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Oil Saturation Is Determined by Different Experimental Methods

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Abstract

Oil saturation was an important parameter of reservoir evaluation, which had important guiding significance for oilfield development. In this paper, the oil saturation of tight oil in G area was studied, and the original oil saturation of the study area was studied by using the comprehensive experimental method. The original oil saturation of tight oil in the study area was determined by *J* function method, rock electricity method and oil-based mud coring method. The results showed that through the comparison of three experimental methods, it could be concluded that the *J* function method leads to the low value of oil saturation in the study area. The oil-based mud coring method was more suitable for the determination of oil saturation in this area than the other two methods because it needs to meet too many conditions and the calculation results were also low. G area was located in Qili Village, Ordos Basin.

Keywords

Oil Saturation, *J* Function, Archie Formula, Oil-Based Mud Coring

1. Introduction

Petroleum geological reserves are an important indicator of oilfield exploration results, and also an important basis for guiding oilfield production and operation. Therefore, it is very important to reasonably determine the original oil saturation of the reservoir to improve the reliability of geological reserves. At present, there are three commonly used methods to determine the original oil saturation of the reservoir in the calculation of reserves by volumetric method: closed coring analysis method, mercury injection method and logging interpretation method. The sealed coring analysis method is the most direct and accurate method to determine the original oil saturation of the reservoir. Usually, the relationship chart is established by using the measured original water saturation (corrected value) and porosity (or permeability) of the core, and the water saturation is obtained by looking up the relationship chart, and then the oil saturation is obtained (Yang et al., 1990). Affected by various factors, there is a significant deviation between the measured oil-water saturation value of the closed coring well and the real underground saturation value, so the error correction of the measured saturation data must be carried out in actual use (Sun et al., 2012; Ye et al., 2016). The capillary pressure curve measured by mercury intrusion method is the key data for studying the pore structure of rock and calculating the original oil saturation (Yang & Wei, 2008; Zhu, 2003). When using the capillary pressure data to obtain the original oil saturation, the dimensionless capillary force curve of each core sample is first obtained, and the corresponding *J* function curve is obtained to eliminate the influence of porosity and permeability on the capillary force. Then, the average of many dimensionless *J* curves is obtained, and a reservoir average *J* function curve is obtained. The capillary pressure curve reflecting the average characteristics of the reservoir is calculated by the relevant formula, and the original oil saturation can be calculated (Lyu & Bi, 1996; Hu et al., 2012). The logging interpretation method is mainly based on the Archie formula (Archie, 1942), with the help of rock physical properties and resistivity logging data to calculate water saturation. In Archie formula, lithology coefficient *a* and *b*, cementation coefficient *m* and saturation index *n* are key rock electrical parameters, which can be calculated and determined by weighted regression method, fuzzy regression method or saturation regression method (Wang, 2014). In this paper, the Chang 6 layer in G area was studied to determine the oil saturation in this area.

2. Oil Saturation Is Calculated by Different Experimental Methods

2.1. *J* Function Method to Determine the Original Oil Saturation

In this paper, the capillary pressure curve is measured by the mercury intrusion method, and the original oil saturation in the study area is determined by the *J* function method. The lithology of the Chang 6 reservoir in the study area is feldspar sandstone, and the pore throat is mainly medium and small pore throat. The throat is poorly sorted, and has a weak micro-small pore throat system that allows fluid to pass through, which occupies a considerable proportion in the whole pore system, resulting in the characteristics of less oil saturation in oil and gas reservoirs. Using the mercury intrusion data of 17 rock samples in Chang 6 of the study area, the J-S_{Hg} relationship of the stratum was plotted by *J* function conversion method, and the average value of *J* function of the stratum was fitted. According to the relationship between *J* function and capillary pressure P_c:

$$J = P_c * \sqrt{\frac{K}{\varphi}} \Big/ \left(\delta_{Hg} * \cos\theta_{Hg}\right) \tag{1}$$

$$c = \sqrt{\frac{K}{\varphi}} \Big/ \left(\delta_{Hg} * \cos\theta_{Hg}\right) \tag{2}$$

$$P_c = J/c \tag{3}$$

In the equation: δ_{Hg}—Interfacial tension of mercury-air system;

θ_{Hg}—The contact angle of mercury-air system is 140˚;

P_c—capillary pressure, MPa;

When porosity (φ) is decimal, $1/(\delta_{Hg}*\cos\theta_{Hg})$ is 0.086.

In this paper, the mercury injection data of 17 rock samples in Chang 6 section of the area are converted by *J* function to obtain *J*-S_{Hg} relationship diagram, and an average *J* function curve of this section is fitted. The average capillary pressure curve obtained from the average *J* function curve by $P_c = J/C$ conversion is shown in **Figure 1**.

According to the relationship between porosity and median radius and the relationship between median radius and median pressure, the relationship can be fitted in two XY scatter plots (**Figure 2**, **Figure 3**) respectively, and then the median radius and median pressure calculated by *J* function method can be obtained through the relationship. The calculated median pressure is brought into the relationship in **Figure 1**, and then the maximum mercury saturation can be obtained. The mercury saturation at this time is the original oil saturation determined by *J* function method, and then the original oil saturation of 17 samples in the study area is determined, as shown in **Table 1**:

Table 1. *J* function method to determine the original oil saturation and measured oil saturation.

Porosity /%	Measured median pressure /MPa	Measured median radius /μm	*J* function method Calculation median radius /μm	*J* function method Calculation median pressure /Mpa	*J* function method Calculation oil saturation /%
8.80	5.57	0.13	0.07	10.50	39.37
8.00	17.94	0.04	0.07	10.50	39.37
5.20	15.73	0.05	0.05	14.70	53.51
10.70	7.94	0.09	0.08	9.19	33.77
5.90	6.96	0.11	0.06	12.25	45.84
5.40	7.46	0.10	0.05	14.70	53.51
8.70	6.91	0.11	0.07	10.50	39.37
9.30	7.12	0.10	0.08	9.19	33.77
8.70	20.02	0.04	0.07	10.50	39.37
9.80	6.85	0.11	0.08	9.19	33.77
8.20	7.72	0.10	0.07	10.50	39.37
9.20	7.77	0.09	0.08	9.19	33.77
8.20	42.48	0.02	0.07	10.50	39.37
6.10	7.46	0.10	0.06	12.25	45.84
4.60	15.40	0.05	0.05	14.70	53.51
5.90	46.44	0.02	0.06	12.25	45.84

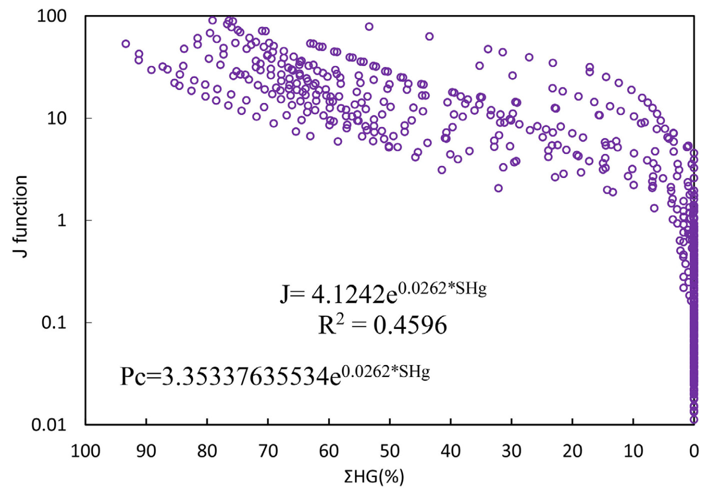

Figure 1. *J* function curve of Chang 6 reservoir.

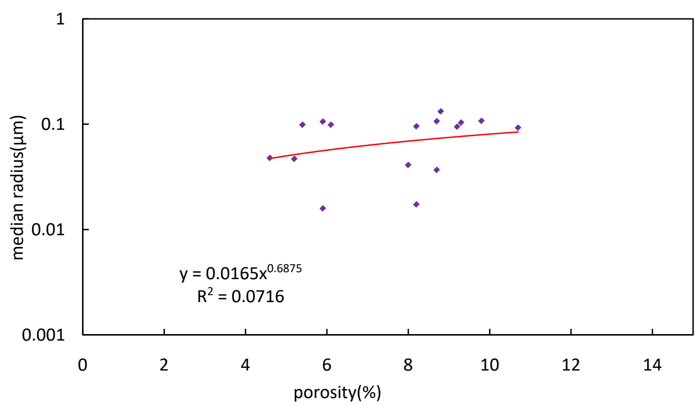

Figure 2. Relationship between median radius and porosity of Chang 6 reservoir.

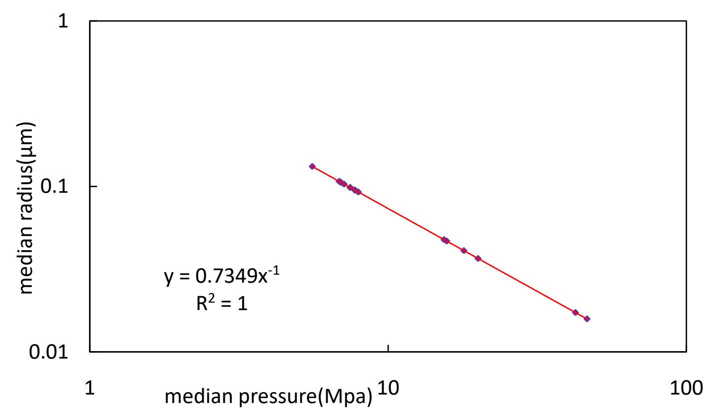

Figure 3. Relationship between median radius and median pressure of Chang 6 reservoir.

2.2. Oil-Based Mud Coring Method to Determine the Original Oil Saturation

High-precision oil saturation data can be obtained by two methods of oil-based mud coring or pressure sealed coring. The purpose of oil-based mud coring is to avoid the entry of mud slurry and to avoid the overflow of irreducible water, and to calculate the original oil saturation according to the size of irreducible water that cannot be overflowed in the mud. Pressure sealed coring is to obtain cores that are not contaminated by mud and can maintain formation pressure by using sealed coring tools that can maintain formation pressure in water-based mud drilling. Then the water saturation and oil saturation are measured by chromatography or distillation method, which is the most accurate method to determine the original oil saturation. It is also the basis for the establishment of other indirect methods and the basis for comparative verification. However, due to the high cost of oil-based mud coring wells and closed coring wells, the oil-based saturation value measured on site is usually used as the relationship between air permeability and oil-based saturation. If the oil column height in large reservoirs is taken into account, the saturation of ordinary coring wells can be calculated by multiplying the gas permeability by the pressure-oil saturation diagram. Using oil-based mud coring, the original oil saturation in the study area was measured, and the oil-based mud cores in the area were analyzed.

In order to obtain the original oil saturation, this study uses the xx well long 6 sealed coring data to obtain the original oil saturation. The footage is 108.02 m, the core length is 103.22 m, and the recovery rate is 95.5%. The oil-based mud length 6 coring section of the well is 493 - 604 m. The lithology is fine sandstone, and the oil-bearing grade is oil spot and oil immersion. Timely sampling and analysis were carried out in the oilfield, and 285 oil-water saturation samples were obtained. The analysis data have high reliability. The porosity and water saturation measured by the oil-based drilling fluid coring reservoir section are plotted as a scatter plot (**Figure 4**), and the φ-S_w relationship curve is fitted to determine the porosity value of the reserve calculation, and then the formula is applied to the corresponding water saturation calculation. Then the water saturation in the study area can be obtained.

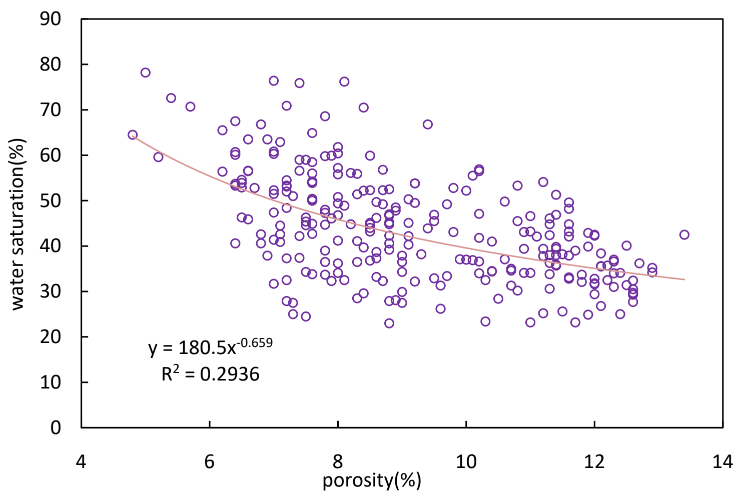

Figure 4. Relationship between coring porosity and water saturation in xx well.

Through the XY scatter diagram of porosity and water saturation, the regression analysis relationship can be made, and the water saturation can be calculated by the regression analysis formula, and then the original oil saturation can be calculated. Through calculation, it can be found that the calculated water saturation of the 285 sets of samples sampled in the study block is greater than the measured water saturation. Therefore, it can be seen that the sampled samples have the phenomenon of water loss. Then the water loss correction can be carried out, that is, the relationship obtained by regression analysis is to correct the measured water saturation. In summary, after water loss correction, the original water saturation of xx wells in the study area is between 35.79% and 67.36%, with an average of 57.07%.

2.3. Archie Formula to Determine the Original Oil Saturation

The saturation is calculated by Archie formula:

$$S_w = \sqrt[n]{\frac{abR_w}{\varphi^m R_t}} \tag{4}$$

In the equation: R_w—Formation water resistivity (Ω·m);

m—cementation index;

n—saturation index;

a, b—lithology factor;

φ—effective porosity (f).

The experimental data corresponding to formation factor (F) and porosity (φ) were measured by 163 rock samples in this area. Through regression analysis, the regression relationship is a power function curve (**Figure 5**), and the equation is:

$$F = \frac{a}{\phi^m} = \frac{1.2547}{\phi^{0.9299}} \tag{5}$$

$$R^2 = 0.948 \tag{6}$$

At the same time, using these samples, 13 sets of resistance index (I) and water saturation (S_w) data were measured by water loss method. After regression analysis, the regression relationship was a power function curve (**Figure 6**), and the equation was:

$$I = \frac{b}{S_w^n} = \frac{1.1326}{S_w^{2.016}} \tag{7}$$

$$R^2 = 0.948 \tag{8}$$

Due to the crossplot and formula of porosity and formation factors in each layer, it can be seen that the φ-F crossplot has deviated from the normal Archie model. Considering that the reservoir of the target layer in the study area is relatively dense, the pore structure is complex, and the shale is contained, which does not conform to the pure sandstone assumed in the original hypothesis of the Archie formula. Therefore, this study adopts the method of variable parameter m value, and obtains the formula of m in each layer of the study area as follows (**Figure 7**).

Through the above experiments, the rock electrical parameters of the Chang 6 layer in the study area are determined as shown in Table 2.

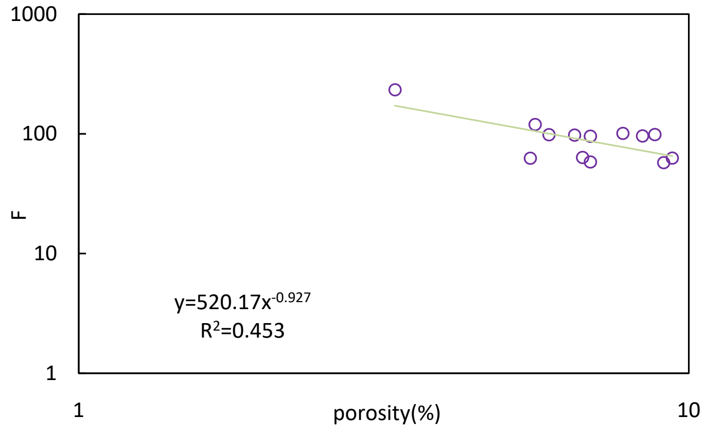

Figure 5. Chang 6 formation factors and porosity relationship diagram.

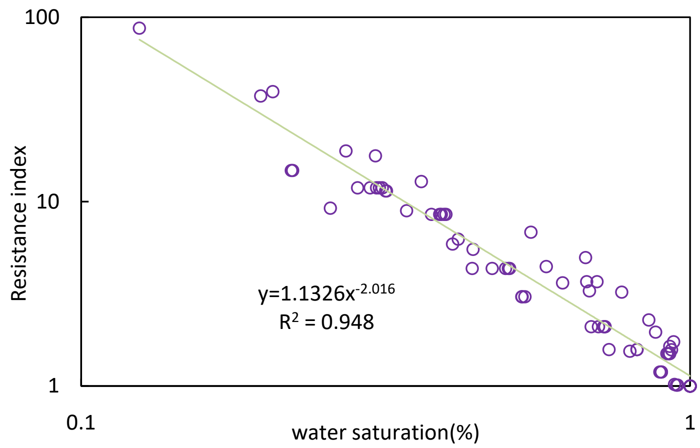

Figure 6. The relationship between resistance index and water saturation of Chang 6.

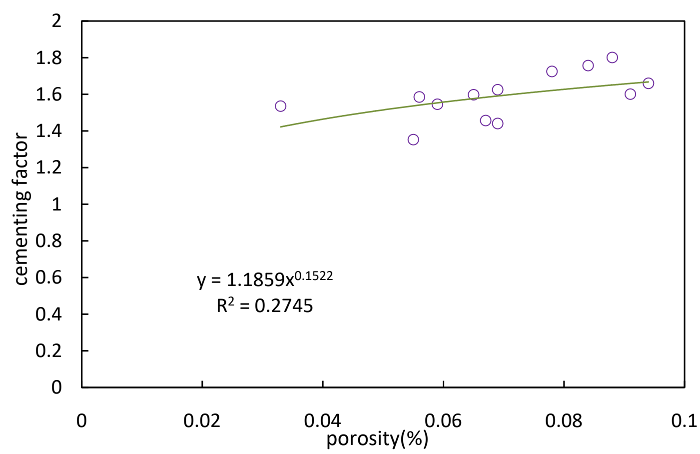

Figure 7. Relationship between porosity and cementation coefficient of variable *m* value method.

Table 2. Summary of rock electrical parameters of Chang 6 layer.

a	*b*	*m*	*n*	variable *m*
1.2547	1.1326	1.573	2.016	$1.1859*POR^{0.1522}$

In this paper, the data of the sand body of the Chang 6 section of the well xx in the study area are read, the average depth of the sand body is read, and the average oil saturation of the sand body is calculated. The oil saturation calculated by the Archie formula in the Chang 6 section of the study area is between 16.36% and 38.32%, with an average of 28.15%. The oil saturation of the sand body measured by the variable m value method is between 11.9% and 34.4%.

3. Conclusion

1) The oil-based mud coring method is a direct means to obtain the original oil saturation of tight sandstone reservoirs, but it is difficult to implement because of the need to retain the initial condition of the formation. For example, in practical work, it is very difficult to require the core to meet the water loss of 0, even if it can be achieved, the cost is very high, so there are not many data to directly determine the original oil saturation of the reservoir by using the core. And the oil saturation calculated in the study area is lower than the other two methods.

2) When there are few data to directly measure the original oil saturation of the reservoir from the core, the method of calculating the original oil saturation of the reservoir according to the capillary pressure curve provides an effective way to determine the original oil saturation of the reservoir. However, in the process of displacement, due to the excessive pressure, it will break through the capillary pressure of some immovable capillaries. Therefore, the oil saturation calculated by mercury intrusion method will get lower results. Therefore, the calculated oil saturation will be low.

3) Archie formula has obvious limitations and shortcomings, whether it can be directly applied to the calculation of underground reservoir saturation is still questionable. Therefore, when calculating oil saturation by Archie formula, the formula should be corrected to obtain more accurate oil saturation. In this paper, the correction of variable m value method is carried out.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Archie, G. E. (1942). The electrical Resistivity Log as an Aid in Determining Some Reser-

voir Characteristics. *Transactions of the AIME, 146,* 54-62.
https://doi.org/10.2118/942054-G

Hu, Y., Yu, X. H., Chen, G. Y., & Li, S. L. (2012). Classification of the Average Capillary Pressure Function and Its Application in Calculating Fluid Saturation. *Petroleum Exploration and Development, 39,* 778-784.
https://doi.org/10.1016/S1876-3804(12)60104-9

Lyu, M. G., & Bi, H. B. (1996). Initial Oil Saturation Determination by Capillary Pressure Curve. *Petroleum Exploration and Development, 23,* 63-66.

Sun, P., Cui, S. T., & Liu, J. Q. (2012). Method of Sealed Coring Saturation Correction Based on Pore Structure. *Lithologic Reservoirs, 24,* 88-92.

Wang, N. (2014). Effect of Temperature, Pressure and Salinity on Core Electricity Parameters. *Science Technology and Engineering, 14,* 141-145.

Yang, S. L., & Wei, J. Z. (2008). *Reservoir Physics*. Petroleum Industry Press.

Yang, S. T., Fan, S. T., Chen, Y. Q. et al. (1990). *Method for Calculating Oil and Gas Reserves* (pp. 18-62). Petroleum Industry Press.

Ye, Q., Zha, Y. Q., Li, F. Y. et al. (2016). The Study of a New Method of Calibrating the Sealed Core Saturation. *Science Technology and Engineering, 16,* 179-184.

Zhu, J. J. (2003). Relationship between Capillary Pressure Data of Intrusive Mercury Method and Oil Saturation. *Petroleum Geology & Oilfield Development in Daqing, 22,* 32-34.