A novel method of fluid identification on low contrast reservoirs

Introduction

Low contrast reservoirs are defined as hydrocarbon-bearing zones with low ratio of resistivity to that of water zones (Akkurt et al., 2008). These reservoirs are difficult to distinguish from water zones for log interpretation and are often overlooked. Although some new logging techniques are helpful for fluid identification in low contrast reservoirs, such as nuclear magnetic resonance logging (Hamada et al., 2001), most of the wells only have conventional logging data, especially the old wells which need to explore the potential zones. Therefor the development of methods for fluid identification on low contrast reservoirs based on conventional logging data has important research significance and application value. The conventional methods of fluid identification mainly include curves overlapping (Abudeif et al., 2018) and cross-plots. The curves overlapping method cannot make full use of the implied information of the logging curves, and the cross-plots method may be with human error.

A novel method of fluid identification on low contrast reservoirs is proposed in this paper. The innovation of this method lies in the calculation of apparent formation water resistivity, and then use the distribution characteristics of apparent formation water resistivity to identify fluid types. In addition, this method can also calculate the hydrocarbon saturation of reservoirs, and its application effect has been verified in practical production.

Calculation of apparent formation water resistivity

According to the Archie formula, the calculation formula of formation water resistivity on clean sand with complete water content is shown in equation (1).

\[ R_w = R_0 \times \phi^m \]  

Where, \( R_w \) is formation water resistivity, \( R_0 \) is water zone resistivity, \( \phi \) is porosity, \( m \) is rock cementation index. For oil and gas-bearing reservoir, \( R_0 \) in equation (1) is replaced by oil and gas zone resistivity \( R_o \) and the calculation result is called apparent formation water resistivity, as shown in equation (2).

\[ R_{wa} = R_1 \times \phi^m \]  

For shaly sand, considering the influence of shale on resistivity, Archie formula is not applicable, Indonesia formula is selected to calculate apparent formation water resistivity, Indonesia formula as shown in equation (3).

\[ \frac{1}{\sqrt{R_t}} = \left( \frac{V_{sh}}{\sqrt{R_{sh}}} + \frac{\phi^{m/2}}{\sqrt{a \times R_w}} \right) S_w^{n/2} \]  

Where, \( R_{sh} \) is shale resistivity, \( V_{sh} \) is shale volume, \( R_w \) is formation water resistivity, \( S_w \) is water saturation, in practical application, usually set a and d value of 1, \( m \) and \( n \) value of 2. Let \( S_w = 1 \), then \( R_{wa} = R_w \), equation (4) can be obtained.

\[ R_{wa} = \frac{\phi^2}{\left( \frac{1}{\sqrt{R_t}} - \frac{V_{sh}}{\sqrt{R_{sh}}} \right)^2} \]  

Equation (4) is analyzed from the viewpoint of petrophysics, \( \frac{1}{\sqrt{R_t}} \) represents the conductivity of the target zone, \( \frac{V_{sh}}{\sqrt{R_{sh}}} \) represents the conductivity of shale part of target zone, when the value of two parts are close, it means that the sand part is almost nonconductive and \( R_{wa} \) is infinite. From the viewpoint of mathematical, the formation resistivity \( R_t \) and shale volume \( V_{sh} \) are taken as independent variables for numerical simulation. According to the prior information of the study area, the resistivity of shale is set to 5ohmm and the porosity is 0.1p.u. The simulation result is shown in figure 1(a). It can be seen from figure 1(a) that when the shale volume is greater than 20 %, the \( R_{wa} \) derived from the Indonesian
formula may be a large value which is not conforming to physical laws, even infinity. To solve this problem, this paper presents a new method for calculating apparent formation water resistivity, as shown in equation (5). The new method is corresponding to correcting the influence of shale on formation resistivity, and uses equation (5) for numerical simulation, the result is shown in figure 1(b).

\[ R_{wa} = R_t \cdot \phi^m \cdot e^{V_{Vf}} \]  \hspace{1cm} (5)

![Figure 1](image)

**Figure 1** (a) \( R_{wa} \) calculated by Indonesia formula; (b) \( R_{wa} \) calculated by new method

Apparent formation water resistivity calculated by two methods are compared in practical formation, as shown in figure 2. Borehole diameter, natural gamma and spontaneous potential in track 1, deep and medium induction resistivity in track 3, neutron, acoustic interval transit time, density in track 4, apparent formation water resistivity derived by Indonesia formula, called as \( R_{wa\_INDONESIA} \) and apparent formation water resistivity obtained by the new method, called as \( R_{wa\_NEW} \) in track 5, the result of oil test in track 6.

![Figure 2](image)

**Figure 2** Comparison of two methods for calculating apparent formation water resistivity

**Fluid identification of low contrast reservoir via water spectrum**

Gaussian distribution fitting is performed on the apparent formation water resistivity \( R_{wa} \) of all depth measurement points of the target reservoir, and the distribution obtained is called the water spectrum. Since oil and gas zones contain water, oil and gas, \( R_{wa} \) is relatively dispersed, and the shape of water spectrum is wide and smooth-out. The water zones only contain water, \( R_{wa} \) is relatively concentrated, and the shape of water spectrum is narrow and sharp, therefore the shape of water spectrum can be used to identify fluid.

There are mass low contrast oil and gas zones in the study area, which are caused by shale additional conductivity and formation water resistivity difference. The resistivity of some oil and gas zones is even smaller than that of water zones, Fluid types cannot be identified based on resistivity. Figure 3(a) and 3 (b) show the effect of water spectrum, borehole diameter, natural gamma and spontaneous potential in track 1, deep and medium induction resistivity in track 3, neutron, acoustic interval transit time, density in track 4, water spectrum in track 5, the results of oil test in track 6. The resistivity of No. 20 and No. 22 zones in Figure 3(a) is close to that of No. 32 and No. 36 zones in Figure 3(b). It is difficult to identify fluid via resistivity. According to the characteristics of water spectrum, it is judged that No. 20 and No. 22 zones in Figure 3(a) are water zones, and No. 32 and No. 36 zones in Figure. 3(b) are oil zones, which is consistent with the results of oil test of two wells.
The water spectrum uses the apparent formation water resistivity data of all depth measurement points of the target zone to avoid the error of manual reading. In addition, for multi-layer test, the R_{wa} of these reservoirs can be used to calculate only one water spectrum, which reflects the overall fluid types of these reservoirs and achieves the purpose of one water spectrum corresponding to one test result, which solves the difficulty of identifying the fluid types of each reservoir in multi-layer test.

![Figure 3](image)

**Figure 3** (a) Water spectrum of water zones; (b) Water spectrum of oil zones

### Calculation of hydrocarbon saturation

The water spectrum contains the information of hydrocarbon saturation, so the parameters of water spectrum can be used to calculate the hydrocarbon saturation of the reservoir. In this paper, the average and variance of water spectrum are used to calculate the hydrocarbon saturation, which is called the double parameter method. The advantages and disadvantages of double parameter method, the Indonesian formula method and the method that using only average of water spectrum calculate the hydrocarbon saturation are compared.

For numerical simulation, 20 formation models are generated randomly. 10 formation models are used to simulate the formations whose upper part is the oil and gas zone and lower part is water zone, and 10 formation models are water zones, as shown in Figure 4(a) and Figure 4(b).

![Figure 4](image)

**Figure 4** (a) formation model whose upper part is the oil and gas zone and lower part is water zone; (b) Formation model of water zone

In order to simulate the influence of formation water resistivity difference and the shale additional conductivity on formation resistivity, the formation water resistivity of the above formation is generated between 0.1ohmm and 1ohmm randomly, and the shale volume is generated between 10 % and 30 % randomly. According to the above conditions, the formation resistivity is generated, and 5 % noise is added. The results are shown in Figure 5(a) and Figure 5(b). The value of formation water resistivity in Indonesia formula is calculated according to the average value of formation water resistivity, because it is often difficult to accurately obtain the formation water resistivity in practical reservoir evaluation. Figure 5(a) shows the results of simulations which run 10 times. In the figure, the blue * curve represents the calculation result of double parameter method, the black + curve represents...
the calculation result of Indonesian formula, and the red hollow circle curve represents the calculation result of average of water spectrum. Figure 5(b) shows the error of the double parameter method in each simulation, which is the result of using the leave-one-out method to run 200 times. It can be seen from the figures that in the low contrast reservoirs which the formation water resistivity is usually not accurately obtained, it is generally better to calculate saturation by double parameter method.

![Figure 5](image1.png)

**Figure 5** (a) Comparison of hydrocarbon saturation calculation methods; (b) Error of double parameter calculation results

Double parameter method is applied in the practical reservoirs, as shown in Figure 6. 125 cores in the study area belong to 6 reservoirs. The double parameter method is used to calculate the saturation, and the correlation coefficient between the hydrocarbon saturation calculated and measurement is 0.72, while correlation coefficient between the hydrocarbon saturation calculated by the Indonesian formula and the measurement is only 0.26.

![Figure 6](image2.png)

**Figure 6** Comparison between double parameter method and Indonesia formula method

Conclusions

This paper presents a novel method of fluid identification on low contrast reservoirs. This method calculates apparent formation water resistivity, which is corresponding to correcting the influence of shale on formation resistivity. And then the water spectrum calculated by apparent formation water resistivity has achieved good application effect in fluid identification. It is difficult to calculate the hydrocarbon saturation of low contrast reservoirs caused by the shale additional conductivity and formation water resistivity difference. In this paper, the average and variance of water spectrum are used to calculate the hydrocarbon saturation of reservoirs, and the application effect has been verified in practical production.

References

