Study of Tight Core Electrical Properties Measurement by Porous Plate

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ABSTRACT

Porous plate method faces some challenges in tight cores, for example, how to displace water in small pores and accurately determine saturation. In this paper, the method of tight core electrical properties measurement by porous plate is discussed. Firstly, we selected three tight cores saturated with brine to conduct desaturation by porous plate both with gas displacement and with oil displacement. The experimental results indicate that the lowest permeability of gas displacement is about 0.1 mD, which is lower than that of oil displacement. Moreover, the equilibrium time of the gas displacement in each step is much shorter than that of the oil displacement. Therefore, gas displacement is more suitable for tight core by porous plate. Secondly, we selected four other cores with permeability values between 0.28 mD and 454.21 mD, and measured their saturation exponents by porous plate gas displacement both with and without pore pressure. The experimental results show that the saturation exponents of the low permeability cores with pore pressure are smaller than that without pore pressure. The largest difference of the saturation exponent between two methods is up to 0.64. However, for high permeability cores, the effect of the pore pressure is negligible. Therefore, the pore pressure must be considered in electrical properties measurement of tight cores. Lastly, the method of electrical properties measurement by porous plate has been built; it uses gas to displace water in tight cores with pore pressure applied at the end of the core. In our experiments, a porous plate with maximum breakthrough pressure up to 1,000 psi was tested. Moreover, the method of water saturation calculation, when pore pressure is applied, is presented; it is based on Quizix pump automatic records and core weighing. The experimental results of tight sandstones from the Erdos Basin, China, show that the method can not only gain ideal resistivity index curves but can also reduce experiment time as possible as.

INTRODUCTION

Archie's equation is used to calculate reservoir oil/gas saturation from electrical logging [1][2]. Three methods of desaturation are widely used in rock electrical parameters measurement: displacement method, evaporation method and centrifugation method. Sprunt analyzed the experimental results of twenty-five cores that measured by different methods in different labs [3]. Fleury et al. studied centrifugation method that used in rock resistivity experiment [4]. Springer, Korsbech and Aage discussed the application of evaporation method in measuring saturation exponent of tight carbonate rock [5]. Walls pointed that the saturation distribution of porous plate method is more reliable than that of centrifugation method [6]. The semi-permeable porous plate method is believed to be the best method for resistivity index measurement. There are two main difficulties in resistivity index measurement of tight cores. First, since the radius of throats in tight cores is small, the displacement differential pressure must be high enough, especially for semi-permeable porous plate displacement method. Another difficulty comes from the calculation of water saturation. These two difficulties highly affect the measurement of rock saturation exponent.

STUDY OF DISPLACEMENT METHOD

Temperature and pressure have significant effects on rock electrical properties, so equipments of rock resistivity measurement under reservoir conditions are widely used in recent years, in which oil or gas is usually used as non-wetting phase. Which is more suitable for electrical experiment of tight core? Therefore, the comparison between gas displacement and oil displacement is firstly conducted in this paper. Table 1 lists the rock properties of three cores (No.82, 96, 95) used for the comparison between gas and oil displacement experiments. The different experimental tests are listed below:

1. Three tight cores were removed the oil by CO_2-solvent extraction (82℃, 15 MPa) and mineral salt in pores by distilled water, and then porosity and permeability were measured after dried in an oven.
2 Cores and semi-permeable porous plate were fully saturated with NaCl brine (10,000 ppm) by vacuum in a closed vessel, and then pressurized for two days at 30MPa. After saturation, the saturated brine volume and pore volume were compared to evaluate the extent of core saturation.
3. The core was loaded in a coreholder. The semi-permeable porous plate, saturated with brine, was placed at the end of the core. The gas displacement experiment at constant differential pressure was conducted. When the resistivity change rate less than 0.1% per hour, the fluid distribution and capillary pressure can be seen as equilibrium and the capillary pressure is equal to the differential pressure (DP). The pressure of core exit was atmosphere and the volume of displaced water can be measured at the exit of coreholder.
4. After the gas displacement, the procedure 2 was repeated and the oil displacement experiment at constant differential pressure was conducted on saturated cores, in which white mineral oil (density 0.82g/cm^3, kinematic viscosity 5m^2/s) was used.

In the experiment, the maximum differential pressure was 0.4 MPa (about 58 psi), and the minimum water saturation was 0.77. Considering the limit of experiment time and the aim of the comparison between experiments, the pressure was not increased further. Table 2 shows the experiment results of gas displacement and oil displacement.

Based on the comparison, the following conclusions can be obtained. Firstly, the equilibrium time of gas displacement is much shorter than that of oil displacement at every differential pressure step. Secondly, gas can displace water in tight core while oil cannot. In other words, the lowest permeability of gas displacement is lower than that of oil displacement. In the case of core 95, the equilibrium time of gas displacement is 14.56 hours at the differential pressure of 0.05 MPa, and its water saturation is decreased by 2%; when differential pressure is increased to 0.2 MPa, water saturation is decreased by 5%. When oil is used to displace the water in the same core, there is no production at differential pressure of 0.05 MPa, and even when differential pressure is increased to 0.4 MPa, the water saturation is only decreased by 1% after 33.97 hours. According to these results, the lowest permeability of gas displacement is about 0.1 mD, while that of oil displacement is higher than 0.1 mD.

In the previous experiments, there is no applied pore pressure. To study the effect of pore pressure on rock resistivity, four additional cores (No.1, 2, 5, 6) are selected to conduct comparison test, and the parameters of cores are listed in Table 1. The experimental procedures are similar to the gas displacement test described above. Firstly, we conducted the gas displacement tests without pore pressure using 5 MPa confining pressure. And then the gas displacement tests with 5 MPa pore pressure using 10 MPa confining pressure, was conducted. In both tests, the effective pressure is the same (5 MPa).

Fig.1, Fig.2, Fig.3 and Fig.4 show the experimental results of the four cores. Saturation exponents are compared in Fig.5. It is observed that saturation exponents with pore pressure are all less than that of without pore pressure, and pore pressure has much more effect on electrical properties of tight core than that of high permeability core. The porosity and permeability of core 1 and core 5 are relatively high, and the maximum difference of saturation exponent between the tests performed with and without pore pressure is 0.16. However, the maximum difference of saturation exponent for tight core 2 and core 6 is 0.64. Therefore, pore pressure should be applied to measure tight rock electrical properties; if not, saturation exponent will be overestimated and oil/gas saturation underestimated.

IMPROVEMENT OF EXPERIMENT

Through the analysis above, gas is more suitable as the non-wetting phase for electrical experiment of tight core, and pore pressure should be applied. We improved the existing experimental method to meet the need of tight core electrical measurement.

A semi-permeable porous plate with high breakthrough pressure

Conventional ceramic porous plate (breakthrough pressure is 15 bar (217 psi)) cannot provide high differential pressure for tight core. For this reason, a new water-wetting semi-permeable porous plate is selected and used in this study, the maximum breakthrough pressure of which is up to 1,000 psi.

The calculation of saturation

As the pore volume of tight core is relatively small, and water saturation calculated only by the displaced brine volume recorded by Quizix pump can lead to significant error. Hence, core weighing is adopted to calibrate the saturation. Assuming the weight of 100% water saturated core is G_0, and the weight of core at the end of displacement is G_r, the water saturation of the core can be expressed as:

$$S_{wr} = \frac{G_o - G_r}{V_p \rho_w} \quad (1)$$

V_p is pore volume of core, and ρ_w is fluid density. Supposing S_{wr}' is water saturation at the end of displacement, which is calculated according to Quizix pump, and S_{wn}' is water saturation in some pressure step, which is calculated according to Quizix pump, then the water saturation in this pressure step can be calibrated to S_{wn} as follows:

$$S_{wn} = S_{wr} + \frac{1-S_{wr}}{1-S_{wr}'}(S_{wn}' - S_{wr}') \quad (2)$$

EXPERIMENT RESULTS

Tight sandstone cores from Erdos Basin, China were selected to conduct electrical experiment of gas displacement using an upgraded apparatus. Considering the the experimental time of constant pressure displacement is relatively long, the constant rate displacement was adopted. The injecting cylinder of Quizix pump was set at a very slow rate (0.00095 ml/min) to ensure equilibrium of fluid distribution, and water saturation was calibrated according to the proposed method above. The frequency for the electrical measurements is 1000Hz. Fig.6 shows the experiment relation between resistivity index and water saturation of one tight core. This core is a typical tight core, and its porosity and permeability are 10.3% and 0.15 mD respectively. Data analysis indicates that its saturation exponent is 1.75, water saturation is finally decreased to 42% because of the use of high breakthrough pressure plate.

CONCLUSION

1. The equilibrium time of gas displacement is much shorter than that of oil displacement. The lowest permeability of gas displacement is about 0.1 mD, while that of oil displacement is higher than 0.1 mD. Therefore, gas displacement is more suitable for desaturation of tight core by porous plate.
2. The experimental results show that the saturation exponents of the low permeability cores with pore pressure are smaller than that without pore pressure. Moreover, pore pressure has much more effect on saturation exponent of tight core than that of high permeability core.
3. The experimental method is improved, making possible gas displacement in the samples. The improved method can not only gain ideal resistivity index curves but also can improve displacement efficiency as possible as.

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Table 1 Porosity and permeability of three tight cores

Core No.	82	96	95	1	2	5	6
Porosity (%)	13.6	11.4	10.4	19.67	15.85	29.18	13.88
Permeability mD)	0.76	0.38	0.14	138.705	8.74	454.21	0.208

Table 2 Tight core experimental results of gas displacement and oil displacement

Core No.	K (mD)	Gas displacement			Oil displacement		
		Differential pressure (MPa)	Equilibrium time (Hour)	Water saturation(%)	Differential pressure(MPa)	Equilibrium time(Hour)	Water saturation(%)
82	0.75	0.05	2.17	0.96	0.05	8.64	0.99
		0.1	2.41	0.95	0.1	6.17	0.97
		0.2	39.17	0.82	0.2	222.92	0.87
96	0.38	0.2	2.33	0.99	0.2	6.53	1.0
		0.4	5.48	0.85	0.4	48.65	0.89
95	0.14	0.05	14.56	0.98	0.2	2.60	0.99
		0.1	4.74	0.97	0.3	14.75	0.99
		0.2	5.45	0.95	0.4	16.62	0.99

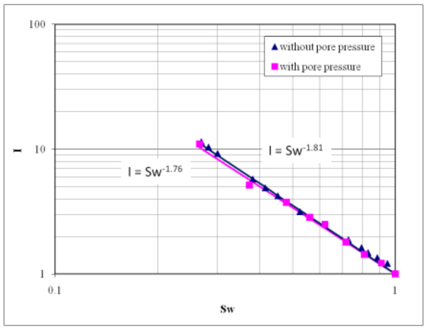

Fig.1 Electrical experimental results of Core 1

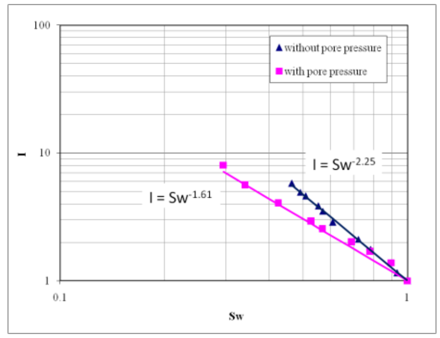

Fig.2 Electrical experimental results of Core 2

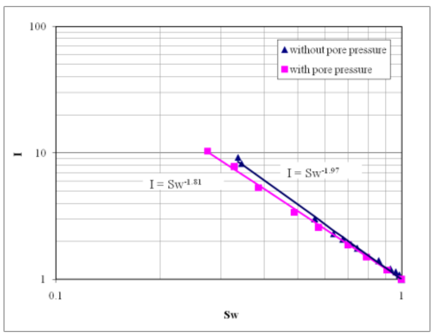

Fig.3 Electrical experimental results of Core 5

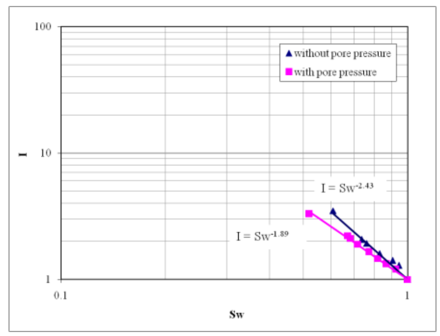

Fig.4 Electrical experimental results of Core6

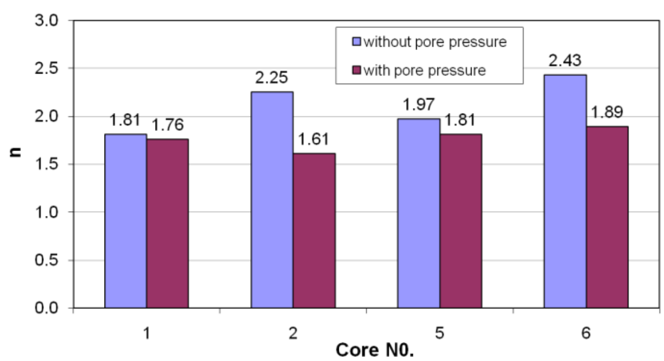

Fig.5 The effect of the pore pressure on saturation exponent n

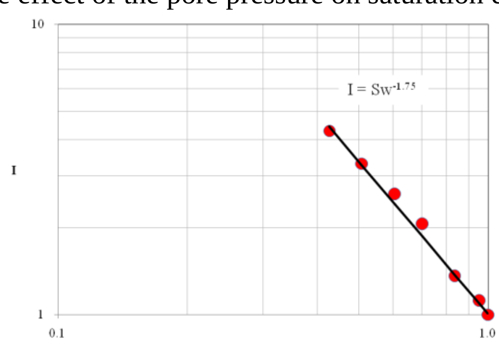

Fig.6 Experimental results of one tight core from Erdos Basin, China