Research on Exploration System of Petroleum Geological Development Based on Oilfield Fracturing Technology

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Abstract. Oil and gas energy is one of the necessary energy sources for social development. In the process of oil development and exploration, hydraulic fracturing technology plays a vital role. Hydraulic fracturing technology can not only stabilize the production of conventional oil and gas fields, realize the development of low-permeability oil and gas reservoirs, help the development and adjustment of old oil fields, but also increase the development production of special oil reservoirs and tap the potential of oil and gas fields. In this paper, an electrical simulation experiment method for the productivity of horizontal well staged fracturing is studied. Firstly, according to the actual formation conditions after staged fracturing of horizontal wells, a set of three-dimensional electric field simulation device is simulated and developed; According to the wellbore trajectory, formation permeability and formation thickness, etc., the electrolyte and electrolytic cell size for electrical simulation are set. Finally, the current signal is collected to determine the size of the production capacity. Using this experimental method, we carried out the optimization simulation of horizontal well fracturing fracture shape and location, optimization simulation of fracture number and spacing, and comparison of different formation thicknesses for a fluvial facies sedimentary sand body. This electrical simulation experiment method can accurately simulate the influence of various parameters of horizontal well fracturing and completion on productivity, and has certain guiding significance for the design of horizontal well fracturing and completion.

Keywords: Oilfield fracturing technology; petroleum geology; petroleum development; exploration system

1. Introduction

The development of society and economy is inseparable from the development and use of energy. With the rapid development of society and economy, people's production and life are increasingly dependent on oil and gas. Therefore, only by strengthening the exploration and development of oil and gas fields, improving the development efficiency of oil and gas fields and the production of oil and gas fields, can people's increasingly strong demand for oil and gas be met. In the exploration and development of oil and gas fields, hydraulic fracturing technology plays a vital role and has become one of the important supporting technologies for oil and gas field exploration [1]. At present, most of the exploration and production of oil and gas fields in China are using this technology, which ensures the recovery efficiency of oil and gas fields and improves the economic benefits of oil production. With the gradual maturity of hydraulic fracturing technology, this technology can also meet the exploration and development of oil and gas reservoirs of different types of oil and gas fields. In terms of technical research, China has no obvious disadvantage compared with foreign companies in terms of fracturing materials and field construction. Proppants, low-damage fracturing fluids, additives and other fracturing materials have formed integrated fracturing, large-scale fracturing, high-sand ratio fracturing, re-fracturing, carbon dioxide fracturing, horizontal well fracturing and other supporting processes. A complete set of ideas has been formed with the supporting aspects of exploration and development. Therefore, hydraulic fracturing plays a crucial role in oil and gas exploration and development.

2. Theoretical basis for productivity calculation of fracturing horizontal wells

2.1 Potential theory and superposition principle of potential

In the plane seepage field, the potential function $\phi(x, y)$ and the flow function $\psi(x, y)$ satisfy the Laplace equation and the Cauchy-Riemann condition, respectively. They are harmonic functions, and the curves represented by them are orthogonal to each other [2]. Therefore, a new analytic function can be constructed by using the potential

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function and the flow function as the real and imaginary parts of the complex variable function, respectively.

$$W(z)=\phi(x,y)+i\psi(x,y) \tag{1}$$

In this way, the plane seepage field is related to the analytic function. In seepage mechanics, the analytic function formed by the potential function as the real part of the complex function and the rheological function as the imaginary part is called the complex potential function of the plane seepage field, or complex potential for short [3]. According to the complex potential, the seepage velocity at any point in the plane seepage field can be obtained.

$$dW=d\phi+id\psi=\frac{\partial\phi}{\partial x}dx+\frac{\partial\phi}{\partial y}dy+i[\frac{\partial\psi}{\partial x}dx+\frac{\partial\psi}{\partial y}dy]=(\frac{\partial\phi}{\partial x}+i\frac{\nabla\psi}{\partial x})dx+(\frac{\partial\phi}{\partial x}+i\frac{\partial\psi}{\partial y})dy \tag{2}$$

Considering the Cauchy-Riemann condition, the above equation can be written as:

$$dW=(\frac{\partial\phi}{\partial x}-i\frac{\partial\phi}{\partial y})dx+i(\frac{\partial\phi}{\partial x}-i\frac{\partial\varphi}{\partial y})dy=(\frac{\partial\phi}{\partial x}-i\frac{\partial\phi}{\partial y})(dx+idy)=(-v_x+iv_y)dz \tag{3}$$

But:

$$\frac{dW}{dz}=-v_x+iv_y$$
$$\left|\frac{dW}{dz}\right|=\sqrt{v_x^2+v_y^2}=|\overline{v}| \tag{4}$$

Because the modulus of $\frac{dW}{dz}$ represents the magnitude of the velocity value, $\frac{dW}{dz}$ is called the complex velocity. Therefore, knowing the complex potential of the plane seepage field, the complex velocity can be obtained by deriving it, and then the seepage velocity at any point in the plane seepage field can be obtained [4]. If there are two-point sinks in the plane seepage field at the same time, the complex potentials of these two-point sinks when they exist alone are:

$$W_1(z)=\phi_1+i\psi_1$$
$$W_2(z)=\phi_2+i\psi_2 \tag{5}$$

Since the potential functions and flow functions ϕ1 and ψ1 and ϕ2 and ψ2 are both conjugate harmonic functions, they all satisfy the homogeneous linear equation-Laplace equation and the Cauchy-Riemann condition, so they can be superimposed to form A new recovery. The new complex potential and the corresponding potential and flow functions still satisfy the Laplace equation and the Cauchy-Riemann condition.

$$W=W_1+W_2=(\phi_1+i\psi_1)+(\phi_2+i\psi_2)=(\phi_1+\phi_2)+i(\psi_1+\psi_2)=\phi+i\psi \tag{6}$$

In:

$$\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}=0$$
$$\frac{\partial^2\psi}{\partial x^2}+\frac{\partial^2\psi}{\partial y^2}=0 \tag{7}$$

This new potential is the complex potential of the plane seepage field with two-point sinks at the same time. It can be seen that, as long as the complex potentials when each point sink exists alone are simply added algebraically, the complex potential when each point sink exists at the same time can be obtained. This is called the superposition principle of the complex potential of the plane seepage field.

2.2 Equivalent seepage resistance method

When multiple wells work at the same time, the exact solution is more complicated. In order to simplify the problem and have sufficient accuracy, the similarity between liquid flow and current is often used in engineering, and the circuit diagram is used to describe the seepage process, and then follow the Kirchhoff circuit [5]. This method is called the equivalent seepage resistance method. There is a straight supply edge, a row of wells is arranged parallel to the edge, the well spacing is 2a, the bottom hole pressure is the same as Pw, and the number of wells is n, as shown in the figure. According to the complex potential theory, the exact solution of this problem can be obtained, and the single well production is:

$$Q=\frac{2\pi Kh(P_e-P_w)}{\mu[\frac{\pi L}{\alpha}+ln\frac{\alpha}{\pi R_w}]} \tag{8}$$

The total production of the full well row is:

$$\sum Q=Q*n=\frac{P_e-P_w}{\frac{v}{BKh}L+\frac{1}{n}\frac{\mu}{2\pi Kh}ln\frac{\alpha}{\pi R_w}} \tag{9}$$

It can be seen from the above formula that the denominators in the formula represent the seepage resistance. The first term of the denominator is equivalent to the resistance of the liquid flow through the cross-sectional area Bh and the distance L, which is the one-way seepage resistance. It is equivalent to the seepage resistance from the supply edge to an imaginary drainage tunnel at the well row, which is called external seepage resistance, expressed by Rou. The relationship between seepage resistance, pressure difference and production can be expressed as:

$$Q=\frac{P_e-P_w}{R_{ou}+R_{in}} \tag{10}$$

In this way, the actual seepage flow can be regarded as a combination of two simple seepage flows, one is a unidirectional flow from the supply edge to the imaginary drainage channel at the well discharge, and the other is a flow from the imaginary supply edge around each well to each well Planar radial flow at the bottom of the well, and the pressures at the imaginary drain and the imaginary circular supply edge are considered equal. From electricity we know:

$$I=\frac{U_1-U_2}{R_1+R_2} \tag{11}$$

Comparing the two formulas, it can be seen that they are similar: the flow rate of seepage corresponds to the current intensity, the pressure difference in seepage flow corresponds to the potential difference, and the seepage resistance corresponds to the resistance. Therefore, the percolation process can be represented and solved by a simple circuit diagram.

2.3 Typical solutions of the mathematical model of elastically unstable seepage in infinite formations

In a large oilfield, due to the small number of wells in the early stage of development, the oilfield boundary and inter-well interference can be ignored for the time being, so that any well can be regarded as the situation of only one well in an infinite formation [6]. If the formation is homogeneous, equal thickness, and level, and there is no external energy supply, the liquid seepage to the well is a complete plane radial flow. At this time, the liquid seepage obeys the mathematical model of single-phase micro-compressible unstable seepage in elastic porous media. for a two-dimensional problem. The equation is:

$$\frac{\partial^2 P}{\partial x^2}+\frac{\partial^2 P}{\partial y^2}=\frac{1}{\eta}\frac{\partial P}{\partial t} \tag{12}$$

Since it is a radial flow on a plane of symmetry, it is more convenient to express it in polar coordinates:

$$\frac{\partial^2 P}{\partial \mathrm{r}^2}+\frac{1}{r}\frac{\partial P}{\partial r}=\frac{1}{\eta}\frac{\partial P}{\partial t} \tag{13}$$

With the following boundary conditions:

$$\begin{aligned} &P\big|_{t=0}=P_i(0\le r\le\infty)\\ &P\big|_{r\to\infty}=P_i(t>0)\\ &(r\frac{\partial P}{\partial r})_{r=R_w}=\frac{Q\mu}{2\pi Kh}(t>0) \end{aligned} \tag{14}$$

It can be solved by separation of variables method, integral transformation method, etc. It can also be solved by Boltzmann transform. Finally, the pressure value at any point in the formation from the well point r at any time t can be obtained:

$$\begin{aligned} &P(r,t)=P_i-\frac{Q\mu}{4\pi Kh}[-E_i(-\frac{r^2}{4\eta t})]\\ &Among\ them:-E_i(-\frac{r^2}{4\eta t})=-E_i(-y)=\int_{\frac{r^2}{4\eta t}}^{0}\frac{e^{-y}}{y}dy \end{aligned} \tag{15}$$

From this formula, it can be seen that a certain value of y corresponds to a certain ratio of r to t. When r is small, t should also be small, and vice versa. This shows that the pressure drop is only formed in a certain range at a certain time; when the oil well is put into production for a short time, the pressure drop is only formed in a small range, and the pressure drop range is gradually expanded with the increase of the production time of the oil well [7]. This conclusion is consistent with the conclusion of the first stage of stress transmission. Therefore, in practice, the solution of infinite formation is often used to solve the problem of unstable early seepage. Actual oil reservoirs work with multiple wells at the same time, and there are often various boundaries. The superposition principle and mirror reaction method can also be used to solve these problems when the elastic instability is the same.

3. Working system layout

The 3D electric field simulation experimental device for horizontal well mining mainly includes an experimental liquid tank system, a positioning system, an electrical signal measurement system, and a data recording and processing system. The devices contained in each system include: rectangular electrolytic cells (1.5 m long, 0.75 m wide, and 0.5 m high). The electrical signal measuring device has a voltage measurement accuracy of 0.005 V and a current measurement accuracy of 0.005 A. Lead screw positioning and displacement sensor system with a positioning measurement accuracy of 1 mm. DC regulated power supply. circulation pump. Waste treatment tank. Data acquisition and processing system. 152.4 mm aluminum-plastic pipe and pipe valve parts constitute a wellbore simulation device. A crack simulation device composed of 20-mesh copper mesh sheets [8]. Figure 1 is a top view of a rectangular electrolytic cell (image cited in Improving the Efficiency of PEM Electrolyzes through Membrane-Specific Pressure Optimization). According to the experimental needs, the device has the following characteristics: the side of the electrolytic cell is made of plexiglass, which is transparent. It has good plasticity and will not deform when filled with liquid. It has a certain strength and is not easily broken by occasionally being hit by hard objects. There is no seal on the top of the electrolytic cell, but the sides and corners are safely treated. Inside the electrolytic cell, a ruler for measuring the liquid level is installed diagonally in the longitudinal direction with an accuracy of 1 mm.

The electrolytic cell is equipped with slide rails and fixing devices for installing wellbore simulation, which can be locked at any position. Conductive meshes are installed on the two longitudinal sides of the rectangle in the electrolytic cell. The conductive mesh is made of conductive copper mesh with a small mesh to ensure a transparency of 30%. A circulating pump is connected to the outside of the electrolytic cell to facilitate the circulation of the liquid. The electrolytic cell and the lower cabinet are detachably fixed, which is convenient for equipment handling.

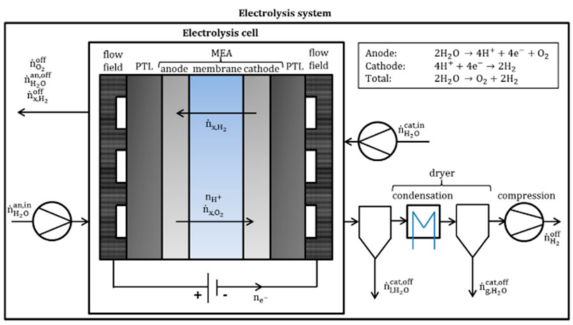

Figure 1. Electric field simulation electrolytic cell device structure

Figure 2 is the structure diagram of the electric field simulation positioning and data acquisition device (the picture is quoted from Improving the Efficiency of PEM Electrolyzes through Membrane-Specific Pressure Optimization). The design includes the following features: The positioning device is mainly used to position the measuring point probe, which can make the probe move in the electrolytic cell in three-dimensional space and record the position and voltage [9]. It can realize automatic operation and manual operation respectively, and there is a conversion mechanism for manual and automatic operation. The limit position is designed with a

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travel control switch, which plays the role of limit and protection. The positioning device is not in contact with the electrolytic cell as a whole, but its position fixing device precisely matches the position of the electrolytic cell. Has one test probe, but can be upgraded to 5 test probes.

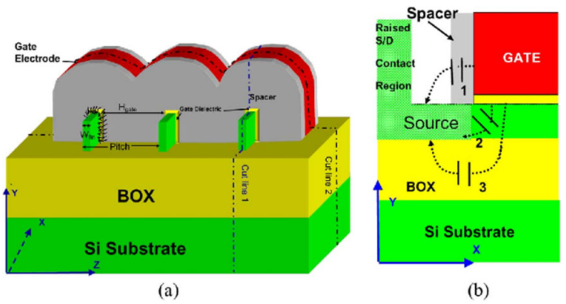

Figure 2. Structure of electric field simulation positioning and data acquisition device

4. Plot the horizontal well productivity and fracture number curve

According to the calculation method in Equation (1), the stress-weak development section of the horizontal well is calculated, and a new parameter Ktr is added to the comprehensive log diagram, and yellow fills are performed at the position higher than 0.85, which is used to identify the stress-weak section development position [10]. The well section with oil well value greater than 0.85 is longer, indicating that natural fractures are developed in the well. When designing the subsection, the sliding sleeve is placed in the weak stress section for concentrated transformation, and a total of 7 sliding sleeves are designed. According to the fracturing horizontal well parameters, the horizontal well production corresponding to the number of fractures is obtained and plotted in Figure 3 below (the picture is quoted from A Data-Driven Workflow Approach to Optimization of Fracture Spacing in Multi-Fractured Shale Oil Wells):

Table 1. Parameters of a fracturing horizontal well

Parameter name	Parameter value	Parameter name	Parameter value
Reservoir thickness (m)	11.9	Wellbore radius (m)	0.12
Formation permeability (mD)	7.5	Original formation pressure (MPa)	11.83
Horizontal section length (m)	555	Bottom hole pressure (MPa)	3
Number of cracks	4	Crude Viscosity (mP.s)	4.8
Crack half length (m)	75	Crude oil density (kg/m^3)	870
Crack width (mm)	5.8	Formation porosity	0.1
Fracture permeability (μm^2)	30	Compression factor (1/MPa)	0.00035
skin factor	0	Volume factor	1.084

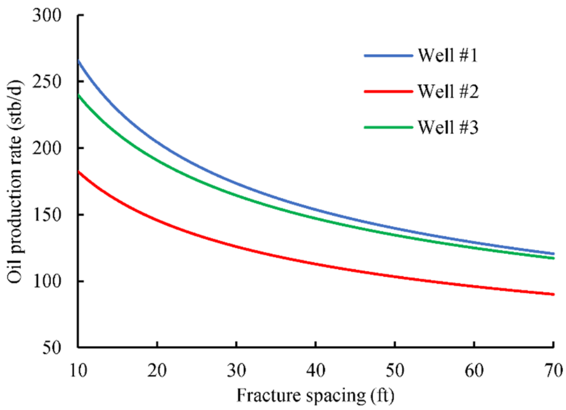

Figure 3. Relationship between fracture number and horizontal well production

It can be seen from the trend of the scatter diagram in Figure 3 that with the increase of the number of fractures, the production of horizontal wells also increases, so it can be concluded that the production of staged fracturing in most horizontal wells is greater than that of overall fracturing.

5. Conclusion

The horizontal well staged fracturing productivity electrical simulation experiment method can simulate the static pressure field and flow around the wellbore under different horizontal well completion methods. The electrical simulation device can be used to simulate the influence of different fracture numbers, fracture sizes, fracture shapes and fracture angles on the productivity of horizontal wells, and then optimize the relevant parameters. The electrical simulation device can simulate the influence of different formation thickness, permeability, micro-fracture development and heterogeneity on the productivity of horizontal well completion methods, which has certain guiding significance for the design of horizontal well completion and fracturing.

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