Academic Journal of Science and Technology
ISSN: 2771-3032 | Vol. 14, No. 2, 2025

Review of Methods for Judging Reservoir Fluid Properties

Tao Shen[1, 2], Ruijun He[1, 2] and Jiaxi Huang[3]

[1]School of Earth Sciences and Engineering, Xi'an Shiyou University, Xi'an 71006, Shaanxi China
[2]Shaanxi Key Laboratory of Petroleum Accumulation Geology, Xi'an Shiyou University, Xi'an 71006, Shaanxi China
[3]College of Petroleum Engineering, Xi'an Shiyou University, Xi'an 71006, Shaanxi China

Abstract: Sand formation has good reservoir conditions due to its relatively developed porosity and permeability and well developed pore throats. After the reservoir is divided from the drilling geological profile, the next step of logging interpretation is to determine the oil, gas and water properties of each reservoir. The oil-bearing property of reservoir can be measured by its saturation, which can be divided into water saturation and oil-bearing saturation. Water saturation refers to the percentage of water-bearing void volume in total void volume of rock, usually expressed as Sw; oil-bearing saturation refers to the percentage of oil-bearing void volume in rock, expressed as Sh. Saturation is usually expressed as percentage (%). Under ideal conditions, the sum of hydrocarbon saturation and water saturation in reservoir pores is 1 (or 100%). Therefore, water saturation is usually used to describe hydrocarbon bearing of reservoir, and it is particularly important to judge reservoir fluid properties. When logging data are applied, natural potential logging, triple laterolog, neutron gamma logging and ordinary resistivity logging are usually used to judge oil and water layers.

Keywords: Permeability; saturability; porosity; reservoir fluid property.

1. Introduction

In oil exploration and development, logging methods are often used to classify the target formation. After completing the classification of the formation and judging the permeability of the formation, it is necessary to judge and analyze the fluid properties in the formation reservoir, which is very important for the exploitation and development of oil and gas reservoirs. Oil reservoir is composed of reservoir rock and reservoir fluid. The rock containing recoverable oil is called reservoir. It is of great significance to understand the characteristics of reservoir rock and reservoir fluid. Oil, natural gas and water are the main fluids existing in oil and gas reservoirs, and are also the main objects to study reservoir fluid.

Petroleum refers to hydrocarbon mixtures dominated by gaseous, liquid or solid hydrocarbons. Under formation temperature and formation pressure conditions, liquid existing in liquid phase and containing a small amount of non-hydrocarbon is called crude oil; gas existing in gas phase and containing a small amount of non-hydrocarbon under formation temperature and formation pressure is called natural gas; gas existing in gas phase under formation temperature and formation pressure conditions, when produced to the surface at normal temperature and pressure, more condensate oil can be separated, called condensate gas. The reservoirs dominated by the three are respectively called oil reservoir, gas reservoir and condensate gas reservoir. The oil-bearing property of reservoir can be measured by its saturation, which can be divided into water saturation and oil-bearing saturation. Water saturation refers to the percentage of water-bearing void volume in total void volume of rock, usually expressed as S_w; oil-bearing saturation refers to the percentage of oil-bearing void volume in rock, expressed as S_h. Saturation is usually expressed as percentage (%). Obviously, the sum of hydrocarbon saturation and water saturation in reservoir pores is 1 (or 100%). Therefore, water saturation is usually used to describe the hydrocarbon potential of reservoir. When logging data are applied, natural potential logging, triple laterolog, neutron gamma logging and ordinary resistivity logging are often used to judge oil and water layers.

2. Judgement of Oil and Water Layers by Difference of Abnormal Amplitude of Natural Potential

When apparent resistivity logging was carried out at the earliest time, it was found that there was a potential change along the depth of the well without power supply to the electrode system in the lower well, which was repeatedly verified to indicate that this potential existed universally. Natural potential logging is one of the most important methods to divide and study reservoirs because of the obvious abnormal display of natural potential curves in permeable layers. Natural potential logging is a common electrical logging method. Logging methods appear early and technical means are mature. Natural potential curve is simple in shape, convenient and effective in application, and can be used to classify sandstone and mudstone, judge reservoir performance and reservoir fluid properties. Scholar Liu Shuguang explained in his report that No.62 Formation of Well W4 is 1614.5~1615.5m, with low acoustic time difference, large density value, three porosity curves in the same direction indicating poor reservoir physical properties, high formation resistivity value and low natural gamma value, which are characteristics of tight sandstone reservoir with relatively pure lithology, and natural potential curve shows weak negative abnormal amplitude. From 1615.5 to 1616.9m of No.63 formation, the logging curve comprehensively indicates that the reservoir physical property is good, and the natural potential curve negative anomaly is obvious. From 1616.9 to 1618.3m of No.64 formation, the natural gamma value is relatively high, and the formation resistivity value is relatively low. The logging curve indicates that the reservoir with relatively high mud content has worse reservoir physical property than No.63 formation, resulting in the natural potential negative anomaly amplitude being lower than No.63 formation. The natural potential curve shows obvious slope change at the interface of the three layers, reflecting the change of reservoir lithology and physical property.

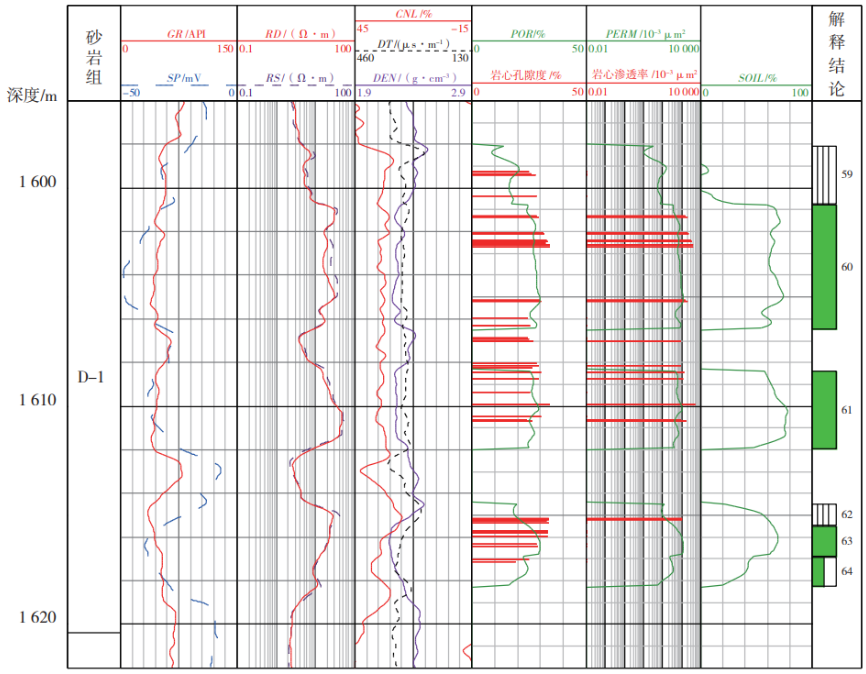

Figure 1. Logging Curve of Well W4(Shuguang Liu,2021)

From the nature of spontaneous potential logging, it can be known that the amplitude of spontaneous potential anomaly of oil-bearing formation with higher resistivity is lower than that of oil-bearing formation when the conditions of formation thickness, lithology and formation water salinity are the same.

In addition, according to the difference of abnormal amplitude of natural potential curve and acoustic time difference logging, oil layer can also be judged. Scholars Ye Xingshu, Chen Long and Wang Jiang found in the research of M-II reservoir oil-water layer in K oilfield of South Turgai Basin of Kazakhstan that when the natural potential amplitude difference of M-II reservoir argillaceous sandstone is less than 45mV and the acoustic time difference is less than 285μs/m, this layer may be oil layer. At the same time, they also use variable m value to calculate the oil saturation of reservoir, which improves the identification ability of oil layer. The oil saturation calculated by traditional Archie equation is only 27%, while the oil saturation calculated by variable m value is 50%, which meets the oil layer interpretation standard of the study area. The oil test of this layer is officially oil layer, and the daily oil production is 50.4 t. Based on the natural potential and acoustic time difference chart, 75 wells have been interpreted by using the method of calculating oil saturation of reservoir with variable m value. There are 125 layers of test oil layers, 114 layers are consistent, 11 layers are inconsistent, and the coincidence rate is 91.2%.

Drilling in sand-mudstone section is generally done with fresh water mud ($C_w > C_{mf}$), so obvious negative anomaly appears in natural potential curve of sandstone permeable interval; in salt water mud well ($C_w < C_{mf}$), positive anomaly appears in permeable interval, which is an important feature for identifying permeable interval.

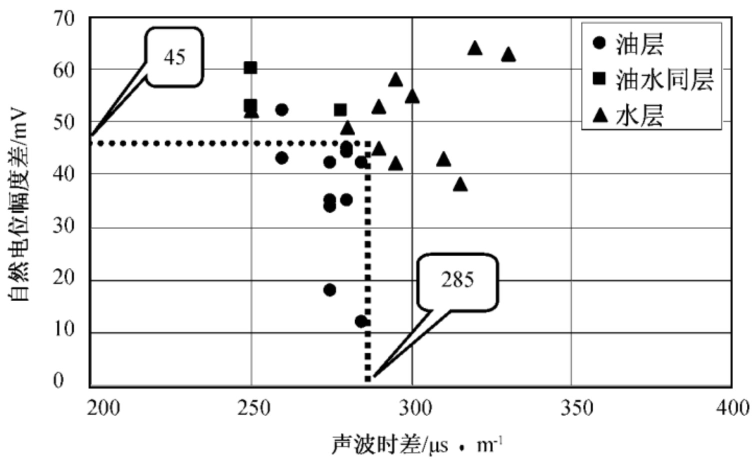

Figure 2. Cross Diagram of Acoustic Time Difference and Natural Potential Amplitude Difference of M-II Reservoir in K Oilfield(Xingshu Ye,2011)

3. The Oil And Water Layers Are Judged Qualitatively By The Method of R_{LL3}^{d}、R_{LL3}^{s}

Ordinary resistivity logging is significantly affected by the surrounding rock and drilling fluid, especially under saltwater drilling fluid conditions, where most of the current flowing out of the power supply electrode is diverted by the drilling fluid. The measured apparent resistivity curve is difficult to reflect the true resistivity of the formation. In the 1950s, lateral logging, also known as focused resistivity logging, was introduced. Among them, the three lateral logging is the earliest lateral logging. The three lateral electrode system consists of three cylindrical metal electrode systems. The basic principle of the three lateral logging is that the main electrode A_0 emits a main current, and the shielding electrodes A_1 and A_2 emit shielding currents of the same polarity as the main current. Under the repulsive effect of the shielding currents of the same polarity, the main current is scattered into the formation in a circular disk shape. It effectively overcomes the power supply defects of point like power supply and spherical divergent general point power supply. Three lateral logging is divided into deep three lateral logging and shallow three lateral logging. Lateral logging can be seen as a series of resistors, and the resistance value of each series resistor will have a significant impact on the total resistance value. Bilateral logging is proposed based on the three and seven lateral logging, which combines the three and seven.The combination of lateral advantages results in better detection depth and stratification ability.

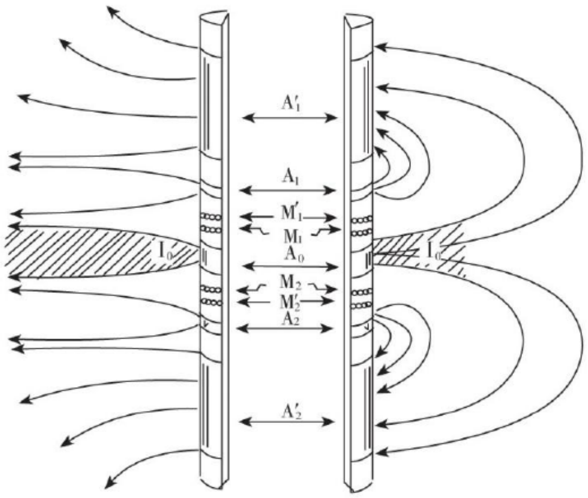

Figure 3. Distribution of power lines in dual laterolog

Overlap and plot the deep and shallow lateral curves (both curves are plotted in the same coordinate system), with the appearance of "amplitude difference" as a marker to describe the permeable layer. When the condition of $R_{mf}>R_w$ is generally met, in the oil reservoir section, the apparent resistivity of the deep three lateral directions is usually greater than that of the shallow three lateral directions, that is, the amplitude difference of $R_{LL3}^{d} > R_{LL3}^{s}$ is called "positive amplitude difference" or "positive difference"; In the water layer well section, the apparent resistivity of the deep three lateral directions is usually lower than that of the shallow three lateral directions; Namely, when $R_{LL3}^{d} < R_{LL3}^{s}$, this amplitude difference is called "negative amplitude difference" or "negative difference". This method can quickly and intuitively make judgments on oil and water layers, but the final confirmation of oil and water layers still requires comprehensive interpretation and depends on geological parameters. In saltwater mud wells, when $R_{mf}<R_w$, a "positive amplitude difference" appears on the deep and shallow lateral curves at both the oil and water layers, indicating a low invasion profile. However, the apparent resistivity of the oil layer is higher than that of the water layer, and the amplitude difference is also larger than that at the water layer. This feature is used to identify oil-water layers. Overall, the mud invasion properties of oil-water layers are different. When $R_{mf}>R_w$, oil layers are mostly characterized by reduced resistance invasion, while water layers are mostly characterized by increased resistance invasion. When the depth side R_{LLD} is greater than the shallow side R_{LLS} , it is an oil layer, and vice versa, it is a water layer.

When the borehole is regular, this method is highly reliable for judging oil and water layers in thick permeable intervals in the well. For thin formations, the apparent resistivity values of deep and shallow lateral directions should be corrected for influence respectively, and then this method can be used to judge oil and water layers.

The resistivity of the wash zone of the oil layer is lower than that of the undisturbed formation, and the oil layer shows the characteristics of low invasion resistivity profile. The resistivity of the wash zone of the fresh water mud water layer is higher than that of the undisturbed formation, and the water layer shows the characteristics of high invasion resistivity profile. The deep lateral resistivity value and the deep induction resistivity value mainly reflect the resistivity value of the undisturbed formation, and the shallow lateral resistivity value and the middle induction resistivity value mainly reflect the resistivity value of the invasion zone, that is, the oil layer: RLLD> RLLS, RILD>RILM, and the water layer: RLLD<RLS, RILD<RILM. Table 1 summarizes the resistivity amplitude characteristics and invasion characteristics of oil and water layers.

Table 1. Resistivity Amplitude and Invasion Characteristics of Oil and Water Layer

fluid properties	R_t	RLLD	RILD	Relative size of RLLD and RILD	RILD/RLLD	Intrusion characteristics	RLLD/RLLS	RILD/RILM
oil layer	High Value	ApproachingR_t	Slightly lower R_t	R_t≈RLLD>RILD	High Value	Low invasion	>1	>1
Water layer (freshwater mud)	low value	Higher than R_t	ApproachingR_t	RLLD>RILD≈R_t	low value	High invasion	<1	<1

According to previous logging interpretation rules, low invasion positive difference is an obvious characteristic of oil layer, but for inclined anisotropic formation under mud invasion condition, due to the influence of anisotropy, the relative difference characteristics between curves are complex, and it is not feasible to identify oil and water layers only by resistivity amplitude difference, so it is very difficult to distinguish reservoir fluid properties.

4. Determination of Oil-water Interface by Neutron-gamma Logging

Because the hydrogen content of oil and water layers is basically the same, only when the salinity of formation water is high, the chlorine content of water layer is significantly higher than that of oil layer, and the neutron gamma logging count rate value of oil layer and water layer has obvious difference (the neutron gamma logging count rate value of water layer is higher than that of oil layer). Therefore, only when the salinity of formation water is relatively high, can the neutron gamma logging curve be used to divide oil and water interface and distinguish oil and water layers.

5. Invasion Effect Judgment of Ordinary Resistivity Logging on Oil and Water Layers

The main task of resistivity logging is to quantitatively determine the resistivity of a formation according to the thickness of the divided formation by resistivity curve . In oil wells, it is of special significance to study the conductivity of the formation, because oil is a substance with extremely high resistivity, while water in natural state is a substance with low resistivity. Therefore, in reservoirs of the same lithology, the resistivity of oil-bearing formations will be higher than that of water-bearing formations. Up to now, the resistivity of a formation is still an important indicator to judge the oil-water properties of a formation.

$$F = \frac{R_0}{R_w} = \frac{a}{\varphi^m}$$

$$I = \frac{R_t}{R_0} = \frac{b}{S_w^n} = \frac{b}{(1 - S_0)^n}$$

$$S_w = \left(\frac{abR_w}{R_t \varphi^m}\right)^{\frac{1}{n}}$$

The above three equations are collectively called Archie equation, which are basic interpretation equations for interpreting water-bearing rocks and oil-bearing rocks with granular pores by using resistivity logging data.

Because there are often invasion zones formed by mud invasion in permeable intervals, the distribution characteristics of radial resistivity depend on the type of invasion.(Also called resistance-enhancing mud invasion), which is caused by mud filtrate resistivity R_{mf} being greater than formation water resistivity R_w. Invasion results in flushing of the belt Resistivity R_{xo} is greater than undisturbed formation resistivity R_t and transition zone. Resistivity (the part of the formation in which formation water is partially replaced) gradually changes from R_{xo} to R_t, but both are greater than R_t, and the amplitude of the apparent resistivity curve measured at this time must be higher than that measured without invasion.(Also called resistance-reducing mud invasion), this is because the resistivity of mud filtrate is generally less than that of liquid contained in pores of oil-bearing layers. Therefore, the amplitude of apparent resistivity curve measured in oil layer interval is lower than that measured without invasion. Oil and water layers can be judged by using this influence factor.

Zhenbei Oilfield is located in the southwest of Ordos Basin. Oil reservoirs are mainly distributed on the main belt of braided river delta front. Controlled by sedimentary facies belt and physical property change, local regional structures have certain influence on oil bearing. Structural nose, palaeo geomor phological slope and mound mouth are favorable areas for oil reservoir formation. There are many standard water layers which can be used as contrast layers in Chang 3 reservoir. If lithology and physical properties are similar, the resistivity ratio between reservoir and adjacent standard water layers can be used to quickly and effectively identify fluid properties.

6. Other Methods

6.1. Determination of fluid properties with electrical imaging data

Traditional logging technology can only obtain vertical and horizontal data information of formation near oil well, which is only suitable for homogeneous formation. Electric imaging logging technology can comprehensively analyze underground aquifer. If the formation has good physical properties, electric imaging logging technology with higher resolution can acquire and interpret data from high water-cut formation and high oil-water interface.

6.2. Compressibility coefficient method

Based on the calculation and analysis of a batch of experimental data reported abroad and the measurement of artificial cores saturated with different liquids and porosity and the principle analysis of models, a method of identifying oil, gas and water layers by using the volume compressibility method is proposed. According to the pressurization experiment of saturated sandstone, the law of acoustic time difference varying with pressure is pointed out. According to the method and rule mentioned above, preliminary attempt to identify oil, gas and water layers by volume compressibility coefficient has been made in 13 wells of 4 structural blocks in Tuha Oilfield, Xinjiang.

6.3. Fluid Identification Using NMR Logging

The principle of NMR double-TW method for fluid identification is to utilize the different polarization time TW required for complete polarization of different fluids, because TW must be greater than or equal to 3 times T1 time in general.(longitudinal relaxation time of fluid) can make the fluid completely polarized, while the T1 difference of water and gas is relatively large.(T1 of water is 1~500ms, T1 of gas is 2000~5000ms). Therefore, long and short TW are used for measurement respectively. In short TW, water has been completely polarized, while gas is not completely polarized. In long TW, water and gas are completely polarized. After subtracting the two groups of signals, the signal of water is subtracted, leaving only the signal of gas and light oil. This qualitative identification method of oil and gas is differential spectrum method .

6.4. Using Swb and Sw overlap to identify fluids

According to the concept of movable water saturation and irreducible water saturation, formation water saturation is the sum of movable water saturation and irreducible water saturation, i.e. $S_w=S_{wm}+S_{wb}$. Therefore, S_{wb} and S_{wb} overlap to show movable water: in oil and gas interval, $S_w \approx S_{wb}$, $S_{wm} \approx 0$; in water interval: $S_w>S_{wb}$; for oil/gas water same layer, it is between them. The method based on irreducible water and movable water is more suitable for actual production than traditional single saturation parameter identification. It has been found that the water saturation of many oil and gas reservoirs is higher than 50.0%, even as high as 60.0%~70.0%, but only oil and gas are produced in testing and production, and no formation water is produced. It is obvious that oil and gas are produced.(i.e. water saturation or hydrocarbon saturation) is only the reflection of static characteristics of pay formation, it can not completely describe the dynamic law of reservoir oil and gas accumulation and seepage .

7. Summary

Judgement of reservoir fluid properties and identification of oil and water layers play an important role in oil and gas field development, and it is also of great significance to the application of logging data interpretation. This paper mainly collects the data application of several logging methods, and judges its specific performance in identifying oil and water layers through understanding the detection principle of certain logging methods. The prerequisite for identifying reservoir fluid properties with logging data is the difference between physical parameters of oil and water, but whether oil and water layers can be identified depends on lithologic, physical properties and pore structure of reservoir.

References

[1] LIU Shuguang. Application analysis of SP curve characteristics changes[J]. Complex Hydrocarbon Reservoirs. 2021,14(04):31-35.DOI:10.16181/j.cnki.fzyqc.2021.04.005.

[2] Ye Xingshu, Chen Long, Wang Jiang. Characteristics of M-II Reservoir and Identification of Oil and Water Layers in K Oilfield, South Turgay Basin [J]. Journal of Oil and Gas Technology,2011,33(01):103-106+138+168.

[3] Rao Yang. Research on the identification method of complex oil-water layers in the grape flower oil layer in the western part of Changyuan [D]. Yangtze University, 2021. DOI:10.26981/d.cnki.gjhsc.2021.000099.

[4] Tang Jianbo. Influencing factors and countermeasures of dual lateral logging [J]. China Petroleum and Chemical Standard and Quality, 2014(6):2.

[5] Si Zhaowei, Deng Shaogui, Lin Fawu, etc. Numerical simulation of lateral logging response of anisotropic formation array invaded by mud [J]. Oil Geophysical Prospecting, 2020, 55(01): 187-196+11-12.DOI:10.13810/j.cnki.issn.1000-7210.2020.01.022.

[6] Li Jing, Li Jiangjiang. Research on Qualitative Identification Logging Technology for Oil Water Interface [J]. Journal of Yan'an University：Natural Science Edition, 2011,30(2):4.

[7] Li Song. Geological characteristics and favorable area prediction of Chang 8 reservoir in Zhenbei Oilfield [D]. Xi'an Shiyou University,2014.

[8] Yang Cai. Discussion on the Progress of Geological Application Research of Electrical Imaging Logging Technology [J]. Petrochemical Industry Technology, 2019, 26(12): 89+93.

[9] Wang Naixing, Liu Wenming.Method for determining oil, gas, and water layers using full wave logging data[C]. //Selected Papers from the 9th Logging Annual Meeting of the Petroleum Logging Committee of the Chinese Petroleum Society Hebei Gaobeidian: Editorial Department of China Offshore Oil and Gas (Geology),1996:109～114.

[10] Xu Fanjun.Research on Intelligent Optimization Method of Logging Interpretation Model Based on Knowledge Graph [D]. NORTHEAST PETROLEUM UNIVERSITY, 2022. DOI:10.26995/d.cnki.gdqsc.2022.000739.

[11] Lin Jingqi.Study on fluid identification technology of complex reservoir in the Junggar Basin[R].Xinjiang Uygur Autonomous Region, China Petroleum Western Drilling Engineering Co., Ltd,2017-08-05.

[12] Cao Zhifeng, Lin Youzhi, Wang Xianhu, etc.Genetic analysis of abnormal invasion characteristics in low-permeability sandstone reservoirs[J].Well Logging Technology, 2018, 42(01): 60-64.DOI:10.16489/j.issn.1004-1338.2018.01.011.

[13] Xue Songren.Geophysical logging methods in coal geological exploration[J].Friend of Science Amateurs,2012(9):2.

[14] Nie Chunyan, Wang Zhuwen, Li Ze, etc.Nonlinear Chaos Characteristics of Reservoir Logging Signals[J].Journal of Jilin University(Earth Science Edition), 2011, 41(01): 305-309+315.DOI:10.13278/j.cnki.jjuese.2011.01.030.

[15] Cao Qiang, Zeng Weihua, Hou Jie, etc.The principle of three lateral resistivity probe and its application in searching for oil and gas[J].Science and Technology Innovation Herald, 2012, No.235 (19):128-129.DOI:10.16660/j.cnki.1674-098x.2012.19.010.

[16] Zhang Jing. Research on Prediction Method of Rock Physical Properties Based on Logging Curve [D]. Anhui University of Science and Technology, 2021. DOI:10.26918/d.cnki.ghngc.2021.000155.

[17] Cai Xin, Tang Lian.Research on the New Three Lateral Logging Forward System [J]. Coal Technology, 2012, 31(06): 160-162.

[18] Li Wei, Yan Weilin, Bai Jianping.Theoretical analysis and experimental study on the influence of freshwater drilling fluid invasion on reservoir resistivity[J].Petroleum Exploration and Development,2004(03):143-145.