Rock Electricity Experiment of Different Gas Components under High Temperature and High pressure and Its Application

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Abstract

Accurately acquiring rock electric parameters is the key step in the evaluation of water saturation of high temperature and high pressure (HTHP) reservoir. Under normal circumstances, rock electrical parameters will change with the temperature and pressure, but under high temperature and high pressure, the effect of CO_2 and CH_4 gas mixture on rock electrical parameters is not clear. So, for water saturation logging evaluation of high temperature, high pressure and CO_2 containing reservoirs, the study of CO_2's effect on reservoir electrical characteristics is of great significance. We conduct rock electrical experiments under simulated reservoir temperature and pressure(The temperature is 150 ℃, the confining pressure is 70MPa, the pore pressure is 50MPa), and carry out core displacement by different CO_2 content of CO_2 and CH_4 mixed gas to determine lithology coefficient b, saturation index n and cementation index m. The effects of CO_2 and CH4 mixed gas on rock electrical parameters are analyzed based on experimental data. The results shows that: ① When different CO_2 content gas mixture were dissolved in formation water, the measured lithology coefficient a and cementation index m didn't change, with 1.0 for a, 1.7 for m. ② With the increase of CO_2 content, lithology coefficient b increases, while saturation exponent n decreases. Equations of using CO_2 content to calculate lithology coefficient b and saturation index n are established based on the experimental data. ③ Water saturation calculated by this method is in good agreement with core analysis results. Conclusions are reached that the experiment-based b and n calculation model is very helpful to improve water saturation calculation accuracy of high temperature and high pressure and CO_2 containing gas reservoirs.

Keywords

CO_2-Containing Gas Reservoirs, High Temperature And High Pressure, Rock Electricity Experiment, Saturation Index, Water Saturation.

1. Introduction

The key point of using Archie formula to calculate reservoir water saturation is to get the right rock electrical parameters [1-3]. There are many factors affecting the rock electrical parameters of high temperature and high pressure reservoirs. A lot of experiments and research have been done by Chinese and foreign scholars. They mainly analyze the influence of temperature and pressure on the rock electrical parameters, and reached the same conclusion: the rock electrical parameters used for calculating water saturation of high temperature and high pressure reservoirs should be measured in the same condition with actual formation temperature and pressure condition[7-15], otherwise, it may cause a great error.

For some areas, in addition to high temperature and high pressure, the reservoir is also rich in CO_2 gas. Such as XF gas field of Yinggehai Basin, is a high temperature and super high pressure area [16-17], due to complex geological background and reservoir accumulation mechanism, the gas field are also rich in CO_2, content up to 90%, and under the condition of formation temperature and pressure, the solubility of CO_2 gas in water is very high, and the dissolution mass percentage is around 10%[18].

There is little research of CO_2's influence on reservoir conductivity. The influence of CO_2 and CH_4 mixed gas on rock electrical parameters under high temperature and pressure is still unknown, which brings great uncertainties to logging interpretation. In this paper, the influence of CO_2 content on rock electrical parameters are discussed by conducting rock electricity experiments of different percentage of CO_2 and CH_4 mixed gas under formation temperature and pressure, so as to improve the water saturation calculation accuracy.

2. Design of rock electricity experiments

2.1 Core basic data

10 core samples (sample No. 1# ~ 10#) which can reflect reservoir characteristics of gas field XF13 are selected for the experiment. The lithology is silty sandstone, porosity ranges from 16.4% to 20.1%, which are shown in table 1.

Table 1. Core basic data

Sample number	1#	2#	3#	4#	5#	6#	7#	8#	9#	10#
porosity /%	17.1	18.2	19.4	18.9	18.7	18.8	16.4	16.9	20.1	19.8
permeability /x10^{-3}um^2	0.22	0.19	1.93	1.03	0.34	2.27	0.03	0.02	10.4	9.81

2.2 Experiment Procedure

Experiment temperature and pore pressure are determined by DST test data in study area, confining pressure is calculated by density curve, formation water is $NaHCO_3$ liquid with salinity of 13000mg / L according to water analysis data, CO_2 and CH_4 mixed gas with CO_2 content respectively 0%, 14%, 57% and 100% are prepared according to sample data. SCMS-E high-temperature and high-pressure core multi-parameter instrument is used in this experiment, its core gripper is improved in order to meet the designed temperature and pressure. Specific experimental steps are: ① wash and dry cores. ② vacuumize cores, dissolve different CO_2 and CH_4 mixed gas in formation water in the high temperature and high pressure saturation device, make cores saturated with above formation water. ③make the temperature and pressure reach the designed value. (The temperature is 150 ℃, the confining pressure is 70MPa, the pore pressure is 50MPa), and then measure formation factor and porosity of each core. ④conduct displacement experiment with respectively 0%, 14%, 57% and 100% CO_2 content and CH_4 mixed gas, get resistance increasing rate and water saturation at each measuring point.

3. Experiment results processing and analysis

3.1 Analysis the value of m and a

Archie formula can be convert to $\log F = \log a - m \log \phi$ when logarithmic on both sides, which shows that the relationship of logF and logΦ is linear, a is the intercept, M is the slope of the line. Figure 1 is relationship between formation factors and porosity under formation temperature and pressure, different a and m values can be got from the plot. Table 2 is a, m values of different CO_2 content of CO_2 and CH_4 mixed gas, we can see that a and m values change very little under different CO_2 content.

Cementation index m is the reflection of pore structures, which is mainly influenced by pore sizes and pore structures. Some study also shows that m is also affected by salinity, but this influence depends on core porosity. When the porosity is high, m of medium and high porosity cores are not affected, but m of low porosity and low permeability cores are significantly affected by formation salinity. The variation of m value obtained from this experiment is consistent with the previous research results.

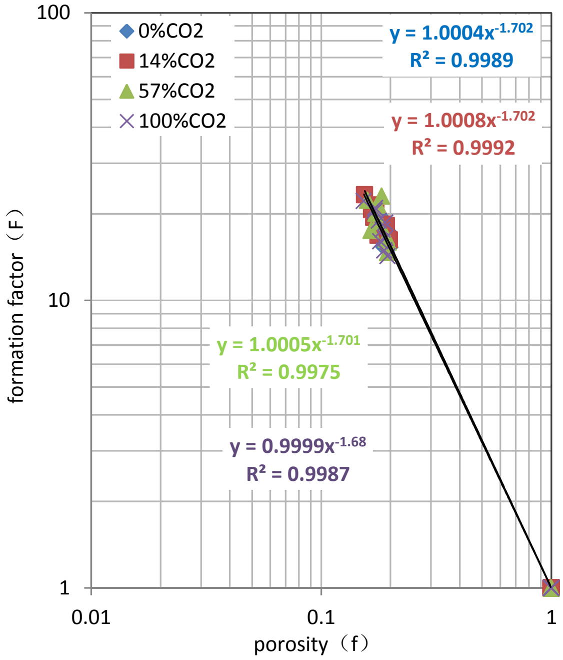

Fig. 1 Relationship between formation factors and porosity under formation temperature and pressure

Table 2 a, m value of different CO_2 content of CO_2 and CH_4 mixed gas

CO_2 content /%	0	14	57	100
Lithology coefficient a	1.00	1.00	1.00	1.00
Cementation index m	1.70	1.70	1.70	1.68

3.2 Relationships between resistivity increasing rate and water saturation in different CO2 content mixed gas displacement experiments

Figure 2 is the relationship between resistivity increasing rate and water saturation under formation temperature and pressure. Archie formula can be convert to $\log I = \log b - n \log S_w$ when logarithmic on both sides, from this relationship, we can get the lithological coefficient b and the saturation index n of every different content mixed gas displacement experiments, specific values are shown in Table 3 below.

Table 3. b, n value of different CO_2 content of CO_2 and CH_4 mixed gas

CO_2 content /%	0	14	57	100
Lithology coefficient b	1.03	1.04	1.05	1.09
saturation exponent n	1.33	1.31	1.26	1.14

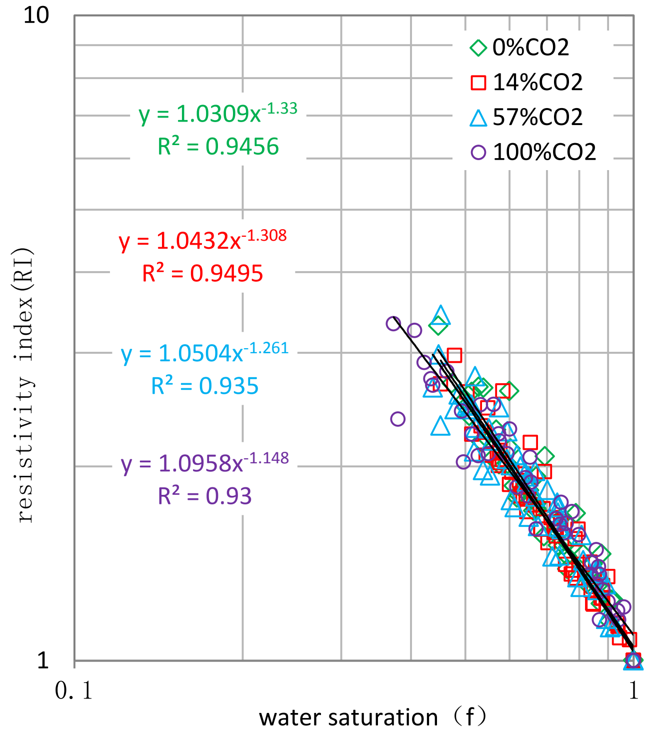

Fig. 2 Relationship between resistivity increasing rate and water saturation under formation temperature and pressure

It can be seen from table 3 that with the increase of CO_2 content, lithology coefficient b increases and saturation index n decreases. This is mainly due to the improved formation water conductivity caused by the ionization of conductive ions when CO_2 dissolved in formation water, which improves rock conductivity.

In order to confirm the influence of CO_2 on formation water conductivity in rock pores, we first simulated CO_2 solubility experiments in 13000 mg / L formation water under different temperature and pressure (Fig. 3). It can be seen from the figure, the solubility of CO_2 gas in formation water decreases with the increase of temperature, but increases with the increase of pressure. The linear interpolation shows that the solubility of CO_2 gas is about 30m3/m3 under formation temperature pressure (150℃, 50MPa).Formation water conductivity gradually increases because carbonic acid solution formed when CO_2 is dissolved in water. And then, we dissolve CO_2 and CH4 mixed gas with CO_2 content respectively 0%, 14%, 57% and 100% in formation water under formation temperature and pressure, and measure formation water resistivity, results were shown in Figure 4. With the increase of CO_2 content, formation water resistivity decreases gradually, that is, the resistivity of formation water increases, which results in the decrease of rock resistivity and then the decrease of resistivity increasing rate.

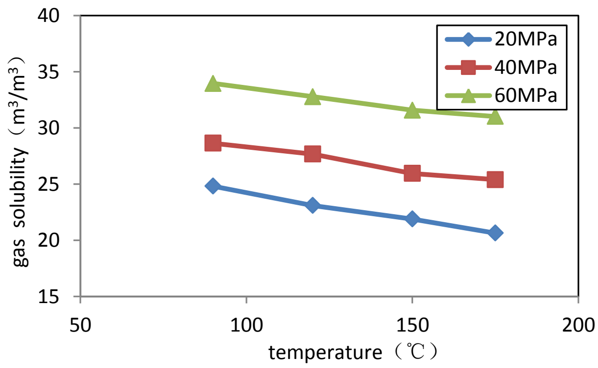

Fig. 3 Relationship between CO_2 solubility and temperature and pressure

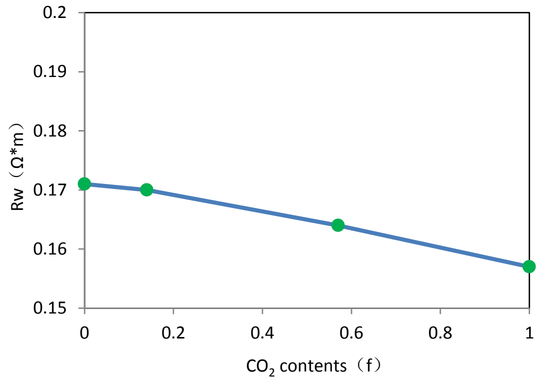

Fig. 4 Resistivity of formation water with different amount of CO_2 dissolved under formation temperature and pressure

In order to study the rules of CO_2's influence on rock electrical characteristics, the relationship between lithology coefficient b and CO_2 content in displacement gas, the relationship between saturation exponent n and CO_2 content in displacement gas was studied respectively, as shown in figure 5 and figure 6. We can see that, with the increase of CO_2 content in displacement gas, b increases while n decreases, these two rock electrical parameters have a good correlation with CO_2 content. Polynomial simulation methods are used to build the equations of using CO_2 content to calculate b and n, as shown in equations 1 and 2:

$$b = 0.0519 * {V_{co2}}^2 + 0.0041 * V_{co2} + 1.0333 \quad (1)$$

$$n = -0.1476 * {V_{co2}}^2 - 0.0367 * V_{co2} + 1.3253 \quad (2)$$

Where： b is lithological coefficient, dimensionless; n is saturation index,dimensionless; Vco_2 is CO_2 content in displacement gas, decimal.

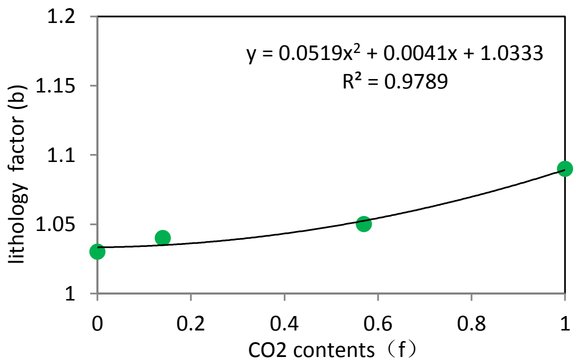

Fig. 5 Relationship between lithological coefficient b and CO2 content

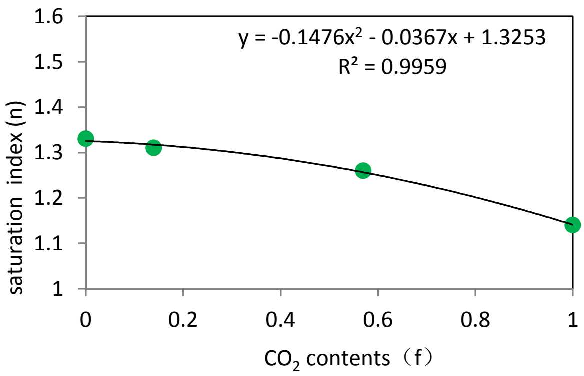

Fig. 6 Relationship between saturation index n and CO2 content

4. Application of experimental results

Figure 7 is the application of the research achievements on logging interpretation of well XF4 in research area. The sixth track is water saturation of log interpretation, the blue curve is calculated by old rock electrical parameters that didn't consider CO_2 effect. MDT test shows 20.2% CO_2 contained at 2865m, so we get new set of parameters where 1.03 for b, 1.31 for n, 1.0 for a and 1.7 for m according to equation 1 and 2, the black curve is calculated by new rock electrical parameters that have considered CO_2 effect. The red dots represent irreducible water saturation obtained from core NMR experiment, it can be seen that the black curve is more consistent with core results. Table 4 is the comparison of water saturation calculated by new and old parameters with core results, it shows that, water saturation calculated by the old parameters is higher than core analysis results, the average absolute error is 5.2%, which doesn't meet reservoir evaluation absolute error standard of 5%, while water saturation calculated by new parameters is more consistent with core analysis result, the average absolute error is 2.1%, which means the new model has higher water saturation calculation accuracy.

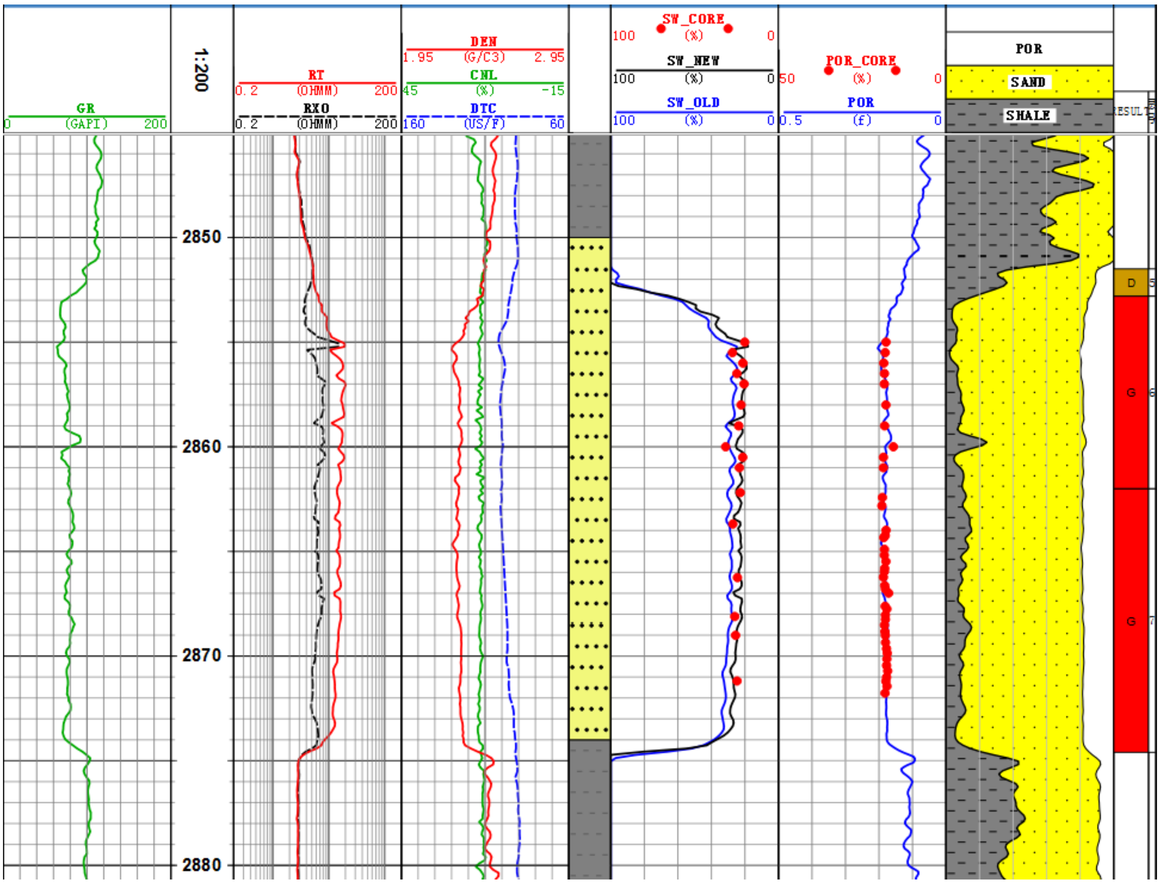

Fig. 7 Water saturation interpretation results of well XF4

Table 4. Comparison of water saturation calculated by new and old parameters with core results of well XF4

Well No.	Core No.	Core depth (m)	Core porosity (%)	logging porosity (%)	Core water saturation _SW_c (%)	Old saturation _SW_o (%)	New saturation _SW_n(%)	absolute error	
								SW_o-SW_c (%)	SW_n-SW_c (%)
XF4	1	2855	17.90	18.54	20.10	25.32	21.06	5.22	0.96
XF4	2	2855.5	18.14	20.19	27.40	29.32	25.60	1.92	1.80
XF4	3	2856	18.57	19.25	21.20	26.64	19.67	5.44	1.53

XF4	4	2856.5	18.38	19.60	24.80	27.68	21.93	2.88	2.87
XF4	5	2857	18.41	18.53	20.50	28.33	18.86	7.83	1.64
XF4	6	2858	17.94	18.21	22.30	28.15	21.06	5.85	1.24
XF4	7	2859	18.31	18.76	23.70	32.38	24.48	8.68	0.78
XF4	8	2860	15.70	17.17	30.50	29.46	25.15	1.04	5.35
XF4	9	2860.5	18.69	18.44	21.30	26.34	19.75	5.04	1.55
XF4	10	2861	18.73	18.24	23.30	28.66	23.31	5.36	0.01
XF4	11	2862.19	18.45	18.17	22.79	31.45	25.19	8.66	2.40
XF4	12	2863.69	17.95	18.28	27.18	29.98	22.74	2.80	4.44
XF4	13	2866.25	18.46	18.71	24.46	29.02	22.87	4.56	1.59
XF4	14	2868.11	18.23	18.48	26.06	29.48	21.76	3.42	4.30
XF4	15	2869.01	18.11	17.76	25.56	30.14	24.87	4.58	0.69
XF4	16	2871.19	18.13	18.38	24.70	34.53	26.87	9.83	2.17

5. Conclusion

1. For high temperature, high pressure and CO_2 containing reservoirs, rock electrical parameters obtained from conventional rock electrical experiments Can't truly reflect reservoir rock conductivity characteristics, it is necessary to consider the influence of CO_2 gas on experimental results.

2. The influence of CO_2 gas on reservoir rock electrical characteristics under formation temperature and pressure is analyzed by selecting appropriate experimental equipment and reasonable experimental procedures. The experiment results show that, under formation temperature and pressure, with the increase of CO_2 content, lithology coefficient b increases while saturation exponent n decreases. Equations of using CO_2 content to calculate lithology coefficient b and saturation index n are established based on the experimental data.

3. The calculation equations of b and n are very helpful in improving water saturation calculation accuracy of high temperature and high pressure and CO_2 containing gas reservoirs, which indicates the experiments have made a significant improvement on reservoir logging evaluation in the study area.

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