using the harmonic average method to determine the location and length of the imaginary cracks randomly, the fracture initiation point is:

$$L_R = \frac{2 L_{Rt} L_{Rk}}{L_{Rt} + L_{Rk}} \qquad (15)$$

(3) The effect of net pressure on the fracture network model

The net pressure is the difference between the fluid pressure in the fracture and the vertical stress acting on the fracture surface. The greater the net pressure, the easier the natural fractures will be opened, and the more likely the hydraulic fracture will extend to other directions, the easier it will form a complex fracture network [21].

The net pressure is calculated as:

$$p_r = p_w - p_{pf} - \Delta p_f - p_c \qquad (16)$$

$$p_w = p_t + \rho_{fl} g H - \Delta p_1 \qquad (17)$$

$$P_{pf} = \frac{223.26 Q^2 \rho_{fl}}{n^2 d^4 C^2} \qquad (18)$$

$$\Delta p_f = 0.167 \times 80.85^{n_l} \times L_f K_l w_z^{-2n_l - 1} \left(\frac{q_f}{h} \right)^{n_l} \qquad (19)$$

$$p_c = \sigma_h \qquad (20)$$

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Pr: net pressure, MPa; Pw: bottomhole pressure, MPa; Pt: wellhead treatment pressure, MPa; ρfl: fracturing fluid density, kg/m^3; g: constant of gravity acceleration; Δp_1: wellbore friction, MPa; Ppf: perforation friction, MPa; n: is the number of perforation holes, no dimension; d: perforation hole diameter, mm; C: flow coefficient, no dimension; Δ_{pf}: pressure drop in the fracture, MPa; L_f: length of fracture, m ; K_l: power law liquid flow consistency coefficient, Pa.s^n; qf: single wing flow rate, m^3/s; n_1: fracturing fluid flow index, no dimension; Pc: fracture closure pressure, MPa.

The initiation point under the influence of the brittleness coefficient and horizontal stress difference was corrected, and the formula for calculating the fracture initiation point considering the net pressure was obtained:

$$L_{RZ}=\frac{L_R(\sigma_H-\sigma_h)}{p_r} \qquad (21)$$

2.2.2 Hydraulic fracture length

Main fracture half length：

$$L_Z = BL \qquad (23)$$

L_Z：main fracture half length, m

The ratio of the main fracture length:

$$B=\frac{\beta_1}{l/L_{RZ}+1} \qquad (22)$$

β_1:coefficient, 2 ; l : the maximum branch fracture length, m（100）。 :

$$L_Z = BL \qquad (23)$$

L_Z：main fracture length, m

2.3 fracture network simulation

According to the horizontal well fracturing design, for one stage hydraulic fracturing, the injection rate is divided according to the number of perforation clusters, followed by the simulation of fracture propagation for a single cluster, and then each cluster and each stage are gradually simulated, and the single cluster fracture network simulation has the following steps:

1) The fracture starts from the perforation point and is perpendicular to the wellbore direction. It gradually expands with the injection of the fracturing fluid. When the natural fracture is encountered, the direction of the extension is determined by the angle θ between the hydraulic fracture and the natural fracture:

① If θ is between 30° and 150°, the fracture extends along both sides of the natural fracture, and the entire natural fractures are opened;

②If θ is less than 30° or greater than 150°, the fracture extends only along the direction away from the wellbore, and a part of natural fractures are opened;

③When the fracturing fluid propagate to the natural fracture's tip, the fracture will continue to extend in the direction of the maximum horizontal stress, forming new fractures.

2) If no natural fractures are encountered within a certain length, calculate according to the following steps:

①When the fracture extends along the direction of the maximum horizontal stress, first calculate L_R;

②Determine if there are natural fractures in the brach fracture networks. If so, the fracture extends according to the natural fractures extending principle; If no natural fractures, branch fractures are opened in the direction of the main fracture.

③Branch fractures extend to both sides of the main fracture, the extending distance is $L_{RZ}/8$, initiating in the direction vertical to the brach fracture to change the extention path.

3) Following the above rules, until the total length of the fractures in the reservoir is equal to the length of the calculated hydraulic fractures, the fracture will stop extending and eventually form the complex fracture networks.

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IV. QUANTITATIVE ANALYSIS OF FACTORS AFFECTING THE FRACTURE NETWORKS

Based on the simulations of the natural fractures and artificial fractures described above, the half-length and the communication effects of the fractures were analyzed.

3.1 half length of fracture networks

Using the single factor analysis method, under the same conditions of other parameters, simulating and analyzing the effects of some factors on the fracture networks' half length, include: brittleness coefficient, horizontal stress difference, natural fracture density, injection rate, and fracturing fluid volume.

(1) The influence of rock brittleness coefficient on the fracture networks' half length

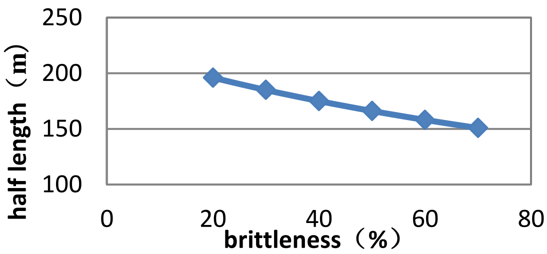

Fig1. Influence of brittleness coefficient on net half length

As shown in Fig. 1, the greater the brittleness coefficient, the easier it is to form complex networks, the better the fractures are connected around the wellbore, the smaller the half-length of the fracture networks.

(2) The influence of horizontal stress difference on the fracture networks' half length

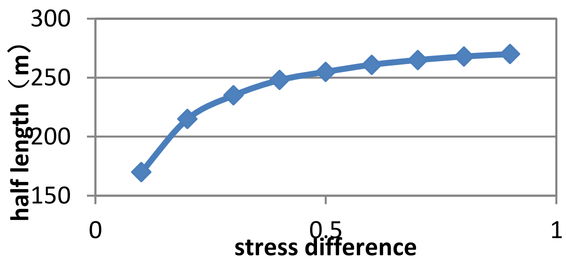

Fig2. Influence of stress difference on net half length

As shown in Figure 2, the greater the horizontal stress difference is, the larger the half length is, when the difference is higher than 0.5, the curve tends to be gentle. This is because when the horizontal sress is high, the fracture tends to extend directly through natural fractures.

(3) The influence of natural fractures' density on the fracture networks' half length

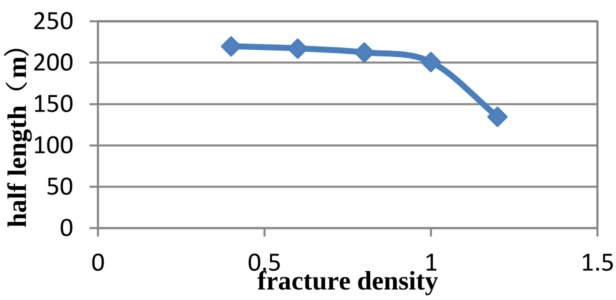

Fig3. Influence of fracture density on net half length

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As shown in Figure 3, the larger the natural fractures' density is, the shorter the half length is; when the density is less than 1, the half length keeps almost the same, when the density is larger than 1, the length decrease rapidly. This is because when the density is large, the fractures near the wellbore are easily connected.

(4) The influence of fluid displacement on the fracture networks' half length

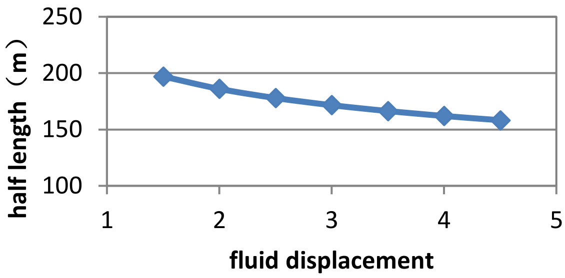

Fig4. Influence of fluid displacement on net half length

As shown in figure 4, when the fluid volume keeps the same, the higher the injection rate, the width of the fracture increase, the shorter the length is. As the injection rate increase, the amplitude of variation decrease.

(5) The influence of fracturing fluid volume on the fracture networks' half length

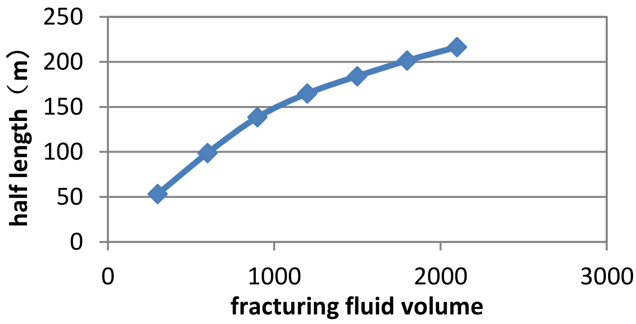

Fig5. Influence of fracturing fluid volume on net half length

As shown in figure 5, when the injection rate keeps the same, the larger the fluid volume, the longer the length is. As the fracturing fluid volume increase, the amplitude of variation keeps the same.

3.2 Communication effect evaluation

While hydraulic fracturing connects the wellbore and the formation, it also increase the contact between the wellbore and the natural fractures, therefore, the communication effect evaluation is performed by using two indicators: the degree of communicating the natural fractures and the increased stimulated volume percentage of the reservoir. Univariate analysis is also used.

(1) Brittleness coefficient

Make sure that the volume of the pre-fracturing reservoir is consistent , the brittleness coefficient is used to study the communication effect. The simulation result is shown in Figure 6.

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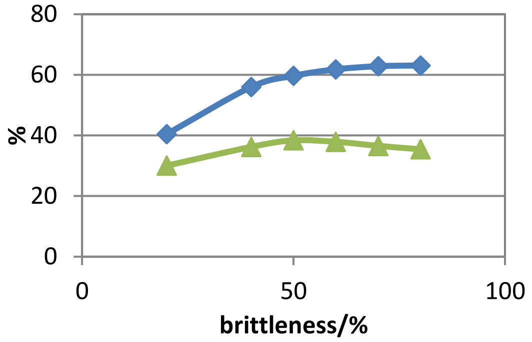

Fig6. Influence of brittleness coefficient on communication effect

The greater the brittleness coefficient is, the greater the natural fractures's communication degree is, it is more likely to from complex fractures; but when the brittleness increases, the half length decreases, which is beneficial to the fractures' communication around the wellbore area, but it is not good to the fracture extension. . There is an optimal value for horizontal and vertical coordination, resulting in a maximum increased stimulated volume percentage of reservoir.

(2) Horizontal stress difference

Make sure that the volume of the pre-fracturing reservoir is consistent, simulating the effects of horizontal stress on the fracture network.

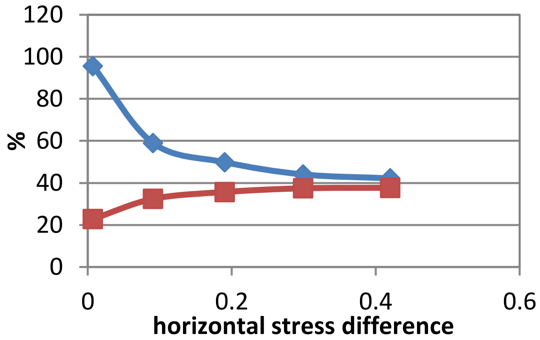

Fig7. Influence of horizontal stress difference on communication effect

As shown in Figure 7, the greater horizontal stress difference, the smaller the main fracture length; the smaller the number of natural fractures, the smaller the degree of communication. The larger stimulated reservoir is due to the greater horizontal horizontal stress difference, so more natural fractures are opened.

(3) Net pressure

The other parameters are unchanged, and the net pressure is changed to simulate the fracture network.

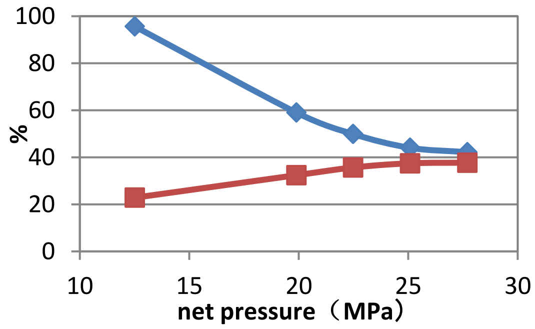

Fig8. The effect of net pressure on communication effect

As shown in Fig. 8 ,the greater the net pressure, the smaller the half length of the main fracture, the smaller number of natural fractures in the fracture network area, the smaller the degree of natural fractures'

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communication ; the greater the net pressure, the more natural fractures are communicated and the more reservoir volume is stimulate. The magnitude of the change between the two is getting smaller and smaller, tending towards a fixed value.

(4) The volume of fracturing fluid

Other parameters remain unchanged, and the amount of fracturing fluid is changed. The simulation results are shown in Figure 9.

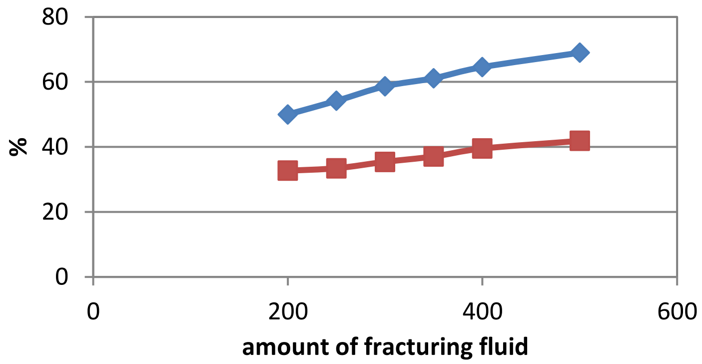

Fig.9 Influence of the amount of fracturing fluid on communication effect

The greater the amount of fracturing fluid, the greater the length of the main fracture is, more natural fractures are communicated in the network area, resulting in the greater the stimulated volume of reservoir .

V. CONCLUSION

1) The tight reservoir fracture network is affected by natural fractures, brittleness coefficient, horizontal stress difference, and net pressure. The factors considered in the fracture network simulation are more comprehensive.
2) The natural fracture simulation is based on the regional geological model, followed by the well deployment and hydraulic fracturing, the integration is more prominent.
3) The fracture network simulation can be used not only for the calculation of fracture network parameters, fracture network simulation, hydraulic fracturing design, production prediction, but also for hydraulic fracturing effect evaluation, natural fracture prediction, and fracture network prediction and corrections, etc.

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