COMPREHENSIVE CORRECTION METHOD OF AIRTIGHT CORING SATURATION BASED ON CORE CLASSIFICATION

by

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The indoor comprehensive analysis of core saturation of airtight coring wells is an important part of well logging interpretation. According to the saturation data, the geological reserves can be accurately calculated, and the remaining oil saturation and water-flooded zone in the later stage of the production well can be accurately evaluated. Due to the influence of many factors in the coring process and the experiment process, the sum of the core oil and water saturation is usually not equal to 100%. At present, conventional airtight coring correction method is generally to analyze the oil-water saturation, and then correct the data of the same factors that affect the results. This article combines two methods for saturation correction of XX oilfield in China. For cores with consistent missing factors, mathematical statistics are used to correct the saturation. When most of the rock pores have irreducible water and remaining oil, the phase percolation split method is used for the correction after the experimental analysis. By comparing with the logging interpretation results and the results of adjacent wells, the feasibility of the comprehensive correction method can be verified.

Keywords*: loss, saturation correction, mathematical statistics, shunt method, phase percolation split method*

Introduction

The main task of logging interpretation is to solve the problem of reservoir parameter evaluation in terms of porosity, permeability and oil-water saturation [1]. At present, in major oil fields, oil and gas saturation is mainly used to evaluate oil and gas reservoirs and calculate geological reserves. It can also evaluate reservoir potential and development effects in production wells and exploratory wells [2]. Interpretation of logging saturation using sealed coring data has an important impact on the accurate calculation of hydrocarbon saturation and the evaluation of oil and gas reservoirs. It can be used as the basis and important basis for development plans and plan adjustments [3, 4].

At present, airtight coring mainly adopts two methods: pressure-maintained airtight coring and atmospheric airtight coring [4-6]. However, the pressure-holding airtight coring method is costly and has complicated technical requirements. Therefore, oilfields often use

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mature and low-cost atmospheric airtight coring technology to obtain oil-water saturation data in the formation [7, 8]. However, in the process of airtight coring at atmospheric pressure, the volume of fluid will change. The pore volume of the rock also changes due to the changes in pressure. For example, the volatilization of oil, gas and water is affected by the depressurization and degassing of crude oil. The invasion of drilling fluid and immature technical conditions will lead to deviations in oil and water saturation [4, 5].

Therefore, based on the oil-water saturation measured by conventional closed coring method. The sum of these saturation is often less than 100%. In low permeability tight reservoirs, the porosity is generally less than 12%, and the permeability is mostly less than 1 mD. How to accurately evaluate the original water saturation is of great significance for exploration and development [9]. Compared with conventional reservoirs, the original water saturation of low permeability tight sandstone reservoirs is generally higher [10-13]. A small error may lead to a large deviation in reserves calculation results, so it is necessary to correct oil saturation accurately. In unconventional reservoirs, deviations in the calculation of water saturation will lead to incorrect results of oil and gas resource evaluation and reserves estimation. This may mistakenly abandon a potential usable oil field because of overestimation. It is urgent to accurately calculate the water saturation based on the coring data [14].

Conventional airtight coring method

Due to the large differences in geological conditions and geographic environments in different areas, different drilling methods are often used in exploration and development. Therefore, technologies such as core-while-drilling, pressure-maintaining coring and borehole wall coring have also emerged, which are used to obtain sealed coring data, fig. 1, [2, 10].

Core-while-drilling technology can carry out coring at the same time during drilling. It speeds up work efficiency by eliminating frequent tripping in traditional methods [15]. The pressure- maintaining coring technology uses a special core barrel and a specific coring method, which allows the core to be taken out to maintain the original pressure and temperature of the formation [16]. The core will not be damaged due to the change of formation pressure. The fluid in the core sample taken by this technology will not be lost or volatilized due to changes in pressure and temperature. But this technology has higher requirements for equipment, so the cost is much higher than other technologies.

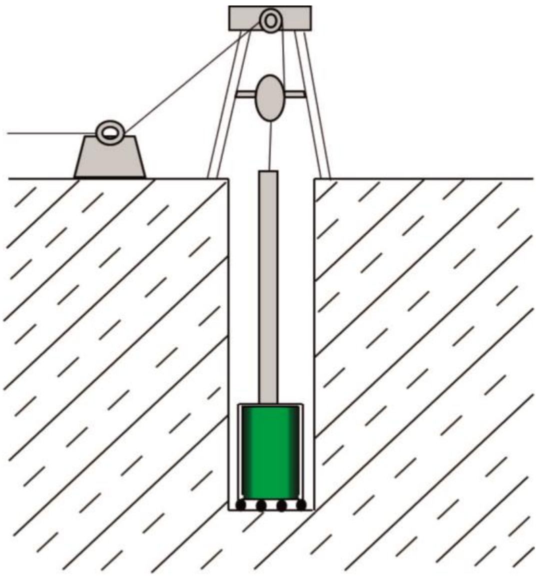

Figure 1. Schematic diagram of coring

The sidewall coring technology mainly includes collisional sidewall coring and rotary sidewall coring. In collisional sidewall coring, it uses gamma instrument to determine target horizon depth. Then, it uses a cable to lower the core holder and the coring gun into the open hole. The core seat was driven into the well wall and the core was taken out after the gunpowder exploded in the coring gun. In rotary borehole coring, it uses hydraulic power to drill into the formation and obtain cores [17, 18].

Factors affecting saturation of closed coring

Under ideal condition, the sum of oil saturation and water saturation is 100%. However, due to the influence of various factors, oil saturation and water saturation will change after airtight coring. Then, the measured oil saturation and water saturation are often not equal to 100%. It is quite different from the real value in the stratum. Generally speaking, the influencing factors of rock water saturation measurement are mainly divided into coring process and experimental analysis process [19].

At first, In the process of rock coring [4, 12], intrusion occurs after the drilling fluid contacts the core. The saturation will be lost because part of the fluid in the core is discharged. Secondly, During the core extraction process, the volume of rock pores and fluids are changed due to the pressure change from underground to the ground. At this time, some fluid will overflow. When it is lifted on the core barrel, it will be driven by dissolved air and pressure-reducing and draining. It will also cause fluid in the core to drain. Thirdly, after the core is out of the barrel, the oil will evaporate because it will be exposed to the air for a period of time. The phenomenon of volatilization or absorption of moisture occurs due to the different external environment. This will result in lower or higher water saturation.

In the process of experimental analysis, during the experiment, the rocks will be exposed to the air long or a short time, causing the volatilization of oil and water. Freezing and preserving the core before the test will cause the volume to expand and then reduce the saturation. In the process of measurement, the influence of uncontrollable factors such as equipment and human operation process leads to errors in the measurement results [20]. On the other hand, the constant existence of capillary force increases the additional flow resistance of the core, so the oil-water saturation obtained in the displacement experiment will also be lost [19, 22-25]. This article starts from the classification of loss and oil-water saturation. Comprehensive application of the airtight coring saturation correction method, the accuracy of the correction result has been greatly improved.

Comprehensive correction method of closed coring saturation

Core classification

The mathematical statistical correction method is classified with permeability and loss [21]. After counting the relationship between permeability and loss of oil-water in the same layer. It is found that as the amount of loss increases, the permeability becomes larger, but gradually tends to level off. According to this, the cores are divided into three types. The first type of core is that the core permeability changes drastically along with the increase in loss. The second type of core is that the permeability increases slowly with the increase in loss. The third type of core is that the permeability tends to be flat with the loss increases. According to the correlation between permeability and loss, the relative relationship between saturation and permeability [2, 9], the cores are divided into three types. It can ensure a high correlation coefficient for the same type of core correction, fig. 2.

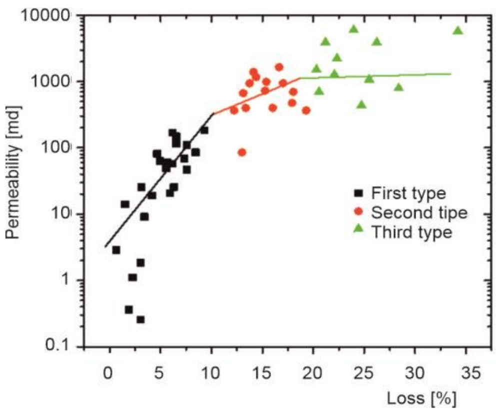

Figure 2. Cross plot of permeability and loss

Mathematical statistics correction method

This method mainly depends on the linear relationship between oil and water saturation data. Based on the similar physical properties of the core, the core is classified and counted. When calibrating similar cores, if the linear correlation coefficient is higher than 0.9, the error of oil-water saturation will be less than 10% after correction [19]. In the same well, if the pressure, temperature, borehole mud, and other physical characteristics of the core section are basically the same. Moreover, if the coring process and measurement method are completely the same, the loss of oil-water saturation can also be considered roughly the same. At this time, the core can be corrected by the same linear relationship [17].

Because of the high linear correlation coefficient, it can be considered that the loss of oil and water in this kind of core is the same. In the original state, the core does not contain free gas:

$$S_O + S_W = 1 \tag{1}$$

It is assumed that the remaining oil rate is η_1 after volatilization, the residual water rate is η_2.

Here:

$$S_o^{'} = \eta_1 \times S_o \tag{2}$$

$$S_w^{'} = \eta_2 \times S_w \tag{3}$$

Combining with eqs. (1)-(3), it can be deduced that:

$$S_o^{'} = \frac{\eta_1 - \eta_1}{\eta_2 S_w} \tag{4}$$

where $S_o^{'}$ is the measured oil saturation and $S_w^{'}$ is the measured water saturation. It can be seen from eq. (4) that the oil-water saturation of the core after volatilization also presents a linear relationship. So, we can get η_1 and η_2 by linear regression. By substituting eqs. (2) and (3), the corrected oil-bearing water saturation can be obtained: After the closed airtight process, the same core will be measured twice to measure the oil saturation and water saturation, respectively. Therefore, the sum of corrected oil-water saturation may not be 100%, so it is necessary to carry out mathematical processing to make the result 100%. This method transforms the correction coefficient of saturation data into the percentage of total loss, so that the sum of corrected oil-water saturation is 100%. Suppose the oil loss percentage is Y and the water loss is $1 - Y$

Existence:

$$Y = \frac{1-\eta_1}{(1-\eta_1)+(1-\eta_2)} \tag{5}$$

The corrected oil saturation is:

$$S_o = \left(1 - S_o^{'} - S_w^{'}\right) \times Y + S_o^{'} \tag{6}$$

$$S_w = \left(1 - S_o^{'} - S_w^{'}\right) \times (1 - Y) + S_w^{'} \tag{7}$$

According to the principle of this method, this paper classified according to the standard of loss, as shown in tab. 1.

According to the standard of loss, there are some cores with oil saturation less than 10% and water saturation less than 20%. These oil saturation and water saturation cannot satisfy the linear relationship of cores with similar losses [8]. At this time, if we continue to use

Table 1. Classification and fitting of loss

S_o	S_w	Loss [%] (100-S_o-S_w)	Samples, N	Fitting formula	Relevance, R^2
$>10\%$	$>20\%$	$0-10$	53	$y = -1.0471x + 95.813$	0.9802
$>10\%$	$>20\%$	$10-20$	65	$y = -0.9279x + 83.081$	0.9767
$>10\%$	$>20\%$	$20-40$	35	$y = -1.0039x + 75.748$	0.9159
$<10\%$	–	–	23	–	–
–	$<20\%$	–	20	–	–

the mathematical statistics correction method, the pure water layer or pure oil layer will no longer be *pure*, as shown in tab. 1. Obviously, the error is no longer acceptable. It is no longer reasonable to use mathematical statistics. In the cores of non-pure water layer and non-pure oil layer, the correlation coefficient is over 90% after fitting. It shows that the correlation is good, and the effect of this method is great, fig. 3.

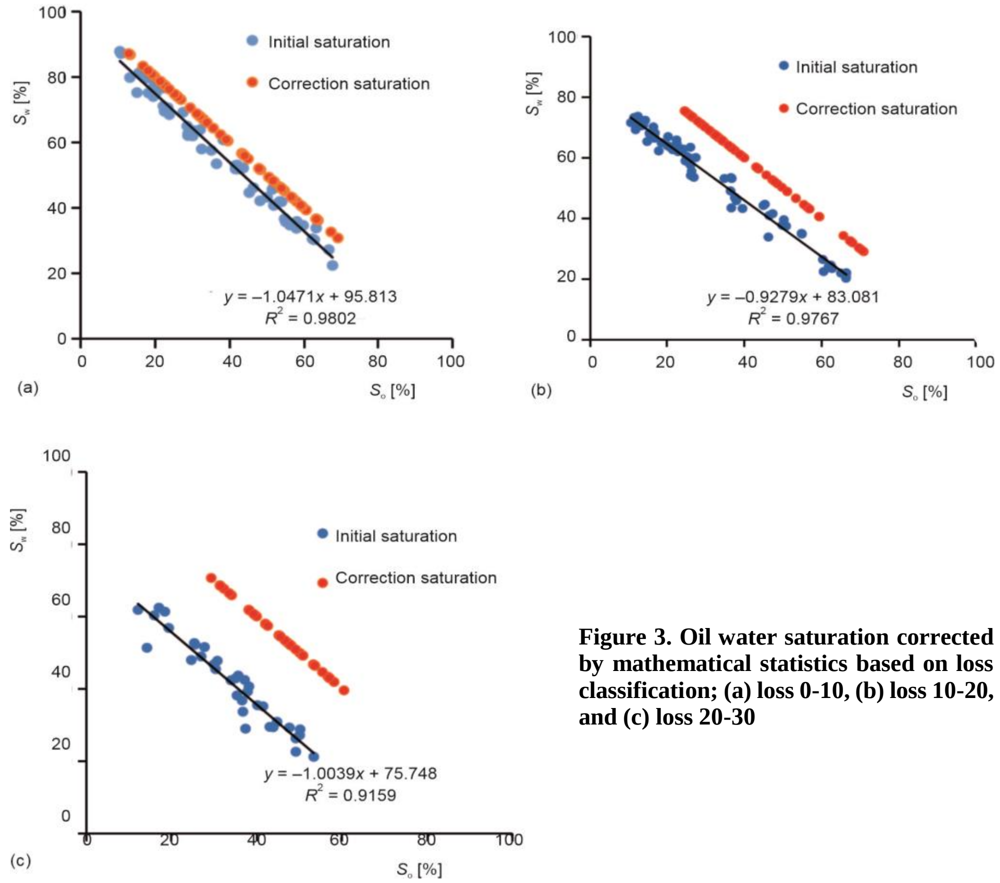

Figure 3. Oil water saturation corrected by mathematical statistics based on loss classification; (a) loss 0-10, (b) loss 10-20, and (c) loss 20-30

Shunt correction method

Cheng *et al.* [2] and others think there are two main factors affecting the oil-water saturation of airtight coring in the core, one is the volume change of the fluid, the other is the degassing and drainage. After converting the oil-water saturation from the analysis results of the ground to the formation conditions, the loss of fluid is distributed according to the principle of percolation mechanics. For the first time, the saturation correction method of airtight coring is proposed based on split flow principle. On this basis, Ma *et al*. [8] and others think in rocks with significant stress-sensitive effects, the volume change of core pores is also a factor that cannot be ignored. Considering the change of pore volume, the influence factor of pore volume change is added to the calibration model.

The saturation diversion model here integrates the research of Xin *et al*. [21], Cheng *et al*. [2], and Ma *et al*. [8]. It mainly considers volume changes of fluid and pore, as well as the influence of crude oil degassing on the saturation analysis results of airtight coring.

According to the experimental data of relative permeability, the total volume of lost oil and water can be divided, as shown in fig. 4(a). Where *fw* is the water production rate, *Krw* is the relative permeability of water, and *Kro* is the relative permeability of oil.

As the external pressure and temperature of airtight coring rock sample decrease, the movable fluid will lose. The loss of immovable fluid (irreducible water and residual oil) is small, which will be enlarged in the formula fitting of split flow method. Therefore, mathematical statistics method should be selected to correct the oil saturation higher than 10% and water saturation higher than 20%. Some cores were mentioned earlier that oil saturation less than 10% and water saturation less than 20%. The oil and water content in the pores of these cores are very low, and most of them are bound water and residual oil [21]. Because the loss in the process from coring to the test is small, it is basically inconsistent with the linear relationship established by mathematical statistics. Based on the analysis of the influencing factors of saturation in airtight coring, these cores should be corrected with physical basis. It needs to combine the principles of percolation mechanics, and then use the phase percolation split flow method to correct saturation. Thus, the correction of the saturation of the oil layer and the water layer can be really solved.

After using the phase percolation split flow method to correct the saturation, the saturation of oil layer and water layer is basically true, as shown in fig. 4(b).

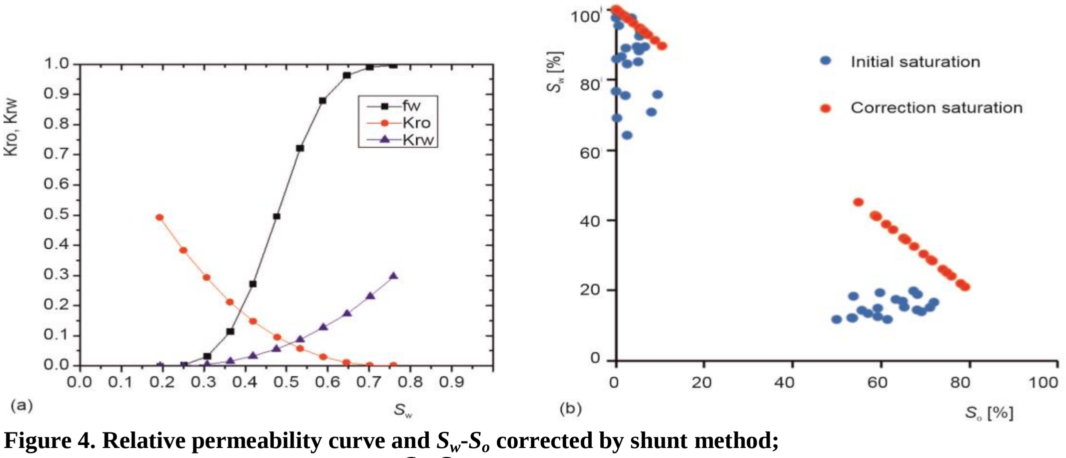

Figure 4. Relative permeability curve and S_w-S_o corrected by shunt method; (a) relative permeability curve and (b) S_w-S_o corrected by shunt method

Validation of results

Based on the mathematical statistics method and phase flow method, the statistics of XX oilfield in Xijiang, China are carried out. After airtight coring and tripping, the temperature and pressure changed sharply. The sum of oil saturation and water saturation is not equal to 100%. After using the mathematical statistics method and split flow method. All data points satisfy the theoretical relationship and lie on the theoretical straight line, fig. 5(a).

According to the relative permeability curve results, we can have a verification of irreducible water, fig. 5(b). The cored rock sample experienced changes in external pressure and temperature, the movable fluid will be lost. However, the loss of irreducible fluid (irreducible water) is small, so the irreducible water of relative permeability curve can be used to verify the corrected saturation. In the saturation of this layer, there are two points on a permeability curve. The irreducible water of the two points of interpenetration saturation is consistent with the corrected water saturation. It can be defined as oil layer, which proved that the correction result is accurate, *e.g.* tab. 2.

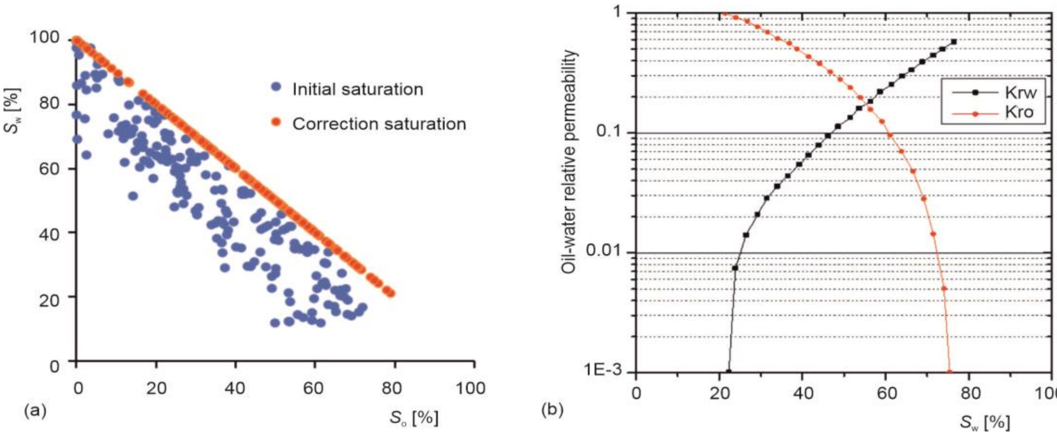

Figure 5. Final saturation and relative permeability curve; (a) oil-water saturation after correction and (b) relative permeability curve

Table 2. Oil-water saturation after correction of relative permeability curve

Corrected depth [m]	Porosity [%]	Permeability [mD]	S_w [%]	S_o [%]	Sum [%]	$S_w^{'}$ [%]	$S_o^{'}$ [%]	Bound water [%]
2865.1	27.2	2603	16.7	71.9	88.6	18.8	81.2	
2866.61	22.5	2314	17.5	63.3	80.8	21.7	78.3	21.3
2867.11	24.7	3438	17	64.8	81.8	20.8	79.2	
2869.6	28.2	3041	21	66.3	87.3	23.9	76.1	22.7

Conclusion

- This article summarizes the methods of common coring and the factors that cause the lack of oil-water saturation during the coring process. It also comprehensively applied the conventional mathematical statistics method and the diversion method to correct the oil-water saturation.
- This paper studies the conventional mathematical statistics method and the phase percolation split method, and also analyzes their advantages and disadvantages as well as their limitations. Different methods are used to classify the cores with different oil and water saturation, and the corrected oil and water saturation data are obtained.
- By comparing the log interpretation results with the relative permeability curve, the corrected data are verified. It fully proves that the corrected data is correct and that the comprehensive saturation correction method is applicable.

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