International Journal of Technical Research and Applications e-ISSN: 2320-8163,
www.ijtra.com Special Issue 12 (Jan-Feb 2015), PP. 76-79

RELATIVE PERMEABILITIES AT SIMULATED LONG TERM WATER FLOODING RESERVOIR CONDITIONS

Zhilin Wang*, Shenglai Yang, Jichen Yu, Hao Lei, Quanzhen Ma
CMOE Key Laboratory of Petroleum Engineering
China University of Petroleum
Beijing, China
wangzhilin87@163.com

Abstract— It is generally believed that the porosity, permeability, wettability of reservoir varies after long-term water flooding. But the researches of relative permeability curve variation of reservoir after long-term water flooding were rare. A laboratory unsteady-state method was used to research oil-water relative permeability for cores under the approximate conditions of oil reservoirs after long-term water flooding, and the results were compared with those of the conventional cores. According to this comparison if the water saturation is fixed, the water-phase permeability of cores after long water drive will be higher than that of conventional cores, and the conventional cores will generally be earlier in water breakthrough and faster in water cut increase than cores after long water-drive, with the cores after long water-drive being higher in the water-free oil recovery and the ultimate oil recovery than the conventional cores. The wettability of cores after long water-drive will change after oil washing, and their remaining oil saturation will somewhat increase due to expanding internal pore surface by the remove of solid particles during oil washing.

Index Terms—relative permeability; water cut; residual oil saturation; water-free oil recovery; ultimate oil recovery

I. INTRODUCTION

For water flooding reservoir, oil-water relative permeability is one of the most important parameters in the calculation of reservoir development. At present, the ashore oil reservoirs in China are mostly entered the middle and later stage of water flooding, therefore the changing rule of the reservoir oil-water relative permeability after long term water flooding is urgent to study by physical simulation. In lab, the determination of conventional core relative permeability curve generally is the steady or unsteady core displacement experiment; however the research about the relative permeability curve after water flooding is less. Literature [1]-[2] compared the parameters (polar, permeability) of conventional core before and after long term water flooding, found that the core parameters (polar, permeability) after long term water flooding are worse than before, and also can simulate the real reservoir physical properties of most water flooding reservoir at present [3]-[5]. In order to make indoor simulation more closer to the real reservoir conditions, the author according to the physical characteristics of the core after long term water flooding, using the laboratory method of unsteady water flooding to obtain cores oil-water relative permeability after long term water flooding, and compared with conventional core’s oil-water relative permeability, flushing efficiency and water content change to obtain the change rule of relative permeability after long term water flooding.

II. RELATIVE PERMEABILITY TEST OF LONG TERM WATER FLOODING CORES

A. *Experimental Method*

The experiment of relative permeability curves of conventional cores and long-term water washing cores is measured by unsteady state method is divided into the following 8 steps [6]:

1) Put the cores soaked in oil into the core holder, saturated oil 10PV,then put them into oil aging for 240h;
2) Put the cores into core holder again to measure oil phase permeability after aging;
3) Water flooding under the experimental condition till the water content at or near 99%, then measure the water phase permeability at residual oil saturation when the water content remain stable;
4) Using oil-water separator to do the oil-water separation in the counter, then record and modify the data;
5) Cleaning and dying the cores, measure the basic parameters, then start experiment of the long term water flooding core relative permeability;
6) Vacuuming the cores, then saturate them with formation water and put into the core holder, measure the water phase permeability of cores under the NPT when the water flooding is stable;
7) Saturate the cores with oil about 3PV, then saturate with oil 10PV at 0.6ml/min displacement speed, measure the oil phase permeability till no water flow;
8) Repeat the steps from 1) to 4).

There are 5 key points in the experiment as following:

1) Using the method of washing the cores to measure the residual oil saturation (more accurate than the method of measuring the displacement quantity);
2) Open the six-way value before the displacement, to eliminate the influence of the oil or water expansion, make the measurement of dead volume more accurate;
3) With the increase of confining pressure, the core permeability is reduced, so the measurement process must be strictly accord with reservoir pressure state and converse into the pressure under the triaxial condition, then set the confining pressure, reduce the test error;
4) After oil saturated, adopting the dynamic switching of water flooding, and keep the pressure balance between the two high pressure vessels before switching;
5) When calculating the relative permeability curve, need to fit multiple functions, which are fitting based on past experience formula, this time the author using the software Expert 1.3 which has high correlation coefficient to fit.

B. *Materials & Conditions*

Oil: From Tuha oilfield lianmuqin area well 8-6, the reservoir oil density is 0.763g/cm^3, viscosity is 3.66mPa•s, bulk coefficient is 1.035, original gas-oil ratio is 6m^3/m^3.

Water: According to formation water salinity and ion content make experimental formation water, water type is NaHCO3, water salinity is 4573mg/L, ion content (K^+, Na^+) is 1648mg/L, ion content of Ca^{2+}, Mg^{2+}, $CO2^{-3}$, HCO^{-3}, Cl^- and SO_2 respectively is 11, 6, 0, 741, 2100, 67mg/L.

Core: Obtain by sealed coring, and directly frozen storage; the experiment measured core sample basic parameters are shown in table 1.

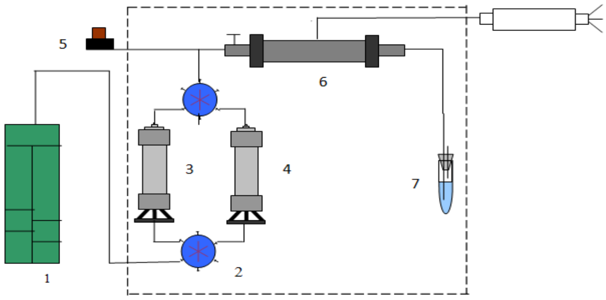
Table I. Basic parameters of cores

Core No.	Dia. /cm	Length /cm	Gas polar /%	Gas permeability /$10^{-3}\mu m^2$
1	2.43	5.14	22.40	1.52
2	2.44	4.92	13.40	27.87
3	2.42	4.54	23.10	38.59
4	2.40	5.02	27.80	196.70
5	2.43	5.13	24.10	235.10
6	2.44	4.77	27.60	620.13

The oil-water relative permeability measured by unsteady method, the temperature is formation temperature (37℃), the simulated depth of 1100m, simulated the pressure under the original formation condition (8.5MPa), and the displacement speed is 0.6mL/min.

C. Experimental Procedure

A schematic drawing of the experimental procedure is shown in Fig.1.



1. CFS Pump; 2. Six-way Valve; 3. High Pressure Vessel (Water); 4. High Pressure Vessel (Oil); 5. Pressure Sensor; 6. Core Holder 7. Flow Meter.

Fig.1. Schematic of oil-water relative permeability curves experiment.

D. Results and Disscussion

Use J.B.N [3] method to process data of both conventional core and long-term washing core, then modify the result with the Boatman empirical formula. The results are shown in Figure 2. Results of the experiments show that, the average irreducible water saturation of conventional cores is 0.31, the average residual oil saturation is 0.38, and the average water relative permeability at residual oil saturation is 0.29. The average irreducible water saturation of long-term washing cores is 0.38, the average residual oil saturation is 0.32, and the average water relative permeability at residual oil saturation is 0.27. In addition, with the water saturation increasing, the oil relative permeability of both conventional cores and long-term washing cores decreased rapidly at early stage, then decreased slowly around the equal permeability point， while the water relative permeability increased slowly. Meanwhile, with the increase of gas log permeability, both the irreducible water saturation and residual oil saturation of these two kinds of cores are reduced. The equal permeability point higher, the water saturation at the equal permeability point is lower, the water relative permeability at residual oil saturation is higher, and the oil-water seepage zone is wider. The water relative permeability at residual oil saturation of long-term water washing cores is higher than conventional cores, also the water saturation at the equal permeability point of long-term washing cores relative permeability conventional core is higher than the conventional cores. The relative permeability curves of long-term washing cores moves right and the oil-water seepage zone is wider, compared with the conventional cores [7]-[9].

The relationship curves between oil displacement efficiency and injection volume of conventional cores and long-term water washing cores are shown in Fig.3. As can be seen from Fig.3, displacement of oil in the two kinds of cores happened mainly in the early stages of water flooding with a high water-free oil recovery between 27% and 50%. Oil displacement efficiency of long-term water washing cores are generally lower than conventional cores.

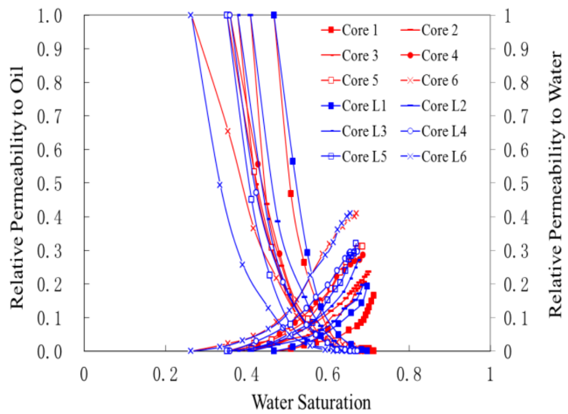


Fig.2 Relative permeability curves of long-term water washing cores and conventional cores

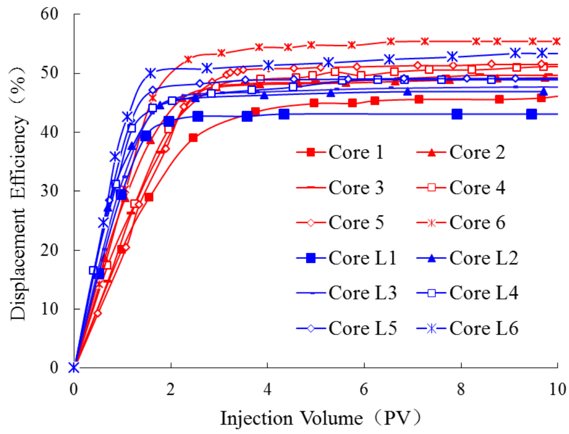


Fig.3 Relationship curves between oil displacement efficiency and injection volume

The relationship curves between oil displacement efficiency and injection volume of conventional cores and long-term water washing cores are shown in Fig.4. As can be seen from Fig.4, For the same core, both the water-free oil recovery and ultimate recovery of long-term water washing cores are lower than conventional cores. The water-free oil recovery of these two kinds cores increased on the whole with the permeability increasing [10].

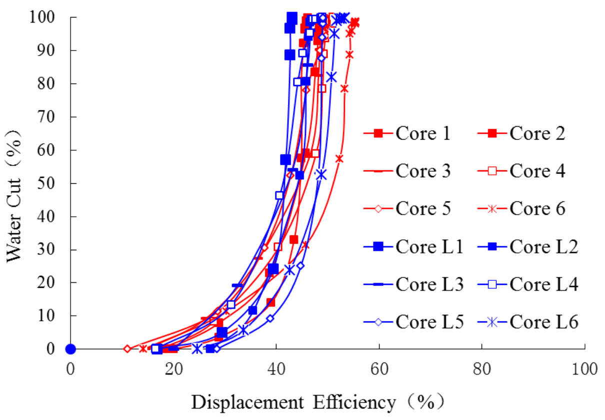


Fig.4 Relationship curves between water cut and oil displacement efficiency

The relationship curves between water cut and oil displacement efficiency of conventional cores and long-term water washing cores are shown in Fig.5. Fig.5 shows that, the water cut of long-term washing cores increased faster than conventional cores and it is also higher than conventional cores at the same injection volume, which draws a conclusion that water breakthrough time of the former is earlier than the latter with faster water cut increasing. The trend of change of water cut for both kinds of cores are approximate-when the injected water breakthrough, the water cut increased rapidly. The water cut reached 90% while the injected volume is not up to 2PV.

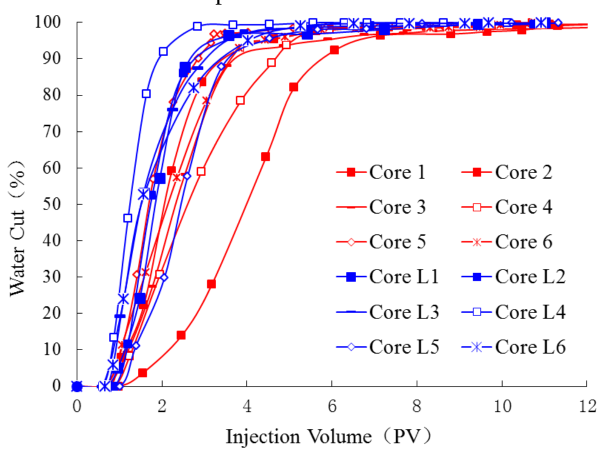


Fig.5 Relationship curves between water cut and injection volume

The water saturation at the equal permeability point of long-term water washing cores is higher than the conventional cores. This quantity is a reflection of rock wettability, which shows obviously shows that the rock wettability changed after long term water flooding.

The residual oil saturation of long-term washing cores is higher than conventional cores, which means the former got more residual oil than the latter. This is because, after long term water flooding, a large quantity of solid particles was washed out, which left certain spaces and expanded both the internal surface of pores and the dead oil zone[11]-[12].

The water relative permeability of long-term washing cores is lower than conventional cores, which reflects the practical production basically. In the practical production, increasing injection to injection wells is always carried out to one direction to increase the water saturation ,expand the water relative permeability, so as to increase the water drive sweep efficiency.

In summary, the original physical properties of cores in formation, especially the relative permeability curves, varies tremendously with the increase of injection volume. So cores which are long term washed by water reflect the virtual situation in reservoir of high water cut stage [13]-[14]. So long term water washing cores is of more important application significance. Using long term water washing cores to carry out physical simulation study is suggested under economic conditions.

III. CONCLUSIONS

1) Comparing the relative permeability experimental results of long-term water washing cores and conventional cores indicates that The water relative permeability at residual oil saturation of long-term water washing cores is higher than conventional cores, also the water saturation at the equal permeability point of long-term washing cores relative permeability conventional core is higher than the conventional cores. Oil displacement efficiency of long-term water washing cores are generally lower than conventional cores. both the water-free oil recovery and ultimate recovery of long-term water washing cores are lower than conventional cores，while the water cut of long-term washing cores increased faster than conventional cores.

1) Analysis of comparing the relative permeability experimental results of long-term water washing cores and conventional cores shows that the rock wettability changed after long term water flooding. This is because after long term water flooding, a large quantity of solid particles was washed out, which left certain spaces and obtained long term washing cores a higher remaining oil saturation。Using long term water washing cores to carry out physical simulation study is suggested under economic conditions.

ACKNOWLEDGMENT

This work was supported in part by a grant from National Science and Technology Major Project of the Ministry of Science and Technology of China (Grant No. 2011ZX05012-003), and in part by National Natural Science Foundation of China (Grant No. 50874114). The authors would like to give special thanks to the laboratory staff of CMOE Key Laboratory in China University of Petroleum, Beijing for their timely help and sincere cooperation.

REFERENCES

[1] Fuzhen Zhao, Xiangmin Zeng, Xinhua Chen, “The influence and correction of frozen process on the core physical parameters,” *Xinjiang Petroleum Geology*, vol.40.pp. 208-215, April 2013.

[2] JONES.S.C,ROSZELLE.W.O, “Graphical techniques for determining relative permeability from displacement experiments,” *JPT*, vol. 78, pp. 5911-5921, October 1973.

[3] Kefeng Lu, Zhenzhong Xu, Jinglin Feng, “A pratical method of quantitative chararcterization of oil-water transition zone saturation distribution”, *China Offshore Oil and Gas*, vol. 59, pp. 154-158, January 1975.

[4] Sigmund, P.M. and McCaffery, F.O., "An Improved Unsteady-State Procedure for Determining the Relative-Permeability Characteristics of Heterogeneous Porous Media," *SPEI*, vol.3.pp. 81-91, January 1988.

[5] Morrow, N.R., Lim, H.T., and Ward, J.S., "Effect of Crude-Oil Induced Wettability Changes on Oil Recovery," *SPEFE,* vol. 18, pp.197–208, July 1997.

[6] Oil-gas field development Speciality Standardization Committee, SY/T 5345-1999, Determination of oil-water relative permeability, Beijing: State Bureau of Petroleum and Chemical Industry.

[7] Craig, F.F. Jr., "The Reservoir Engineering Aspects of Water flooding, Monograph Series", *SPE*, vol.39. pp. 343-348, June 2012.

[8] Treiber, L.E., Archer, D.L., and Owens, W.W., "A Laboratory Evaluation of the Wettability of Fifty Oil-Producing Reservoirs," *SPEI* (Dec.1972) 531-40; *Trans.*, AIME, 253.

[9] Johnson, E.F., Bossler, D.D. and Naumann, V.O.: "Calculation of Relative Permeabilityfrom Displacement Experiments", *Trans AIME* (1959) 216, 370.

[10] Welge, H.J.: "A Simplified Method for Computing Oil Recovery by Gas or Water Drive", *Trans AIME* (1952) 195, 91.

[11] Buckley, S.E. and Leverett, M.C., "Mechanismof Fluid Displacement in Sands", *TransAIME* (1942) 146,107.

[12] Rapoport, L.A. and Leas, W.V.: "Properties of Linear Waterfloods" *Trans AIME* (1953) 198,139-148.

[13] MeLatchie,A.S.,Hemstock, R.A.and Young J.W."The Effective Compressibility of Reservoir Rock and Its Effects on Permeability" *Trans. AIME* vol.21.pp. 386-388, June 1958.

[14] C.R. Mckee, A.C. Bumb and R.A. Koenig, "Stress dependent permeability and porosity of coal and other geologic formations," *SPE Formation Evaluation*, vol.3.pp. 81-91, January 1988.