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Investigation on Percolation Theory and Optimization Method in Low Permeability Reservoir Injection-Production Pattern on the Condition of Fracturing

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Abstract

This passage investigates the productivity formulas in low permeability reservoir with vertical wells combined with fracturing well of the five spot rectangular pattern, seven spot pattern and nine spot pattern as well as the productivity of inverted nine-spot rhombus fractured vertical well mixed pattern. Further, the five-point rectangular patterns and the rectangular fracturing well patterns are optimized. The results reveal that widening well spacing, narrowing row spacing and changing the shape factor well network within a certain range can improve the development effectiveness, while length of the crack and area of well pattern are given, we could determine the length and width of rectangular pattern.

Key words: Low permeability; Well pattern; Productivity formula; Optimization

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INTRODUCTION

Due to low permeability and low natural deliverability of the low permeability reservoir, usually, the reservoir can be put into development by fracturing, so the study of low permeability reservoir pattern exploitation theory and considering the influence of starting pressure gradient and anisotropy are very important to the efficient development of low permeability reservoir. The study research the productivity formula in low permeability reservoir with vertical wells combined with fracturing well of the five point rectangular pattern, seven spot pattern, nine spot pattern, as well as the productivity of anti-nine rhombus fractured vertical well mixed pattern[1], by using the conformal transformation, Huiyuan reflection and superposition principle of seepage theory, and to which of the five-point rectangular pattern and the law rectangular fracturing well pattern optimization analysis.

1. THE PRODUCTIVITY FORMULA OF COMPOSITE WELL PATTERN

Newtonian fluid flows in the capillary flow of linear follow Darcy's law, while crude oil belongs to plastic fluid, namely, non-Newtonian fluids. According to rheology, when plastic fluid flows in the capillary, the relationship between shear stress and limiting shear stress, plastic viscosity, velocity gradient can be shown with Bingham formula[2].

1.1 Deliverability Calculation of Five-Spot Rectangular Pattern

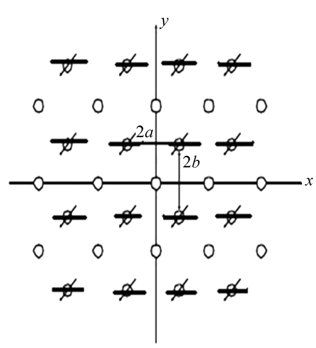

Figure 1
Fractured Vertical Well Mixed Well Network Diagram

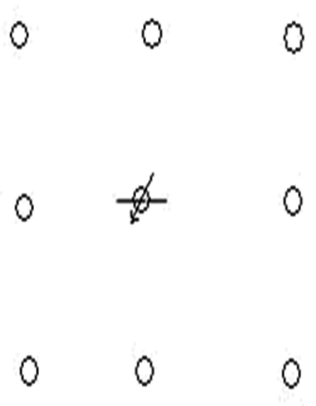

Figure 2
Inverted Nine Wells Fractured Wells Network Diagram

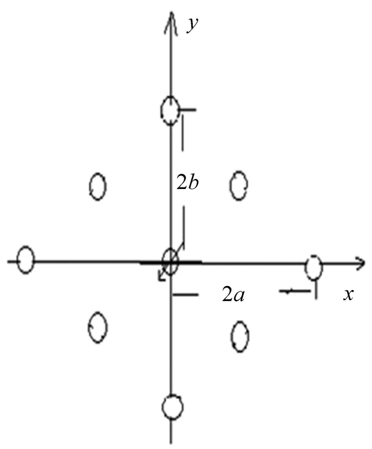

Figure 3
Vertical Well Fracturing Well Staggered Rhombus Inverted Nine Well Network Diagram

Suppose there are five-point rectangular pattern consists of a 4 vertical wells and 1 wells in the plane, and length is 2a and width is 2b in rectangular pattern. Fracture length is 2L in fracturing well, z plane coordinate origin is located at the well center. Using conformal mapping, mirror image method and superposition principle, made $a = b$ for the square well pattern, according to conventional literature. Due to the presence of starting pressure gradient, fluid percolation characteristics of low permeability oilfield doesn't obey the Darcy's law and the corresponding kinematic equations[3]. Therefore, we should consider the influence of starting pressure gradient and anisotropy coefficient in the development of low permeability reservoirs, and the flow quantity of low permeability reservoir can be expressed as:

$$Q_h = \frac{2\pi\sqrt{K_x K_y}\,h\left(\Delta p - G\sqrt{a^2+b^2}\right)/\mu}{2lR + \beta h\left(\ln h\beta - \ln 2\pi r_w\right)}\ . \tag{1}$$

Annotation: G is starting pressure gradient.

1.2 Deliverability Calculation of Seven-Spot Pattern

Assuming there are seven-spot pattern consists of a 6 vertical wells and 1 wells in the plane, and 6 vertical injection wells arrayed uniformly hexagonal, and well spacing is $2d$, and crack length of fracturing well production is $2L$. Due to the presence of starting pressure gradient, fluid percolation characteristics of low permeability reservoir doesn't obey the Darcy's law and the corresponding kinematic equations. Consequently, we should consider the influence of starting pressure gradient and anisotropy coefficient in the development of low permeability reservoirs, and the flow quantity of low permeability reservoir can be approximately expressed as:

$$Q = \frac{2\pi\sqrt{K_x K_y}\,h\left(\Delta p - \lambda\sqrt{a^2+b^2}\right)}{\mu\left(\frac{1}{3}\ln\frac{2\sqrt{6}}{3}\frac{d_1}{r} + \frac{1}{12}\ln E + \frac{\beta h}{2L}\ln\frac{\beta h}{2\pi r_w}\right)}\ . \tag{2}$$

1.3 Fluids Rate Forecast of Nine-Spot Pattern

Due to the presence of starting pressure gradient, fluid percolation characteristics of low permeability reservoir doesn't obey the Darcy's law and the corresponding kinematic equations. Consequently, we should consider the influence of starting pressure gradient and anisotropy coefficient in the development of low permeability reservoirs[4], and the flow quantity of nine-spot pattern in low permeability reservoir can be expressed as:

$$Q_{9f} = \frac{4\pi\sqrt{K_x K_y}\,h\left(\Delta p - G\sqrt{a^2+b^2}\right)/\mu}{\frac{c^2 - ab}{a+2b-3c} + \frac{\beta h}{4\pi}\ln\left(\frac{\beta h}{2\pi R_w}\right)}\ . \tag{3}$$

Annotation: a, b, c are less than zero.

1.4 Fluids Rate Forecast of Anti-Nine Rhombus Pattern

By using the conformal transformation and the superposition theory, deduced the potential of fracturing wells at any point of any space in formation. Through deduction and simplification, and the existence of starting pressure gradient, fluid percolation characteristics of low permeability reservoir doesn't obey the Darcy's law and the corresponding kinematic equations. Therefore, we should consider the influence of starting pressure gradient and anisotropy coefficient in the development of low permeability reservoirs, and the flow quantity of the XY plane in low permeability reservoir can be expressed as:

$$Q \approx \frac{2\pi\sqrt{K_x K_y}\,h\left(\Delta p - G\sqrt{a^2+b^2}\right)}{\mu(R_o + R_i)}\ . \tag{4}$$

Annotation: R_o, R_i - The dimensionless potential difference of XY plane and YZ plane.

2. WELL PATTERN OPTIMIZATION OF FIVE-POINT RECTANGULAR PATTERN

2.1 The Optimization Methods

By means of the previous formula, the yield of fracturing wells are concerned with various factors on fracturing wells, in addition to formation parameters such as permeability, ENS and producing pressure drop away, also related to wellbore length of fracturing well ($L = 2l$), pattern shape parameters (a and b), and pattern area ($S = 4ab$). In order to facilitate the analysis, we defined two dimensionless parameters, pattern shape factor is and dimensionless length of fracturing well[5].

Well pattern Optimization methods are that change the size of pattern shape factor (F) and calculate the yield, so as to obtain the rule curve yield varied with the shape factor of well network when give dimensionless length of fracturing well and make the other parameters unchanged. We can find the maximum yield point on the curve, and the corresponding pattern shape factor (F) is defined as the optimal well pattern shape factor (F_{op}). In this pattern area and reservoir thickness conditions, we should record dimensionless length (l_D), corresponding dimensionless yield(Q_{hD}) and F_{op}. The new F_{op} and Q_{hD} can be determined when we change l_D and repeat the above steps. Using the above-mentioned method, the computer program is compiled[6]. In the process of calculation, via considering the actual situation of oil field, the well pattern area are respectively 22,500 m^2, 40,000 m^2 and 90,000 m^2, and reservoir thickness are 10 m, 30 m and 50 m. In order to get the relationship between l_D and F_{op}, Q_{hD}.

2.2 The Optimization Results

By optimizing data sheet, in different reservoir thickness and pattern area condition , F_{op} tend to 1. Yield increases with the increase of dimensionless length, and the optimum shape factor increases with increasing dimensionless length, but the rate is relatively small.

According to analysis data that F_{op} and l_D of fracturing well in different reservoir thickness and pattern area condition, indicate that there are linear relationship between l_D and F_{op}, and the influence of the pattern area and there servoir thickness are very small to the frontal relationship (10 to 100 meters), and even ignored. And we can find that the optimum shape factor increase, namely the well deviation square degree increase, along with the increasing of l_D. There exist an optimal shape factor and the pattern area that make the fracturing well dimensionless yield maximum when length of fractured well is fixed. This condition can be used for design of FDP.

Pattern shape is close to the square when only well length of the fracturing are short, in mixed well conditions. And we can find that dimensionless yield of fracturing well decrease, along with the increase of reservoir thickness, and dimensionless yield of fracturing well are smaller when pattern area are greater in the same conditions of dimensional length and reservoir thickness of fracturing wells, and the influence of fractured wells dimensionless production that changes of reservoir thickness caused are reducing, with the increasing of pattern area[7].

The increasing percentage of dimensionless yield assumes almost linear relationship for dimensionless length. The increased yield is more when the dimensionless length increased, and the dimensionless yield can be increased by 1% or so. Especially for small areal well pattern of oil sheet, the rate of increasing is more obviously. Therefore, we shall adopt the rectangular pattern when the dimensionless length is larger in the oil sheet. Productivity gradient present increasing with increasing of dimensionless length when the pattern area remain unchanged.

2.3 The Influence of Starting Pressure Gradient

Consider the optimal shape factor of different starting pressure gradient, the optimum shape factor increased with the increasing of pressure difference[8]. Its influence on the optimum shape factor is very small when starting pressure gradient are more than 0.05, and it can be negligible.

2.4 The Effects of Reservoir Anisotropy

Considering the anisotropy of reservoir, in the low permeability reservoir, alternating pattern capacity of rectangular five-point straight wells and fracturing is the following formula.

$$Q_h = \frac{2\pi\sqrt{K_x K_y}h}{\mu} \frac{\Delta p - \sqrt{\nu}l}{\frac{1}{8}\ln\frac{[(v+w)^2-1]\cdot 4vw^2}{[1-(v-w)^2]r_w^2/l^2} + \frac{\beta h}{2l}\ln\frac{\beta h}{2\pi r_w}} . \tag{5}$$

Similarly, the definition of fracturing well dimensionless yield is the following formula.

$$Q_{hD} = \frac{\mu}{2\pi\sqrt{K_x K_y}h\Delta p} Q_h . \tag{6}$$

After optimization, we can find that specific data shown in Figure 4 when well area is 40,000 m^2 and anisotropic coefficient (β) are respectively 2, 10 and 20. From the figure, F_{op} that different dimensionless length correspond is also different when the pattern area is 40,000 m^2 and anisotropic coefficient is different. According to the optimization data, the optimal shape factor is corresponding to the same dimensionless length decreases, with the increase of the anisotropy coefficient.

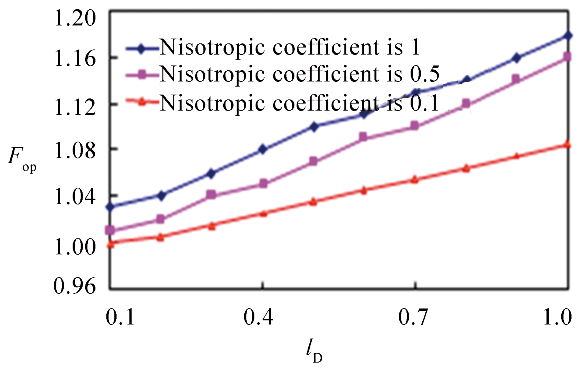

Figure 4
The F_{op} With Different Nisotropic Coefficients

CONCLUSION

Through the research and analysis, we get the following conclusions:

(a) For the low permeability reservoir, rhombus anti-nine vertical and fractured well mixed pattern productivity were studied, and there are optimal analysis for five-point rectangular well pattern that fracturing and vertical wells combined, and for rectangular fracturing wells. Therefore, we can prove that can improve the development effect of argument when pull large well spacing, narrow row spacing and make the well shape factor in a certain range.

(b) In the actual design of field development plan, we can know that determine the length and the width of the rectangular pattern, if the crack length and well net area were given, by using the dependence of well dimensionless length and optimal shape factor of fracturing wells.

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