Research and application of the quantitative characterization method for the influence of raising liquid production on oil-water two-phase flow

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Abstract

At present, W oilfield has entered the end of the high water cut stage, Raising liquid production measures are the main means to increase oil production, since 2009, a total of 23 raising liquid production measures have been carried out, the cumulative incremental oil up to 43.15×104 m3. The research on the microscopic mechanism of raising liquid production by means of nuclear magnetic resonance imaging and microscopic visualization of glass has made some achievements, but the results of microscopic experiments can not be effectively applied to practical production. In this paper, through a lot of research, reservoir engineering and numerical simulation methods, explores the method of quantitative characterization of the raising liquid production effect on oil-water two phase flow, try to extract microscopic mechanism applied to macroscopic description. The results show that the proposed method can effectively improve the accuracy of numerical simulation by considering the influence of liquid extraction on the oil-water two-phase flow. The numerical simulation results show that without considering the impact of oil and water on the oil and water two-phase flow law increased oil 3.7×m3 104, considering the oil increase of 5.9×104 m3, The latter is consistent with production cognition. This method opens up a new path for the application of the microscopic mechanism of liquid extraction in the production practice.

Keywords

Raising liquid production, Relative permeability curve, Quantitative characterization, Microscopic mechanism, Macro application.

1. Introduction

Raising liquid production is an effective measure to improve oil production for high water cut wells. Based on percolation theory, Feng Qihong et al. established a three-dimensional surface by computer simulation to reflect the variation of relative permeability with water saturation and displacement pressure gradient[1].Gu Jianwei and others showed that the relative permeability of oil and water increased with the increase of displacement pressure gradient[2].Through laboratory core experiments, Bing Shaoxian qualitatively gives the variation law of oil-water relative permeability curves under different pressure gradients[3].At present, domestic and foreign scholars have gained three points in understanding the microscopic mechanism of raising liquid production.(1)Raising liquid production can increase sweep efficiency.(2)Raising liquid production can reduce the effect of Jia Min and improve the mobility of isolated oil droplets.(3)Raising liquid production can increase surface flux and improve oil displacement efficiency[4-10].As the above research results are still in the qualitative description stage, it is impossible to realize the macroscopic transformation and application of the micro-mechanism of raising liquid production. Therefore, this paper discusses how to quantitatively characterize the influence of raising liquid production on oil-water two-phase flow, and the research results have guiding significance for similar oilfields.

2. Quantitative characterization of pressure gradient effects on two-phase flow

Oil-water relative permeability is an important parameter in reservoir work. Oil-water relative permeability curve is the basis of studying multi-phase flow. It is an indispensable and important data in oilfield development calculation, production performance analysis, oil-water saturation distribution determination and various index calculation related to water drive. Generally speaking, the shape of permeability curve can be controlled by four characteristic parameters, which include displacement efficiency, water phase permeability under residual oil saturation, water phase index and oil phase index. After the irreducible water saturation is measured by core experiment, the residual oil saturation, i.e. the right end point of the oil phase curve, can be controlled by the displacement efficiency, the water phase permeability under the residual oil saturation, the right end point of the water phase permeability curve, and the oil-water phase index can control the shape of the phase permeability curve. The shape of the permeability curve can be controlled by establishing the relationship between a certain factor and the four characteristic parameters.

From the point of view of the change of production pressure difference after raising liquid production, the relationship between pressure gradient and four characteristic parameters of phase permeability curve is proposed to quantitatively describe the change of oil-water percolation law caused by raising liquid production. The detailed calculation process is as follows:

(1) The relative permeability curves of the same or similar permeability cores under the same pressure gradient were measured through laboratory core experiments.

(2) Normalizing the relative permeability curve.

$$S_{wn}=(S_w-S_{wi})/(1-S_{wi}-S_{orw}) \quad (1)$$

$$K_{rwn}=K_{rw}/K_{rwmax} \quad (2)$$

$$K_{ron}=K_{ro}/K_{romax} \quad (3)$$

(3) Regression of oil phase index and water phase index.

$$K_{rwn}=(S_{wn})\text{^}n_w \quad (4)$$

$$K_{ron}=(1-S_{wn})\text{^}n_o \quad (5)$$

(4) The normalized phase permeability curves were obtained by uniformly assigning S_{wn} values of formula (4) and formula (5) to 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.

(5) Normalized phase permeability curve. The normalized phase infiltration data K_{rwn} and K_{ron} were averaged under the pressure gradient.

$$K_{rwna}=(K_{rwn1}+ K_{rwn2+} K_{rwn3}+\ldots\ldots+ K_{rwnn})\text{^}(1/n) \quad (6)$$

$$K_{rona}=(K_{ron1}+ K_{ron2+} K_{ron3}+\ldots\ldots+ K_{ronn})\text{^}(1/n) \quad (7)$$

(6) Geometric averaging of five eigenvalues: original water saturation Soi, residual oil saturation S_{or}, water phase permeability K_{rw}(Sor) under residual oil saturation, oil phase index no and water phase index nw.

(7) De-Normalized oil-water relative permeability curve.

$$S_w=S_{wn}(1-S_{wi}-S_{orw})+S_{wi} \quad (6)$$

$$K_{rw}=K_{rwa}\times K_{rwna} \quad (7)$$

$$K_{ro}=K_{roa}\times K_{rona} \quad (8)$$

(8) Repeat the above process (1) ~ (7) to regress the relative permeability curve under different pressure gradients.

(9) Establishing mathematical expressions of regression pressure gradient and displacement efficiency, water phase permeability under residual oil saturation, oil phase index and water phase index.

Five samples with similar physical properties were selected for core displacement test to measure oil-water relative permeability under different displacement pressure gradients. The experimental core is a natural core with a diameter of 2.52 cm and a length of 5.54-8.21 cm. The air permeability is 669-795 mD. The displacement water is manually prepared with potassium chloride solution with a salinity of 30 000 mg/L. The experimental oil is white oil with a viscosity of 24.2 mPa.s at 50 degrees Celsius.

Figure 1 shows the five oil-water relative permeability curves under different pressure gradient getting by the above method. The experimental pressure gradients were 0.00125 MPa/cm, 0.00353 MPa/cm, 0.00498 MPa/cm, 0.00711 MPa/cm and 0.0114 MPa/cm. Under the five pressure gradients, the oil displacement efficiency is 54.52%, 63.56%, 65.33%, 68.30%, and 69.63%; Krw(Sor) is 0.1438, 0.2640, 0.3333, 0.4020, 0.5028; water phase index is 2.1752, 2.1042, 1.9855, 1.9124, 1.8640; oil phase index is 3.0342, 2.8218, 2.6058, 2.4660, 2.1201. Regression equation between pressure gradient and four parameters is shown in Figure 2.

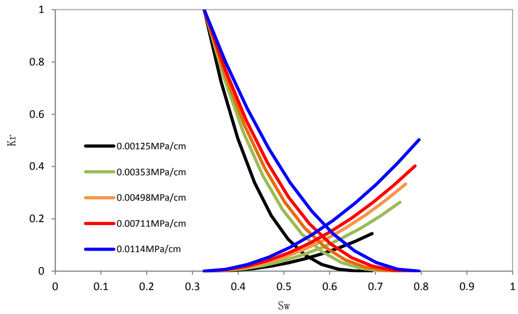


Fig.1 Oil water relative permeability curves under different pressure gradients

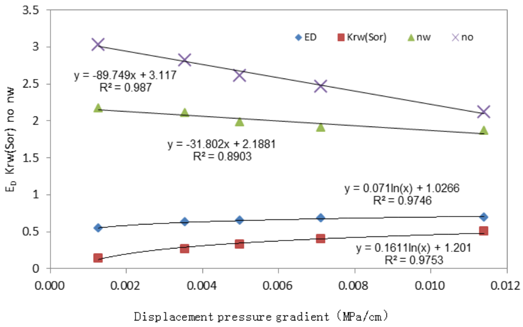


Fig.2 Relation curve of displacement pressure gradient and ED、Krw(Sor)、nw、no

Table 1 shows the mathematical relationship between five pressure gradients and four characteristic parameters. According to the relationship between different pressure gradients and characteristic parameters, the phase permeability curves under arbitrary pressure gradients in a certain range can be obtained.

Table 1 The mathematical relationship between pressure gradient and characteristic parameters

characteristic parameter	mathematical relationship	R2
ED	y=0.0710ln(x)+1.0266	0.9756
Krw(Sor)	y=0.1611ln(x)+1.2010	0.9753
no	y=-89.7490x+3.1170	0.9870
nw	y=-31.8020x+2.1881	0.8903

3. Numerical simulation study

A1H well was putting into operation in June 16, 2008 to develop ZJ2I. By the end of May 2016, A1H well produces oil 10 m^3/d, cumulative production of crude oil 38.27×10^4 m^3, comprehensive water cut

92%. ECLIPSE numerical simulation software black oil model was used to carry out numerical simulation.

Figure 3 is the statistical scatter plot of the maximum pressure gradient after A1H raising liquid production (Quotient between production pressure differential and wellbore distance from oil-water interface). The pressure gradient distribution of this well is 0.1-1.8 MPa/m, and the phase permeability curve under the corresponding pressure gradient can be obtained. Fig. 4 shows the fitting effect of raising liquid production on phase permeability is not considered, and the fitting effect is not satisfactory. Figure 5 is a fitting curve considering the effect. It can be seen from the graph that the water cut drops slowly, and the fitting accuracy is greatly improved.

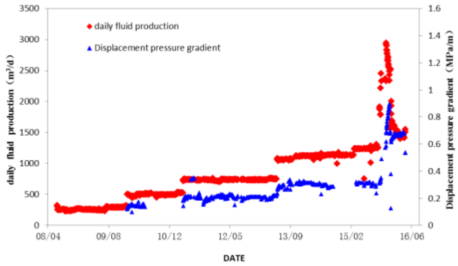


Fig.3 Statistics of pressure gradient in raising liquid productions

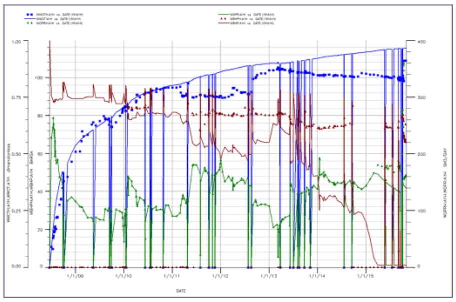


Fig.4 Fitting effect diagram without considering relative permeability curve change

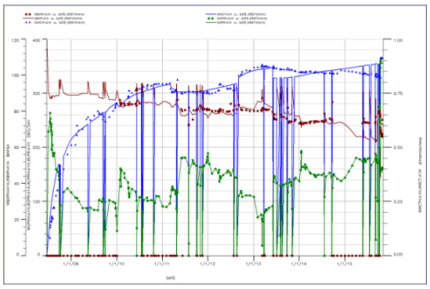
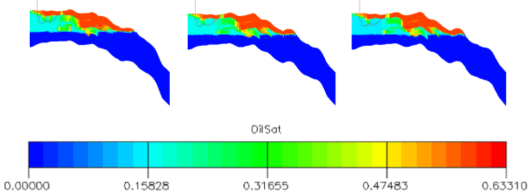


Fig.5 Fitting effect diagram with considering relative permeability curve change

Based on the above model, three schemes were designed, and the prediction conditions were produced for 10 years. Scheme 1 is continuous producing liquid 1500 m^3/d; Scheme 2 is raising liquid to 2000 m^3/d; Scheme 3 is 2000 m^3/d and phase permeability curve is replaced. Figure 6 is the remaining oil saturation diagram of the three schemes. After raising liquid production, the oil at the bottom of the reservoir is drived, and the scheme considering the influence of the raising liquid production on the phase permeability has affected the residual oil to be further drived.



(a) Basic scheme (b) No change in phase permeability curve (c) change in phase permeability curve

Fig.6 The remaining oil saturation distribution map of three schemes

Figure 7 is the curve of three schemes for water cut, daily oil production rate and bottom hole flowing pressure. From the water cut curve, it can be seen that without considering the effect of raising liquid production on phase permeability, the water cut shows a continuous increase, while considering the effect shows a downward trend first and then upward trend, and the later upward trend is more gentle than that without changing phase permeability. From the daily oil production curve, it can be seen that both methods have achieved oil increment, and the oil increment considering the effect is greater. It can be seen from the bottom hole flowing pressure curve that the flow pressure of the two cases are falling to a certain extent, but the flowing pressure is lower than the previous 3000 m^3/d in 2000 m^3/d without considering the influence, which is obviously not Inconsistent with reality.

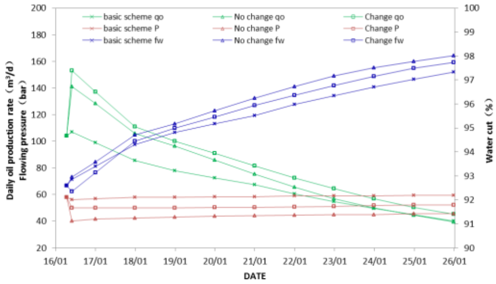


Fig.7 Index prediction curve of three schemes

Table 2 shows the recovery ratio of the three schemes. It can be seen from the table that the recovery ratio of the three schemes are 41.58%,43.96%,45.37%.

Table 2 Statistics of oil recovery

case	Daily fluid production rate /(m3·d-1)	Water cut /%	Annual oil production /(104m3)	Annual oil increase /(104m3)	Accumulative oil increase /(104m3)	Oil recovery /%
base	1500	92.86	46.6	-	-	41.58
No change curve/raising	2000	92.94	48.9	2.3	3.7	43.96
Change curve /raising	2000	92.32	49.2	2.6	5.9	45.37

4. Conclusion

(1) A quantitative characterization method of the relationship between pressure gradient and oil-water two-phase seepage law is proposed by analyzing the experimental data of core phase permeability under different pressure gradients.

(2) The prediction accuracy of the numerical simulation method is improved by using the new method of replacing permeation curve after raising liquid production. The prediction result of new method is more consistent with production practice.

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NOMENCLATURE			
Swn	Normalized water saturation	Kro	Relative permeability of oil phase
Sw	water saturation	Kromax	End point of relative permeability of oil phase
Swi	Irreducible water saturation	nw	Water index
Sorw	Residual oil saturation	no	Oil index
Krwn	Normalized Krw	Krwna	Average normalized relative permeability of water phase
Krw	Relative permeability of water phase	Krona	Average normalized relative permeability of oil phase
Krwmax	End point of relative permeability of water phase	ED	displacement efficency
Kron	Normalized Kro		