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The Influence of Stimulated Reservoir Volume in Dense Reservoir on the Fracturing Effect

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Abstract. Based on the finite element theory, the mathematical model of oil-water two-phase flow is established. Applying the mixed element finite element method to numerical simulation studies for complex artificial fracture which after volume fracturing of horizontal well in dense reservoir, using arbitrary triangle elements to describe the formation, line elements to describe the artificial fracture. For the convenience of simulation calculation, the fracture network is processed into two parts of the main fracture and the high permeability stimulated region. The bandwidth of stimulated region is determined by results of the micro seismic monitoring; the permeability is determined by single well history matching. Aiming at the problem of volume fracturing of horizontal well in dense reservoir, in the way of natural energy exploitation, with the single well as the research object, according to different calculation schemes to carry out stimulated reservoir volume(SRV) calculation, to study the influence of the SRV on fracturing effect. Research results show that under the condition of natural energy, when the fracture half-length is unchanged, with the increasing of the transformation segment number, the SRV increases, the cumulative oil production increased. However, the increasing of oil production is smaller gradually, so there is an optimal SRV. Under the given conditions, when the fracture half-length is 240m, horizontal well length is 600m, 800m and 1000m, 1200m, the optimal SRV respectively are $350\times10^4m^3$、$500\times10^4m^3$、$600\times10^4m^3$、$750\times10^4m^3$。

1. Introduction

As an important unconventional energy, dense reservoir has attracted much attention of many domestic and foreign oil workers. After 2000, with the large-scale industrial application of horizontal well fracturing technology, the exploration and exploitation of the Bakken reservoir won the breakthroughs, the use of new technologies such as volume fracturing enhanced recovery efficiency [1] of oil well more. Preliminary exploration and research prove that China's tight reservoirs have the good prospects, forecasting the geological resources of dense resources maybe up to $70\sim90\times10^8$t[2,3].In Yanchang formation of Ordos Basin, The proven geological reserves of petroleum in the tight reservoir whose air permeability is less than 1×10^3 μm^2 are more than 10×10^8t[4], the potential of exploration and exploitation is enormous. Therefore, it is of great significance to strengthen the research of the volume fracturing transformation in the dense reservoir to China dense reservoir resources.

At present, there are two main research methods for fracturing transformation: one is analytic method [5,6]; another is numerical simulation method. The difficulty of numerical simulation in volume fracturing modification is how to make a reasonable description of the complex fracture after transformation. In this paper, applying the hybrid finite element method to numerical simulation studies for complex artificial fracture which after volume fracturing of horizontal well in dense reservoir formation. The formation is divided into arbitrary triangular elements, the artificial fracture is divided into line elements. The time discretization using a stable backward differential format. Compared with the difference method which commonly used in numerical simulation, this method has obvious advantages that the artificial fracture description is more flexible and accurate, more in line with the actual. This method's reservoir numerical simulator compiled by the Fortran language can achieve the numerical simulation study that the transformation effect of tight reservoir volume fracturing.

2. The establishment of mathematical model

2.1. basic assumptions

(1) oil reservoir exists oil and water two phase fluid;
(2) fluid and rock can be compressed slightly;
(3) considering the influence of starting pressure gradient;
(4) considering the effect of capillary force;
(5) ignoring the effect of gravity.

2.2. seepage differential equation

Low velocity non-Darcy percolation law in low permeability reservoirs:

$$v=\begin{cases}-\dfrac{K}{\mu}\left(\dfrac{\partial p}{\partial r}-G\right) & \left|\dfrac{\partial p}{\partial r}\right|\geq G\\ 0 & \left|\dfrac{\partial p}{\partial r}\right|<G\end{cases}$$

The differential equation of oil and water two phase flow:

$$\nabla\cdot\left[\frac{\rho_o KK_{ro}}{\mu_o}\left(\nabla p_o-G_o\right)\right]+q_o=\frac{\partial\left(\varphi\rho_o S_o\right)}{\partial t} \tag{1}$$

$$\nabla\cdot\left[\frac{\rho_w KK_{rw}}{\mu_w}\left(\nabla p_w-G_w\right)\right]+q_w=\frac{\partial\left(\varphi\rho_w S_w\right)}{\partial t} \tag{2}$$

Among them, (1) equation for oil phase, (2) equation for water phase

2.3. Auxiliary equation and initial boundary value condition

Auxiliary equation:

$$
\begin{aligned}
&K_{\mathrm{ro}} = K_{\mathrm{ro}}(S_{\mathrm{w}}) \\
&K_{\mathrm{rw}} = K_{\mathrm{rw}}(S_{\mathrm{w}}) \\
&\phi = \phi(p_{\mathrm{o}}) \\
&p_{\mathrm{c}} = p_{\mathrm{c}}(S_{\mathrm{w}}) = p_{\mathrm{o}} - p_{\mathrm{w}} \\
&S_{\mathrm{o}} + S_{\mathrm{w}} = 1
\end{aligned}
$$

2.4. Derivation of finite element equation

Based on formula (1) and formula (2), the oil phase pressure equation and water phase saturation equation are obtained:

oil phase pressure equation:

$$\nabla \bullet \left[\frac{K \bullet K_{\mathrm{rw}}}{\mu_{\mathrm{w}}} (\nabla p_{\mathrm{o}} - \nabla p_{\mathrm{c}} - G_{\mathrm{w}}) \right] + \nabla \bullet \left[\frac{K \bullet K_{\mathrm{ro}}}{\mu_{\mathrm{o}}} (\nabla p_{\mathrm{o}} - G_{\mathrm{o}}) \right] = \phi C_{\mathrm{t}} \frac{\partial p}{\partial t}$$

water phase saturation equation:

$$\nabla \bullet \left(\frac{K \bullet K_{\mathrm{rw}}}{\mu_{\mathrm{w}}} \nabla p_{\mathrm{o}} - \frac{K \bullet K_{\mathrm{rw}}}{\mu_{\mathrm{w}}} \nabla p_{\mathrm{c}} - \frac{K \bullet K_{\mathrm{rw}}}{\mu_{\mathrm{w}}} G_{\mathrm{w}} \right) = \phi \frac{\partial S_{\mathrm{w}}}{\partial t}$$

In the formula ,

$$\nabla p_{\mathrm{c}}^{n+1}(S_{\mathrm{w}}) = \nabla \left(\frac{\partial p_{\mathrm{c}}}{\partial S_{\mathrm{w}}} S_{\mathrm{w}}^{n+1} \right) + \nabla p_{\mathrm{c}}^{n} - \nabla \left(\frac{\partial p_{\mathrm{c}}}{\partial S_{\mathrm{w}}} S_{\mathrm{w}}^{n} \right)$$

In it, n-1 representative last step, n representative this step.

In the finite element calculation, every fracture can't be regarded as a whole structural unit. In order to facilitate the different arrangement of fracture s and does not affect the division of finite element mesh, in this paper, we analyze the high efficiency diversion of the fracture s by using the hidden fracture line elements. The so-called hidden unit, is the fracture line unit hidden in the matrix unit. So, the matrix elements of the division and the fracture line unit at the same time, it must be the fracture line element stiffness added to the finite element whole stiffness.

The conversion formula of implicit fracture line element stiffness matrix onto the matrix unit for:

$$[N]^{\mathrm{T}}[K_e][N] = [K_{\mathrm{F}}]$$

Among it, $[K_{\mathrm{e}}]$——Stiffness matrix of the fracture line element in the whole coordinate system;

$[N]$ ——shape function matrix;

$[K_{\mathrm{F}}]$ ——matrix element stiffness matrix。

3. Example calculation

3.1. Description method of complex fracture system

To select a block of dense reservoir in Changqing Oilfield as an example and study the influence on the fracturing effect of the volume fracturing under the natural energy. The well area belongs to low porosity, extra low permeability and tight oil reservoir. The single horizontal well as the research object, its exploiting method are the exploitation of rely on natural energy; fracturing method for segmented multi cluster volume fracturing. After the volume fracturing, forming the complex fracture network, the permeability of the stimulated region improved. For the convenience of simulation calculation, the fracture network will be disposed into two parts that the main fracture and the high permeability stimulated region, as shown in Figure 1. Artificial fracture is described by line unit, the formation of fracture system after volume fracturing including the main fracture and the high permeability stimulated region, the main fracture half-length is 240m, when 2 clusters in the segment, the bandwidth of the stimulated region which according to the micro seismic monitoring results determine 60m, 3 clusters and 4 clusters are taken for 70m and 80m. The permeability of the stimulated region is determined by the single well history to be $3\times10^{-3}\mu m^2$.

3.2. Simulation area and mesh generation

The positions in the horizontal well fracturing take the way of uniform distribution, to 600m, 800m and 1000m, 1200m four horizontal segment length respectively, simulation calculate the influence of SRV on the fracturing effect under the condition of segment are cluster 2, cluster 3, cluster. 2 segments of 6 clusters of mesh generation is shown in Figure 2

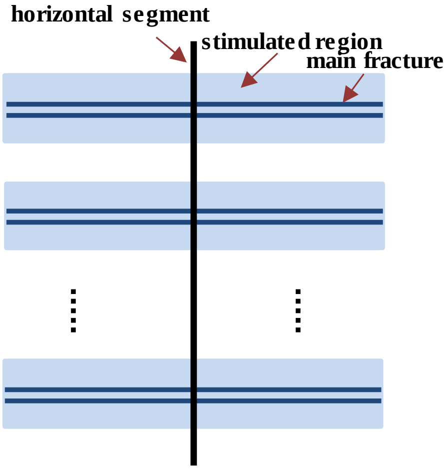


Fig. 1 Schematic diagram of simulation area

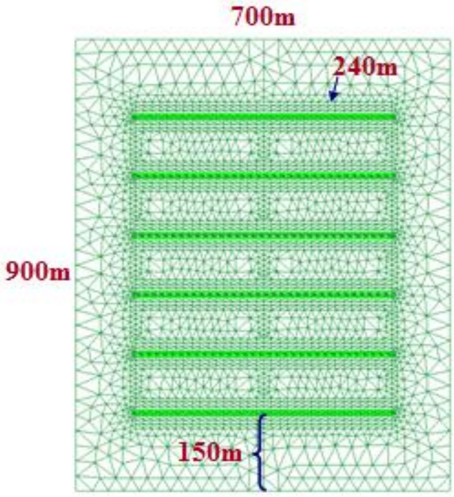


Fig. 2 2 segments of 6 clusters of mesh generation

3.3. Calculation parameters

The basic parameters used in the simulation calculation are shown in Table 1

Table 1 Basic calculation parameters table

Parameters	value	Parameters	value
Formation permeability （$10^{-3}\mu m^2$）	0.30	Original formation pressure (MPa)	14
Formation porosity (%)	11	Formation crude oil density （kg/m^3）	750
Formation crude oil viscosity （mPa·s）	1.5	Formation oil volume factor	1.2
Effective thickness of oil layer （m）	16	Bottom hole pressure of horizontal well (MPa)	6.5
Starting pressure gradient (MPa/m)	0.4	Simulated production time (y)	5

3.4. transformation volume calculation

Dense reservoir volume fracturing stimulated reservoir volume (SRV) calculation use the resulting product of the length, bandwidth each stimulated region of and the transformation of the area, and reservoir effective thickness of the product is the SRV. Formula for:

$$SRV = \sum_{i=1}^{n} W \times L \times h$$

Among it, W——bandwidth，m；

L——long，m；

h——reservoir effective thickness，m。

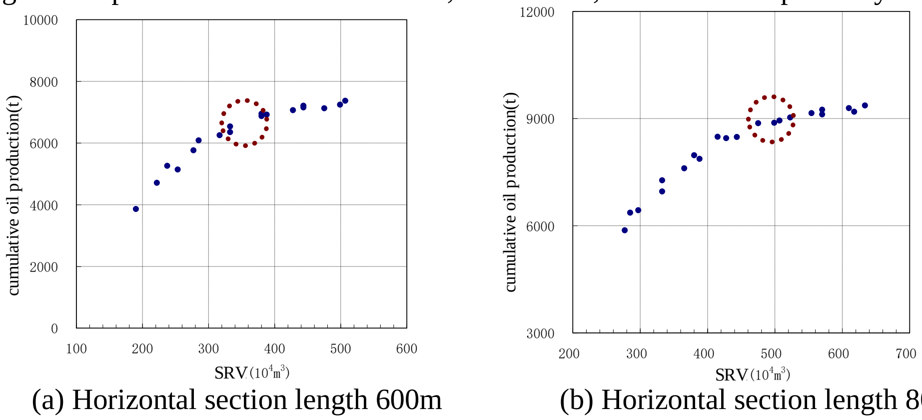
When the horizontal section length is 600m, were designed 18 schemes, in 2, 3 and 4 clusters, respectively 6 schemes be taken. Computational results that SRV of different schemes is shown in table 2.

Table 2 Transformation volume of different schemes

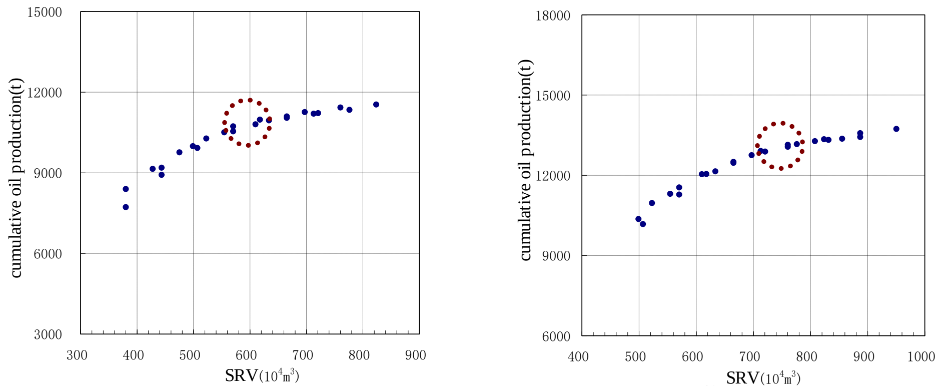
Schemes	Segments	Clusters	Cluster spacing(m)	Number of main fractures	Transformation volume（10^4m^3）
1	5	2	10	10	238
2	6	2	10	12	285
3	7	2	10	24	333
4	8	2	10	16	380
5	9	2	10	18	428
6	10	2	10	20	475
7	4	3	10	12	222
8	5	3	10	15	277
9	6	3	10	18	333
10	7	3	10	21	388
11	8	3	10	24	444
12	9	3	10	27	499
13	3	4	10	12	190
14	4	4	10	16	253
15	5	4	10	20	317
16	6	4	10	24	380
17	7	4	10	28	444
18	8	4	10	32	507

3.5. the influence of the transformation volume on the fracturing effect

According to the SRV of different calculation schemes and the calculation results of cumulative oil production, as shown in Fig. 3(a). Under the condition that the same fracture half-length, with the increase of the SRV, corresponding to the cumulative oil production is increasing, when the SRV bigger than $350\times10^4m^3$ around, with increase of the SRV, cumulative oil production increased slightly. Research shows that the horizontal section length is 600m, the fracture half-length is 240m, the optimal SRV is about $350\times10^4m^3$. Horizontal section length is 800m,1000m,1200m respectively, corresponding to the optimal SRV are $500\times10^4m^3$, $600\times10^4m^3$, $750\times10^4m^3$ respectively.



(a) Horizontal section length 600m (b) Horizontal section length 800m



(c) Horizontal section length 1000m (d) Horizontal section length 1200m

Fig. 3 Relationship between SRV and cumulative oil production

Figure 4 is the pressure distribution at different time during the period of 8 segments, the horizontal segment length is 600m, 2 clusters in the segment. From the figure can be seen, due to stimulated region permeability is 10 times to no transformation, so the stimulated region pressure consumes rapidly. When the pressure drops reached no stimulated region is due to the presence of high starting pressure gradient, area of low-pressure diffusion speed is very slow, no stimulated region pressure decreased slowly. Produced crude oil was mainly derived from the stimulated region, so when using the natural energy exploitation method, we can continue to increase fracture length of the stimulated region.

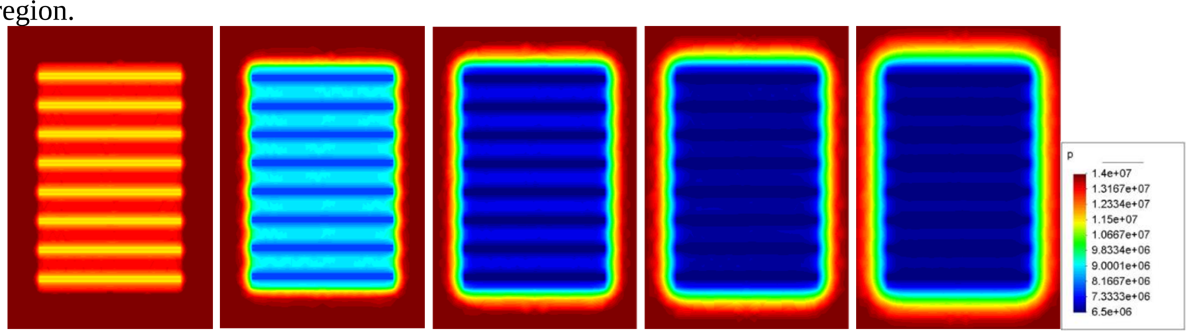


Fig.4 Pressure distribution of 2 clusters at different times in the segment

4. conclusions

1.Applying the basic principle of finite element method, establish finite element model considering the capillary force and starting pressure gradient. The Artificial fracture network divides into two parts: main fracture and high permeability stimulated region. This method can realize of the complex fracture network numerical simulation study in dense reservoir volume fracturing.

2.calculation methods are given for different SRV, according to different calculation schemes. the results of the SRV is given.

3. Under the condition of natural energy, when the fracture half-length is 240m and horizontal section length is 600m, optimal SRV is $350\times10^4m^3$. Horizontal section length is 800m, optimal SRV is $500\times10^4m^3$. Horizontal well length is 1000m, optimal SRV is $600\times10^4m^3$. Horizontal well length is 1200m, optimal SRV is $750\times10^4m^3$.

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