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Study of numerical simulation with low permeability reservoirs based on nonlinear seepage

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ABSTRACT

There are obvious different with special percolation characteristics of low permeability reservoir and high permeability reservoirs, the seepage law is unique. Because of its unique characteristics, using suitable for middle and high permeability reservoirs theory technology development is bound to cause all sorts of problems. In this paper, in accordance with the special low permeability oilfield reservoir core, fluid percolation features of the corresponding nonlinear seepage flow model was constructed, and non-linear percolation mathematical model for numerical simulation of the developed related numerical simulation software, further research and analysis of nonlinear seepage law characteristics of low permeability reservoirs.

KEYWORDS

Nonlinear seepage; Low permeability; Numerical simulation; Research.

INTRODUCTION

Fluid flow in low permeability porous media flow law of internal porous medium and high permeability, which shows the flow law, it is the most prominent characteristic, is Inconsistent with the Darcy's Law. Under special circumstances, only in the porous media is more than a pressure gradient under the condition of only liquid percolation, but through the permeability of porous media seepage law of special in-depth research and analysis, and on this basis, construct the percolation theory of low permeability reservoirs. This paper mainly discusses the nonlinear seepage under the special low permeability oil reservoir numerical simulation.

THE CONSTRUCTION OF A LOW PERMEABLE RESERVOIR NON-LINEAR SEEPAGE MODEL

The extra-low permeability reservoirs reservoir characteristics and the law of seepage

Detection cores of extra low permeability in different permeability pore and throat radius, the level of different permeability core holes size, distribution of nature, there is a big difference between centralism manifests in the throat size and its distribution. This suggests that the low permeability reservoir characteristics are constrained by the throat, and throat size directly affect the reservoir flow properties is good or bad, and development progress. And for the same in terms of extra low permeability core, because of it is composed of different levels of the throat, and small throat radius occupy larger proportion, with the change of the pressure gradient and permeability change [1-2]. As shown in Figure 1. The horizontal axis shows pressure gradient, the unit Mpa·m-1, the vertical axis represents water permeability measurement, unit 10-3 μ m2. The water in the cores of extra low permeability decreases as the pressure gradient and permeability measurement to improve gradually. Because of pressure low hours, the core of a few large throat radius water drives, most of the small throat radius of water use is difficult, so the water permeability measurement is small. And if the pressure gradient increases, the water in the part of the throat will participate in the flow, the corresponding permeability increasing, for all the throat of low permeability cores are both involved in flow, its permeability to approximate and constant.

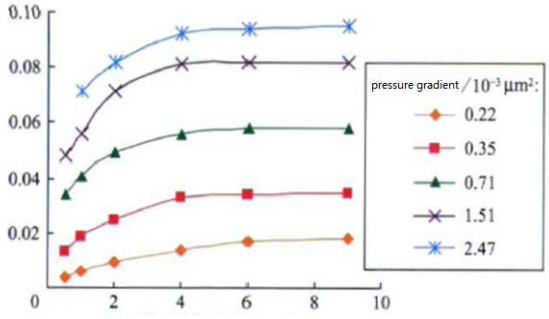


Figure 1 : water pressure gradient and permeability test of diagram

A low permeability reservoir fluid nonlinear seepage flow model

Low permeability reservoirs in reservoir characteristics and seepage rule as the foundation to build the model, using formula expressed as:

$$v = \frac{k}{\mu} / p\left(1 - \frac{\delta}{p}\right) \quad (1)$$

The variable v in formula (1) stand for the velocity, permeability k, μ stand for viscosity, δ stand for start-up p stand for pressure gradient, pressure gradient, the corresponding unit is respectively: m/s, 10-3 μ m2, Mpa·s, Mpa/m, Mpa/m. This institute is a low permeability reservoir of fluid seepage model and nonlinear studies of people before, by contrast, permeability, start-up pressure gradient are variable, of which change with the change of the pressure gradient and permeability, the start-up pressure gradient as the change of water saturation, throat radius.

A LOW PERMEABILITY RESERVOIR SOLUTION OF NON-LINEAR SEEPAGE MODEL

Assumptions are put forward

In black oil simulation assumptions based on the basic assumption nonlinear seepage, a low permeability reservoir fluid seepage hypothesis for the isothermal flow within the reservoir, and exist in the reservoir more three-phase oil, gas, water, oil and water don't mix, and the gas can be dissolved in the oil and water phase, and timely exchange and free gas. Reservoir system in oil and gas two phase can quickly achieve the phase equilibrium, and oil and water phase flow according to the law for the nonlinear seepage, rather than the classic Darcy's Law.

Mathematical model and numerical solution method

A low permeability reservoir seepage numerical simulation mathematical model of nonlinear operation equation formula is:

$$v_o = \frac{kk_{ro}}{\mu_o} \cdot \nabla p_o \left(1 - \frac{\delta_{oi}}{\nabla p_o}\right) \quad \textbf{(2)}$$

$$v_w = \frac{kk_{rw}}{\mu_w} \cdot \nabla p_w \left(1 - \frac{\delta_{wi}}{\nabla p_w}\right) \quad \textbf{(3)}$$

$$v_g = \frac{k_a k_{rg}}{\mu_g} \cdot \nabla p_g \quad \textbf{(4)}$$

Continuity equation formula is:

$$\nabla \bullet (\rho_o v_o / B_o) + q_o = \frac{\partial(\phi \rho_o S_o / B_o)}{\partial t} \quad \textbf{(5)}$$

$$\nabla \bullet (\rho_w v_w / B_o) + q_w = \frac{\partial(\phi \rho_w S_w / B_w)}{\partial t} \quad \textbf{(6)}$$

$$\nabla \bullet \left(\frac{\rho_g}{B_g} v_g + \frac{R_{SO}\rho_g}{B_o} v_o + \frac{R_{sw}\rho_g}{B_w} v_w\right) + q_g = \frac{\partial}{\partial t} \phi \rho_g \left(\frac{S_g}{B_g} + \frac{R_{SO} S_o}{B_o} + \frac{R_{sw} Sw}{B_w}\right) \quad \textbf{(7)}$$

Auxiliary equation formula is:

$$S_o + S_w + S_g = 1 \quad \textbf{(8)}$$

$$p_{cgw} = p_g - p_w, p_{cow} = p_o - p_w \quad \textbf{(9)}$$

In the above formula, K_a stand for air permeability, ($10^{-3}\,\mu\,m^2$); and K_{ro}, K_{rw}, K_{rg} shows the relative permeability of oil and gas; ρ is density (g/cm3); S is saturation; B stand for volume coefficient; p_{cgw} and p_{cow} stand for gas capillary force between water and oil/water interface; ϕ is stand for measurement; According to oil phase and water phase start-up pressure gradient; Q is represented by a certain time stratigraphic volume injection or the quality of output flow; (kg/m3·s), and also some stand for gas in oil, coefficient of dissolved in water; The subscript o,g stand for oil, gas, water, respectively. By using the implicit pressure explicit saturation method obtains the solution of various parameters, because this kind of method to calculate less workload, less memory and simple, the result is stable.

THE NONLINEAR SEEPAGE FLOW'S INFLUENCE ON THE PRODUCTION RULES

The comparative analysis of nonlinear seepage and linear seepage law

Analysis below Figure 2 recovery degree found in differential pressure producing or fluid volume production conditions, the same time period according to Darcy model to compute the data obtained, its recovery degree at first, the second nonlinear model calculation, the third for the start-up pressure gradient model calculation, because of its excessive expanded formation resistance, then expand the formation don't flow in the area, reduces the recovery degree. But Darcy`s model rarely by pressure gradient and the nonlinear effects of seepage, to a certain extent, prompted of fluid in formation is reduced, recovery degree and conformance to ascend.

In differential pressure producing or fluid volume production conditions, with the aid of the moisture content of different model calculated curve is different, as below in Figure 3. By Darcy`s model related to the moisture content of computing speed is very slow, is the fastest to start-up pressure gradient model, nonlinear model centered. Because quasi start-up pressure gradient model oil phase in the specific calculation process start-up pressure gradient this factor into consideration, and ignore the water phase start-up pressure gradient, prompting oil phase seepage resistance, crude oil flows forward ability is lower than the water phase, when the body form between the injection-production well effective for pressure, is likely to induce fingering, tongue into the phenomenon, improve the moisture content increased speed. However, the intrinsic permeability coefficient in the field of soil under practical conditions is difficult to get accurately; the differences of test results between the laboratory and field are large. Therefore, a reasonable intrinsic permeability coefficient is the key

of the numerical analysis, engineering model validation should be calculated based on field observation data, to obtained more accurate material penetration parameters, and then takes predictive analysis for to site conditions.

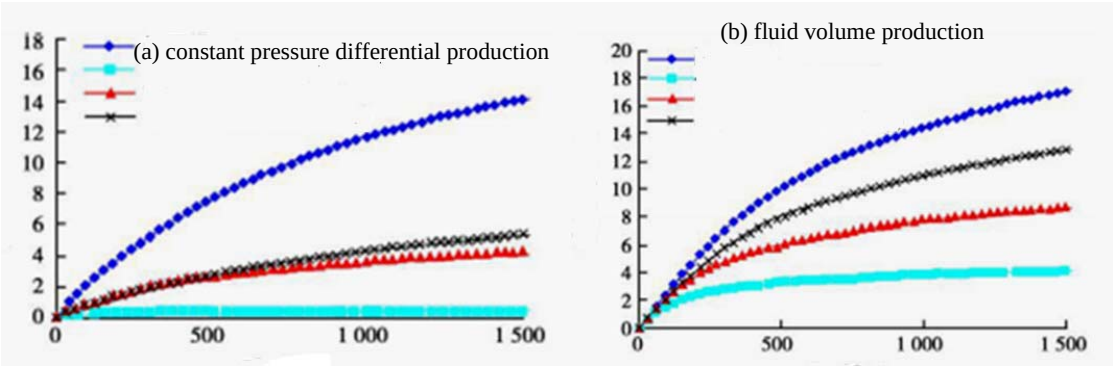


Figure 2 : Recovery degree curves

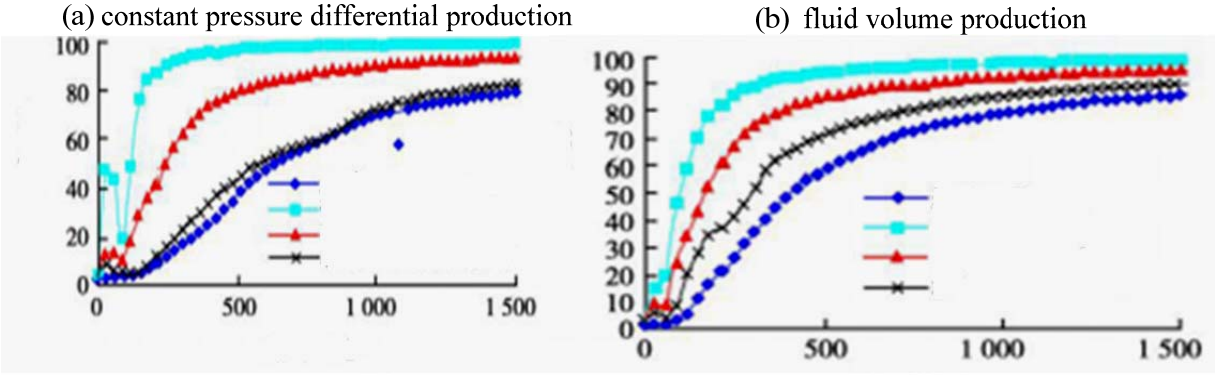


Figure 3 : Water cut curve

The research proposed a start-up pressure gradient model, nonlinear model on the basis of calculating the initial moisture content, and compared with Darcy model, it shows obvious differences. Their initial moisture content is mainly for the rise and fall - rising change characteristics. If considering formation water will nonlinear seepage such factors, so this kind of phenomenon may be reduced, when the proposed model, the nonlinear model of start-up pressure gradient under the condition of linear degree is very close to the above phenomenon will disappear[3]. Reason: the oilfield fluid in the start-up pressure gradient model in the absence of an effective displacement form before production Wells around belong to elastic drive form, together with start-up pressure gradient is greater than the water of crude oil, the phenomenon of water has little impact, so the initial moisture content increased significantly. When the elastic pressure range continues to rise to the largest value, moisture content will also rise to the largest number, to form effective displacement mode, to a certain extent, supplemented by elastic energy drainage area.

Calculations shows that LNAPLs will into the non-saturated soil and migration under gravity after ground leak, some remain in the soil pores, when reaching the water table, due to the low density than water, LNAPLs will float on the water and continue lateral migration, while density of DNAPLs is bigger than water, it will invade the groundwater system. Because all NAPLs have some solubility, partly soluble components will go into the groundwater, causing long-term contamination of soil and groundwater environments. If the injection water not reaches the production Wells, has been the decrease of the moisture content. According to the related literature material[4-5] hint: in the initial moisture content of low permeability oil reservoirs can produce this kind of abnormal phenomenon, at the same time as the irreducible water saturation degree increased, the phenomenon has become more obvious. Also has a lot of injection-production well distance is longer or has not been timely supplement the energy of low permeability reservoir, in this case, it is difficult to build a single well effective form of displacement, and the pressure of production well its falling speed will be enhanced in a short period of time, at the same time, this abnormal situation may will be covered with a large number of degassing of crude oil.

The result calculated on the basis of the different models of pressure maintenance level as shown in Figure 4. Analysis chart 4 shows that Darcy model of stress level, the lowest to keep the highest level of start-up pressure gradient model of pressure, nonlinear model centered. Prompt Darcy model calculating minimum income stratum seepage resistance, quasi start-up pressure gradient is the largest, and the nonlinear model calculated formation seepage resistance centered.

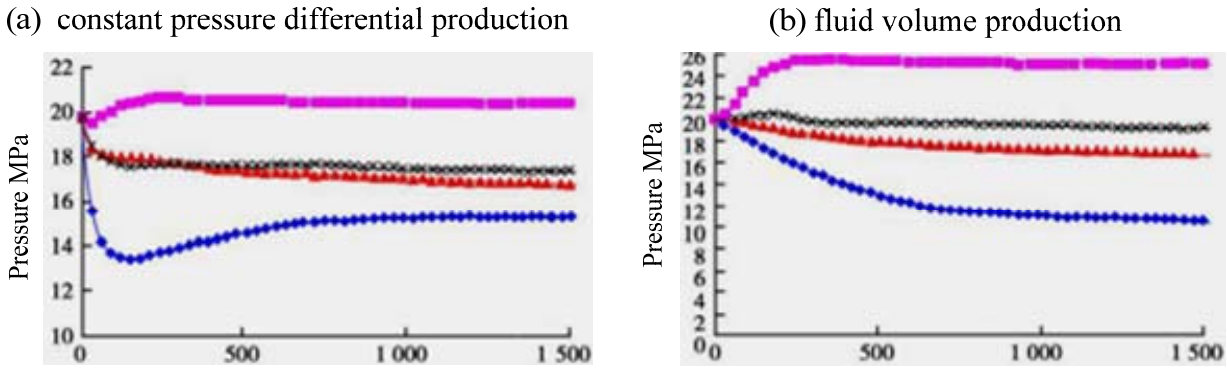
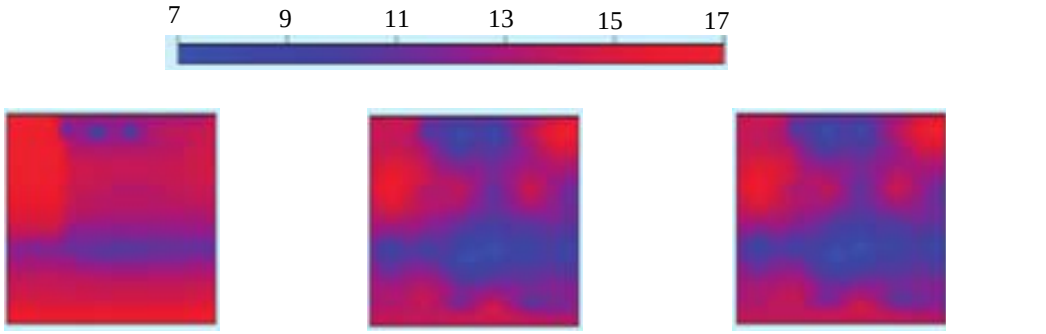


Figure 4 : Figure stress level

Finite element analysis has been obtained the quality distribution characteristics of LNAPLs at different times, it can be seen, after the LNAPLs leak on soil surface, firstly vertical downward movement under gravity, meanwhile, due to the capillary pressure to produce part horizontal migration: gravity has the more obvious effects, so the migration rate in vertical direction is greater than that in horizontal direction, the LNAPLs front reaches is over 1.5 m of the water table at 3 months; six months later, the front reaches the water table, due to the density is less than water and low solubility, its vertical transport will be subject to arrest, LNAPLs gathered in the groundwater surface, making partial saturation increases; over a year after the migration, LNAPLs form a high water table mass distribution peak area with little change in vertical migration range, while expanding the scope of horizontal expansion along the ground plane. The numerical results and centrifuge model test of Liming Hu et al (2002) obtained the same migration law of LNAPLs, which indicate that the numerical simulation can reasonable to predict transport processes of NAPLs contaminant.

The influence of the production rule

From above two, whether it's constant pressure difference or fixed fluid volume production, the water phase nonlinear seepage factors into consideration, have a certain degree of recovery degree ascension. Because if blindly consider nonlinear seepage oil phase factor, according to the Darcy's law, the smaller the water seepage resistance, the faster the flow velocity, if found parts production Wells with water, can produce water phase advantage channel, lead to recovery degree decreases, the moisture content has a certain degree of improvement. But if considering nonlinear seepage water, water seepage resistance, and obviously promoted, means to reduce the oil and water flow rate, and increased the recovery degree, reduce the moisture content of[6]. As shown in Figure 5, take into consideration of the nonlinear seepage water phase factors, improve the overall level of formation pressure, shows that with the appearance of water phase nonlinear seepage, seepage resistance, increase the whole and to ensure the constant pressure of reservoir or quantitative production, must enhance the level of overall formation pressure.



(a) Without considering starting pressure gradient

(b) The inner boundary conditions are not considered starting pressure gradient

(c) The inner boundary conditions are considered the starting pressure gradient

Figure 5 : Pressure distributions to consider different factors

Research shows that the numerical simulation method can be used to study the migration law of NAPL and reasonably describe the migration characteristics. Residual saturation of NAPLs and soil intrinsic permeability coefficient has a significant impact on its transport properties. The calculation parameters are accurate or not have a major impact on the predicted results, and therefore should also be carried out experimental studies and field observations on multiphase flow in porous media and material parameters of the constitutive model to get a more reasonable calculation results.

And in a low permeability reservoir development, the formation pressure as the growth of the development time of its internal layered spread around the wellbore. Pressure gradient along the row of oil and water Wells and injection Wells in the direction of the propagation speed faster and faster, its pressure gradient profile to spread around an oval shape. When in development time under the condition of same, the greater the pressure of well spacing its propagation speed is slow, at the same time, the well will also slower. Research result shows that when the well spacing is 100 m the faster development of water drive effect, at this time to minimize the residual oil distribution area, obtain the best development effect.

CONCLUSION

A low permeability reservoir with research and analysis of reservoir characteristics and the percolation rule as the foundation to build a low permeable reservoir fluid nonlinear seepage model, have been physical meaning clearly. The percolation process is mainly distributed in the following areas: quasi linear and non-linear seepage area, bypassed oil, and inside the extra-low permeability reservoirs, quasi linear area < nonlinear area, shows, through the analysis of the nonlinear seepage theory research of low permeability reservoir is very important. At the same time, the quasi linear seepage more appear in the local scope around the oilfield wellhead, most regional distribution within the strata of nonlinear seepage, it has an important role in the formation of seepage. The nonlinear seepage simulation is close to in a certain extent, it is reasonable to narrow well array distance, improve the development effect of low permeability oil reservoirs.

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