

Experimental Study on Starting Pressure Gradient of Percolation in Low Permeability Sandstone Reservoir Based on Single Well Productivity Sequence

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Abstract: Low permeability oilfields have gradually become the main battlefield in China, and the study of starting pressure gradient is the key to study the seepage law of low permeability reservoirs. Therefore, the starting pressure gradient of low permeability sandstone reservoir is studied. The results show that the minimum starting pressure gradient of oil-water two-phase low-permeability sandstone is a function of curtain function. Aiming at the factors affecting the pressure gradient, such as reservoir permeability, fluid viscosity, displacement pressure gradient, oil-water interfacial tension, etc., measures to improve the development of low permeability reservoirs are proposed.

1. Introduction

With the deepening of oilfield exploration, low-permeability reservoirs that were not concerned by petroleum geologists have received more and more attention and become an important supplement to oil and gas fields [1]. The reservoir conditions of low permeability reservoirs are poor, the liquid production index decreases sharply with the increase of water content, the yield decreases rapidly, and the actual product liquid production index is lower than the reasonable production index [2]. Therefore, under the premise of prolonging the low water cut period, it is especially important to ensure that the oil field reaches the maximum liquid production and slows down the production. With the deepening of oil field exploration and development, the proportion of low permeability reservoirs increases year by year, and the development of low permeability reservoirs occupies an increasingly important position [3]. Therefore, from the perspective of oil and gas development, many scholars have studied the percolation characteristics of oil and gas in the process of water flooding in low permeability reservoirs by means of simulation experiments. Production practice shows that improper selection of injection-production well spacing is one of the main factors causing contradictions between injection and production in low permeability [4]. In the seepage process of low permeability reservoirs, the surface molecular force acting on the solid-liquid interface, i.e. the seepage resistance gradient, which can not be neglected, is called the start-up pressure gradient [5]. In order to develop low permeability oilfields well, first of all, we should correctly understand the reservoir characteristics and seepage law, correctly calculate the seepage mechanics, and determine a reasonable development plan [6].

Underground seepage in low permeability reservoirs is complex. One of the important points is that fluid seepage in low permeability reservoirs no longer follows Darcy's law, which brings difficulties to the development and calculation of oilfields [7]. Because of the existence of the starting pressure gradient, there is a non-linear flow in which the permeability varies with the pressure gradient. Start-up pressure gradient of reservoir rock is an indispensable parameter for determining reasonable injection-production well spacing. Therefore, obtaining a real and reliable start-up pressure gradient of reservoir rock is the premise for accurately determining reasonable well spacing [8]. In recent years, oilfields discovered and not developed in China are mainly low-permeability oilfields. With the development of low-permeability oilfields in China, special seepage characteristics and laws in low-permeability rock reservoirs have received more and more attention, and the study of starting pressure gradients is one of the keys to research in this field. Therefore, research on the pressure gradient of low permeability reservoirs has become very important [9]. A large number of research results show that many low-permeability reservoirs

discovered at present have low porosity and permeability in the reservoir formation period, which is a low-permeability reservoir. Therefore, its accumulation process should be characterized by low permeability and accumulation. The migration and accumulation characteristics of oil and gas may be very different from conventional reservoirs [10].

2. Methodology

Contrary to the oil and gas development process, the hydrocarbon accumulation process is a process of oil or gas displacement. The reasonable oil-water well ratio refers to the ratio of the production well to the injection well that can obtain the highest liquid production under the condition that the flow pressure of the oilfield injection well and the production well is constant and the total number of development wells is constant. An important basis for adjustment. The results show that the seepage of oil, gas and water in the development of low-permeability reservoirs is non-Darcy flow, and there is a low-speed non-Darcy flow phenomenon of fluid. At present, the petroleum industry has established experimental techniques and calculation methods for indoor measurement of starting pressure gradients, and effectively guides the determination of reasonable well spacing in multiple low-permeability oil fields. The pore size is small, the pore throat effect is enhanced, the influence of micro pore structure is enhanced, and the high specific surface area has obvious influence on fluid flow. The smaller the permeability is, the higher the viscosity is, the smaller the fluidity is, and the larger the initial start-up pressure gradient is. The larger the permeability is, the lower the viscosity is, the larger the fluidity is, and the smaller the initial start-up pressure gradient is. The sum of single well production data is used as the basis of data calculation for each index. The calculated index reflects the comprehensive average level of the whole reservoir. The information of reservoir development effect and residual potential mapped by single well productivity difference is often concealed or neglected.

From the measured start-up pressure gradient data of core samples with different permeability, it can be seen that the smaller the permeability, the greater the start-up pressure gradient. As shown in Figure 1.

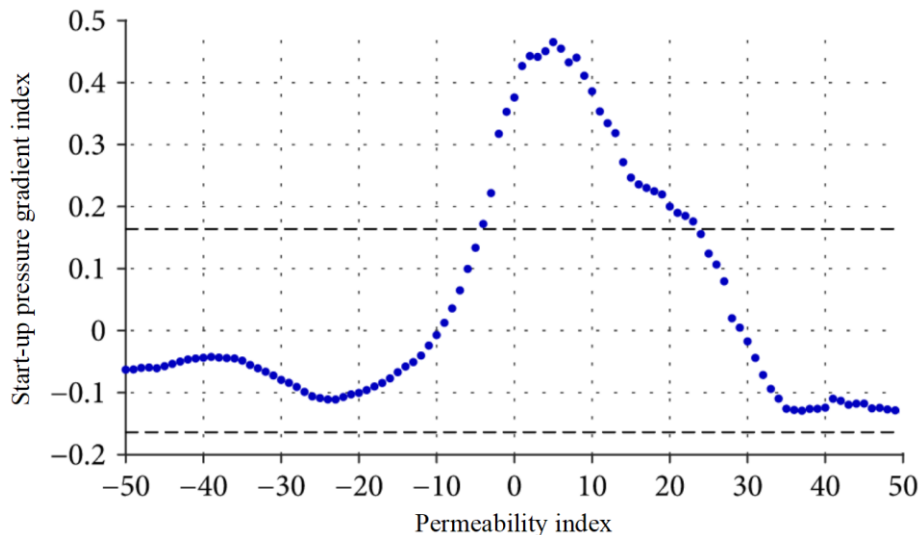


Fig.1. Curve of relationship between starting pressure gradient and core permeability

It can be seen from the characteristic curve of single-phase infiltration of low permeability core that the "pressure difference-flow" relationship is a curve that does not pass through the origin due to the existence of the starting pressure gradient, and the curve converges near the origin of the coordinate. In the field of reservoir development, the research object changes from the geological reserves in the resource evaluation to the remaining recoverable reserves under the single well control. Each well controls a certain amount of remaining oil, which indirectly reflects the extent of remaining oil enrichment through single well productivity. With the increase of air permeability, the variation of the starting pressure gradient is small when the water saturation is low, and the

variation of the starting pressure gradient is large when the water saturation is high. This is because the starting pressure gradient is determined by both the nature of the rock itself and the nature of the fluid. However, for low permeability reservoirs with serious heterogeneity, well spacing calculated from the data of starting pressure gradient measured in laboratory at present will lead to great difference in recovery degree of different low permeability reservoirs, prominent contradictions between planes and layers, and worse development effect. Some scholars have used the capillary equilibrium method and differential pressure-flow method to determine the minimum threshold pressure gradient in the experimental study of seepage start-up pressure gradient in low permeability sandstone reservoirs. Finally, the pseudo-start pressure gradient can be obtained by solving the difference equation and P-T fitting.

Fitting the experimental data of seepage velocity-displacement pressure gradient of composite cores to determine the starting pressure gradient of composite cores (Table 1).

Table 1 The measured and calculated values of starting pressure gradient of composite cores

Core combination	permeability ratio	Combination mode	Start-up pressure gradient	
			Experimental determination	Formula calculation
First group	1:1:1	Series connection	1.36×10^{-3}	1.14×10^{-3}
		Parallel connection	1.11×10^{-3}	1.23×10^{-3}
Second group	1:3:12	Series connection	1.58×10^{-4}	1.53×10^{-4}
		Parallel connection	2.22×10^{-3}	3.62×10^{-3}

3. Result Analysis and Discussion

In the experiment of measuring start-up pressure gradient, some scholars obtained the equation of motion of low permeability reservoir through the experimental flow measurement in the experimental study of percolation characteristics of ultra-low permeability reservoir. In 2008, a new method for simultaneous determination of start-up pressure and flow velocity-pressure difference relationship was established in "A new method for determining start-up pressure of low permeability reservoirs". It is a combination of "capillary equilibrium method" and "steady state method". Therefore, the pore structure and surface physical properties of low permeability sandstone reservoirs are very complex, and their seepage mechanism and oil-water movement law are quite different from those of general medium-high permeability sandstone reservoirs. The starting pressure gradient calculation formula of the series/parallel combined core is established by mathematical derivation, and the starting pressure gradient value of the single core is substituted into the calculation formula to obtain the starting pressure gradient under the heterogeneous condition. Because the oil-water two-phase starting pressure gradient is inversely proportional to the reservoir permeability, for low-permeability reservoirs with strong stress sensitivity, the formation pressure should be kept as much as possible to prevent the reservoir permeability from decreasing. For low-permeability reservoirs suitable for acidification, an acidification method can be used to increase the permeability of the reservoir and reduce the oil-water two-phase starting pressure gradient of the low-permeability reservoir. In order to accurately determine the size of the starting pressure gradient, it is necessary to further process the experimental data.

For oilfields where reservoir fractures are not developed, a reasonable well pattern adjustment method should be selected according to the development of reservoir sand bodies. From the perspective of the sweeping coefficient of water flooding area of different well networks, under the same fluidity ratio, the sweeping coefficient of the water flooding area of the five-point well pattern network is significantly higher than that of the row water injection and the anti-nine point well

network. As shown in Figure 2.

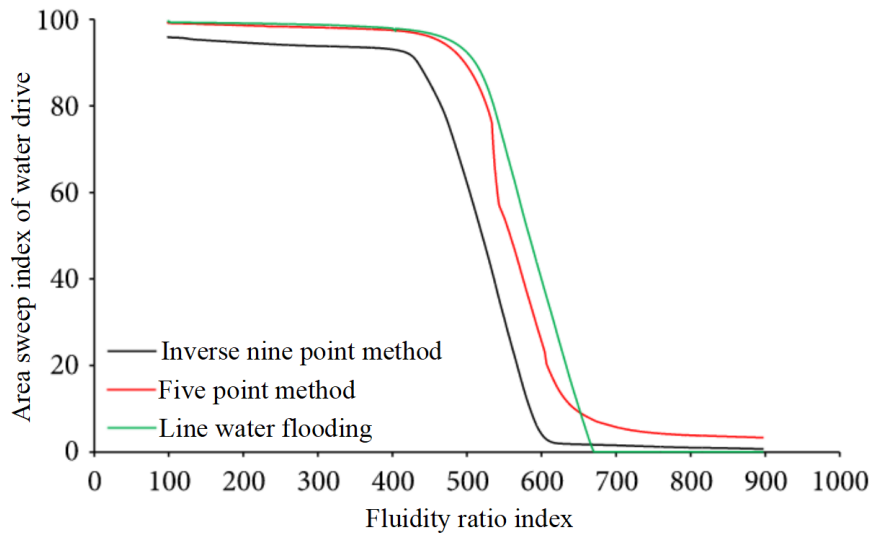


Fig.2. Curves of sweep coefficient of water drive area with fluidity ratio in different well patterns

Based on the influencing factors and experimental results of oil-water two-phase start-up pressure gradient in low permeability sandstone reservoirs, the measures to improve the development effect of low permeability reservoirs are put forward. In the field of reservoir development, the application of Pareto's law is still a blank. The main reason is that the traditional view holds that Pareto's law is mainly applicable to the study of resource distribution. The displacement pressure gradient required for the fluid to enter the linear section from the non-linear section is also the maximum displacement pressure gradient in the non-linear seepage section, which is called the critical pressure gradient. There are many methods to determine the pressure gradient. The slope method is used here, that is, when the slope of the non-linear seepage section is equal to the slope of the linear section, the corresponding pressure gradient is the critical displacement pressure gradient. Then, the start-up pressure experimental data of series/parallel composite cores are obtained through laboratory steady flow experiment. By comparing the calculated results with the experimental results, a method for determining the start-up pressure gradient of heterogeneous sandstone reservoirs is finally established. However, core displacement experiments are carried out on a single small core, which is a one-dimensional one-way flow. The small core is relatively homogeneous, without considering the influence of heterogeneity. The specific method is to connect cores with different permeability levels in series to simulate the plane heterogeneity of permeability. Cores with different permeability levels are connected in parallel to simulate the vertical heterogeneity of permeability.

4. Conclusions

Low-permeability reservoirs are mainly formed in relatively low-energy environments where the supply of coarse clastic materials is insufficient. The outstanding features are poor reservoir lithology, poor physical properties, poor oil-bearing occurrence, low oil saturation, and serious heterogeneity. The timing of adjusting the production well network should be favorable to maintain the formation pressure at a reasonable level. After the injection-production well network can not meet the development needs, the earlier the adjustment, the more favorable the oilfield development effect. When the same viscosity of petroleum migrates in different physical sandstones or oils of different viscosities migrate in the same physical sandstone, the position of the seepage curve, the curvature of the nonlinear segment curve and the intercept of the straight line segment on the pressure gradient axis are different. By comparing several important results of experimental study on starting pressure gradient in recent years, the application of "capillary equilibrium method" and "differential pressure-flow method" and steady state method and unsteady state method in low permeability reservoirs are summarized. The starting pressure gradient of vertical heterogeneous

reservoirs can only be calculated from the starting pressure gradient of a single core, which is equal to the weighted average of the starting pressure gradient of each permeability layer with respect to the product of permeability and seepage area. The principle of using single well productivity sequence to evaluate reservoir development effect is different from reservoir engineering method, so it enriches and improves the existing reservoir development effect evaluation system.

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