International Journal of Energy
ISSN: 2957-9473 | Vol. 2, No. 3, 2023

Numerical Simulation of Carbon Oxygen Ratio Logging Response in Natural Gas Hydrate Reservoirs

Qing Jiang [1], Pengju Li [1, 2]

[1] School of Earth Science, Northeast Petroleum University, Daqing 163318, China
[2] Accumulation and Development of Unconventional Oil and Gas, State Key Laboratory Cultivation Base Jointly-constructed by Heilongjiang Province and the Ministry of Science and Technology, Northeast Petroleum University, Daqing 163318, China

Abstract: In the process of oil and gas field development, in order to identify the gas hydrate reservoir more accurately, we try to use the carbon oxygen ratio spectrum logging technology to study the log response law of this reservoir, and compare it with the reservoir response law to better guide the oil field production. Firstly, the theoretical response law of carbon and oxygen concentration ratio of natural gas hydrate reservoir and oil layer is deduced according to the petrophysical model, and then the response law of carbon and oxygen concentration ratio of two types of reservoirs simulated by Monte Carlo numerical simulation is studied, and the similarity law and difference between the two types of reservoirs are summarized. The results show that the carbon oxygen ratio has a regular change relationship with the porosity and saturation of the reservoir. The carbon oxygen ratio can be used to preliminarily distinguish and qualitatively identify the two types of reservoirs.

Keywords: Natural Gas Hydrate; Carbon Oxygen Ratio Logging; Monte Carlo Numerical Simulation; Carbon Oxygen Counting Ratio.

1. Introduction

Natural gas hydrate, also known as combustible ice, is a solid substance formed by natural gas and water under low temperature and high-pressure conditions, similar in appearance to ice. In the exploration and development process of natural gas hydrates, geophysical logging methods are important methods for qualitative identification and reservoir evaluation [1-3]. This paper studies the response law of natural gas hydrate reservoir through carbon oxygen ratio energy spectrum logging [4][5]. This logging method records the inelastic gamma rays released by non-elastic scattering of elements in the formation to obtain the complete energy spectrum composed of each energy count rate. Moreover, because carbon can be used as the indicator element of natural gas hydrate, oxygen can be used as the indicator element of water [6-8], The characteristic peak energies of the two are 4.43 MeV and 6.13 MeV, respectively, which can be distinguished in the energy spectrum. As long as the appropriate window opening range is selected, the carbon oxygen energy window counting ratio can be used to analyze and evaluate natural gas hydrate reservoirs.

2. Theoretical Response of Carbon Oxygen Ratio Logging in Natural Gas Hydrate Reservoirs

2.1. Theoretical Response of Carbon Oxygen Ratio Logging in Natural Gas Hydrate Reservoirs: Relationship between Carbon Oxygen Concentration Ratio and Porosity and Saturation in Natural Gas Hydrate Reservoirs

The changes in porosity and natural gas hydrate saturation in the formation result in changes in C and O concentrations. Assuming that the pores in sandstone formations are only composed of water and natural gas hydrates, the porosity of the formation can be set as ϕ, if the water saturation is S_w, and the natural gas hydrate saturation[9] is S_c, then equation (1) can be obtained:

$$S_c + S_w = 1 \tag{1}$$

Assuming that the concentrations of C and O in sandstone formations are N_c and N_o, respectively, the carbon oxygen concentration ratio can be obtained from the volume model as follows:

$$\frac{N_c}{N_o} = \frac{m\phi S_c + n(1-\phi)}{x\phi S_c + y\phi(1-S_c) + z(1-\phi)} \tag{2}$$

In the formula: m - the number of carbon atoms per unit volume of natural gas hydrate;

n - the number of carbon atoms in the skeleton of sandstone per unit volume;

x - the number of oxygen atoms in a unit volume of natural gas hydrate;

y - the number of oxygen atoms per unit volume of water;

z - The number of oxygen atoms in a sandstone skeleton per unit volume.

For sandstone formations, the density of the rock skeleton (SiO_2) is 2.65g/cm^3, the density of water (H_2O) is 1.0g/cm^3, and the density of natural gas hydrates is 0.91g/cm^3. Based on the atomic mass and material density listed in Table 1, the five unknown parameters in the above equation can be calculated, and the calculation results are shown in Table 2.

So, the carbon oxygen concentration ratio of sandstone reservoirs can be expressed as:

$$\frac{N_c}{N_o} = \frac{0.46\phi S_c}{2.63\phi S_c + 3.35\phi(1-S_c) + 5.32(1-\phi)} \tag{3}$$

Table 1. Atomic mass of each element in the stratum

atomic type	H	C	O	Si
mass(g)	1.674×10^{-24}	1.993×1^{-23}	2.657×10^{23}	4.65×10^{23}

Table 2. Parameters in the formula

parameter	m	n	x	y	z
value	0.46	0	2.63	3.35	5.32

According to equation (3), calculate the corresponding relationship between the porosity of sandstone formation and the carbon oxygen concentration ratio within the range of 0-40%, and obtain Figure 1. From the graph, it can be seen that when the saturation of natural gas hydrates is zero, the change in formation porosity does not lead to a change in the carbon oxygen concentration ratio. The carbon oxygen concentration ratio is a constant value because at this time, all the pores are filled with water. When the saturation of natural gas hydrates is greater than zero, it can be seen that as the porosity of the formation increases, the carbon oxygen concentration ratio shows a significant increasing trend. The higher the porosity of the formation and the saturation of natural gas hydrates, the more obvious the growth trend of the carbon oxygen concentration ratio.

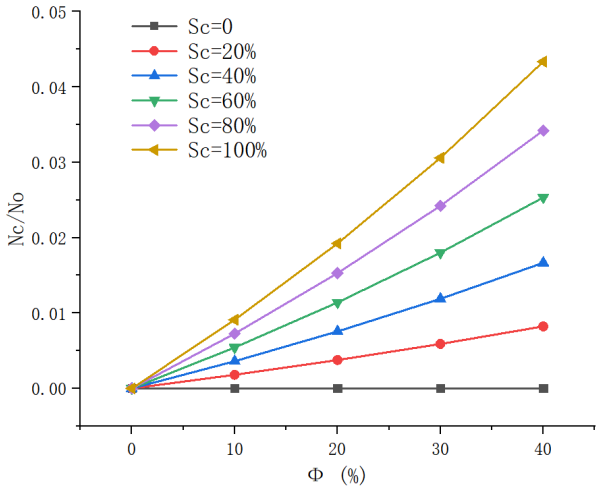


Fig 1. Relationship between formation porosity and carbon/oxygen concentration ratio

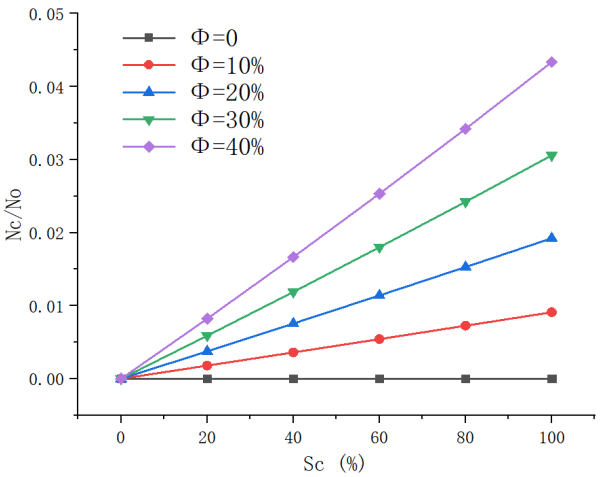


Fig 2. Relationship between gas hydrate saturation and carbon oxygen concentration ratio

At the same time, the corresponding relationship between the saturation of natural gas hydrates and the carbon oxygen concentration ratio can be obtained when the saturation changes from 0 to 100%, as shown in Figure 2. When the porosity of the formation is zero, there is no porous fluid and the carbon oxygen concentration ratio is zero. When the porosity of the formation is greater than zero, the carbon oxygen concentration ratio increases with the increase of natural gas hydrate saturation. The larger the porosity of the formation, the more obvious the growth trend of the carbon oxygen concentration ratio.

2.2. The Relationship between Carbon Oxygen Concentration Ratio and Porosity and Oil Saturation in Oil Reservoirs

In sandstone formations, if there is only oil and water in the pores, the formation porosity is assumed to be ϕ. The density of the rock skeleton (SiO_2) is 2.65g/cm^3, the oil saturation is S_o, the density of oil (C_nH_{2n}) is 0.87g/cm^3, the water saturation is S_w, and the density of water (H_2O) is 1.0g/cm^3. Analogous to the derivation of the carbon oxygen concentration ratio of natural gas hydrate reservoirs, the calculation can obtain the carbon oxygen concentration ratio of the oil layer as follows:

$$\frac{N_c}{N_o}=\frac{3.74\phi S_o}{3.35\phi(1-S_o)+5.32(1-\phi)} \tag{4}$$

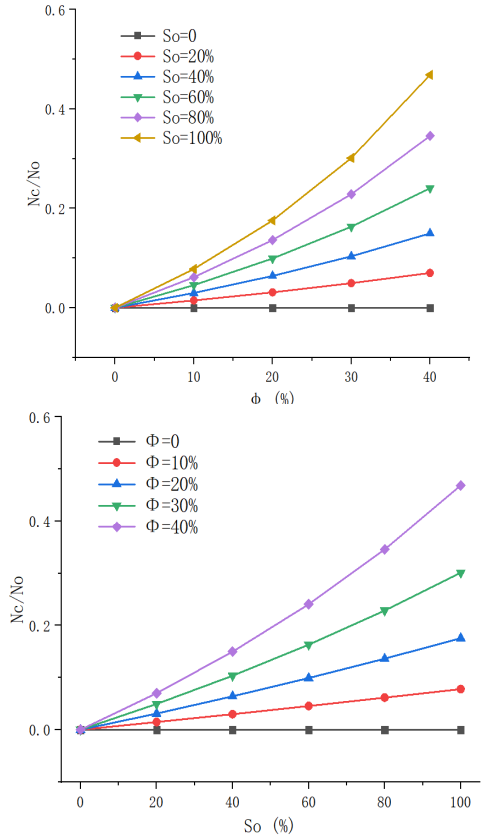


Fig 3. Relationship between formation porosity, oil saturation and C/O concentration ratio

According to the above formula, the corresponding relationship between the porosity of the sandstone formation and the carbon oxygen concentration ratio within the range of 0~40% and the corresponding relationship between the oil saturation and the carbon oxygen concentration ratio when the oil saturation changes from 0 to 100% can be obtained, as shown in Figure 3. From the graph, it can be seen that the trend of changes in the oil layer is similar to that of natural gas hydrate reservoirs, both of which increase the porosity of the formation and the ratio of carbon to oxygen concentration. However, under the same geological conditions, the carbon oxygen concentration ratio of oil layers is significantly higher than that of natural gas hydrate reservoirs, and with the increase of formation porosity, the growth trend of the carbon oxygen concentration ratio of oil layers is more obvious, with a greater increase in amplitude.

3. Response of Carbon Oxygen Ratio Logging Simulation in Natural Gas Hydrate Reservoirs

3.1. Monte Carlo Numerical Simulation of Stratigraphic Physical Model

In order to restore the formation situation in actual logging as much as possible and improve the accuracy of simulation, it is necessary to establish a physical model of the formation that is in line with actual production [10] [11]. This article uses Monte Carlo numerical simulation software (MCNP5) to simulate the response data of natural gas hydrate reservoirs and oil layers [12] [13], and the established stratigraphic model is shown in Figure 4. This model is an ideal cylindrical model with a height of 180cm and a diameter of 100cm. The wellbore diameter is 20cm, and the fluid between the wells is filled with fresh water; Use 14 MeV pulsed neutron source; The near and far detectors use lanthanum bromide ($LaBr_3$), the shielding material is tungsten, and the instrument is set in a vacuum state.

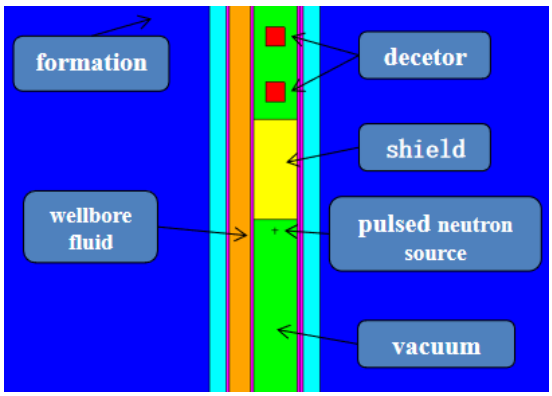


Fig 4. Formation physical model of Monte Carlo numerical simulation for carbon-oxygen ratio logging

3.2. The Relationship between Carbon Oxygen Counting Ratio and Porosity and Saturation in Natural Gas Hydrate Reservoirs

By simulating the detector, the relative counting rates corresponding to each energy can be recorded. The carbon window range set in this article is 4.15-4.81 MeV, and the oxygen window range is 4.89-6.34 MeV. Calculate the sum of the counting rates within the respective energy window ranges of carbon and oxygen, and thus obtain the carbon oxygen counting ratio (C/O). This study simulated and calculated the corresponding relationship between the porosity of natural gas hydrate reservoir in sandstone formation and carbon oxygen count ratio in the range of 0~40% and the corresponding relationship between the saturation of natural gas hydrate in the range of 0~100% and carbon oxygen count ratio. The trend line of change was obtained by fitting, and the results are shown in the following figure.

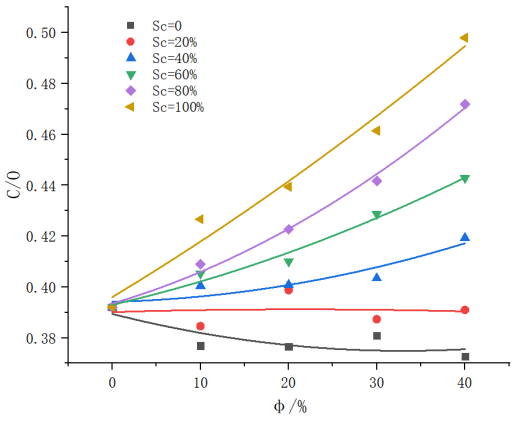


Fig 5. Relation curve between porosity of gas hydrate reservoir and carbon and oxygen counting ratio

From the graph, it can be seen that when the saturation of natural gas hydrates is less than 20%, the carbon oxygen count ratio decreases with the increase of formation porosity. The smaller the saturation of natural gas hydrates, the more obvious the decreasing trend; When it is greater than 20%, the carbon oxygen count ratio increases with the increase of formation porosity, and the higher the saturation of natural gas hydrates, the more obvious the trend of increase.

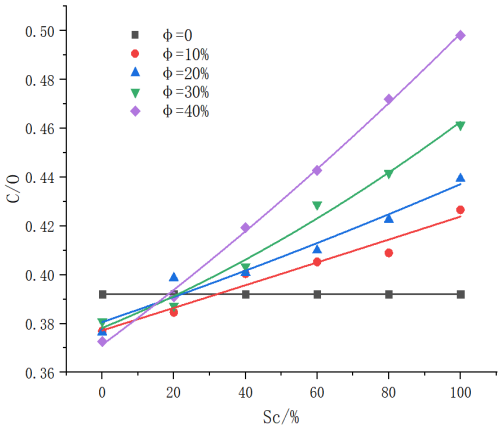


Fig 6. Relation curve between gas hydrate saturation and carbon and oxygen counting ratio

As shown in the figure, when the saturation of natural gas hydrates is less than 20%, the larger the porosity of the formation, the smaller the carbon oxygen count ratio, and the carbon oxygen count ratio is close, with little change; When the saturation of natural gas hydrates is greater than 20%, the larger the porosity of the formation, the greater the carbon oxygen count ratio. It can be seen that when the saturation of natural gas hydrates is low, the carbon oxygen count ratio is more difficult to distinguish the reservoir.

3.3. The Relationship between Carbon Oxygen Count Ratio and Porosity and Oil Saturation in Oil Reservoirs

At the same time, the corresponding relationship between

porosity of sandstone formation oil layer and carbon oxygen count ratio in the range of 0~40% and the corresponding relationship between oil saturation in the range of 0~100% and carbon oxygen count ratio is simulated and calculated. The trend line of change is obtained by fitting, and the results are shown in Figure 7.

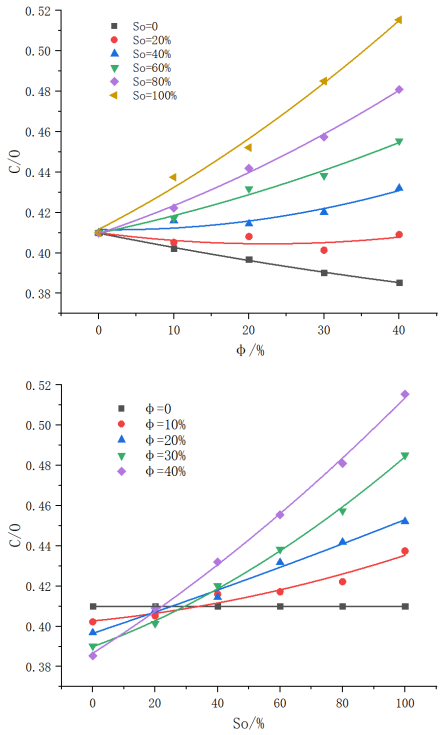


Fig 7. Relation curve between formation porosity, oil saturation and carbon and oxygen counting ratio

From the above figure, it can be seen that the logging response patterns of the two types of reservoirs are similar, but under the same formation porosity and saturation conditions, the carbon oxygen count ratio of the oil layer is generally higher than that of the natural gas hydrate reservoir. When So ≤20%, the carbon oxygen count ratio decreases with the increase of formation porosity, and the smaller the oil saturation, the more obvious the decreasing trend; When So≥40%, the carbon oxygen count ratio increases with the increase of formation porosity, and the greater the oil saturation, the more obvious the increasing trend. When the oil saturation is around 20%, the change in carbon oxygen count ratio is very small, which also indicates that carbon oxygen ratio spectroscopy logging can more accurately qualitatively and evaluate reservoirs when the oil saturation is high.

4. Conclusion

(1) Based on the rock physics model, the theoretical response expressions of the carbon oxygen concentration ratio of natural gas hydrate reservoirs and oil layers in sandstone formations with respect to formation porosity and saturation were derived. It was found that the carbon oxygen concentration ratio, porosity and saturation of both types of reservoirs showed a relatively obvious single change pattern.

(2) By establishing a suitable stratigraphic model and using Monte Carlo numerical simulation to calculate the relationship between the carbon oxygen count ratio, porosity, and saturation of natural gas hydrate reservoirs, it is concluded that when the saturation of natural gas hydrate exceeds 20%, the analysis and evaluation of the reservoir can be more accurate.

(3) Under the same stratigraphic model, the simulation results of oil layers have similar variation patterns to natural gas hydrate reservoirs. However, under the same formation porosity and saturation conditions, there are certain differences in the carbon oxygen ratio between the two types of reservoirs. This difference can be used for qualitative analysis of reservoirs.

References

[1] He Meixing, Fang Hui, Zhu Youhai, et al. Study on tectonics characteristics and geological conditions of gas hydrate accumulation in Hala Lake Depression of Qilian Mountains [J]. Geology of China, 2020, 47 (1): 173-187.

[2] Wang Pingkang, You Hai, Lu Zhenquan, et al. Review of research progress on natural gas hydrates in the permafrost areas of the Qilian Mountains in Qinghai [J]. Chinese Science: Physics, Mechanics, Astronomy, 2019, 49 (3): 72-91.

[3] Wu Shuyu, Xu Huaning, Liu Jun, et al. Frequency division inversion of heterogeneous natural gas hydrate reservoirs in the Shenhu Sea area of the South China Sea [J]. Marine Geology and Quaternary Geology, 2020, 40 (6): 106-120.

[4] Collett T S, Wendlandt R F. Formation evaluation of gas hydrate-bearing marine sediments on the blake ridge with down geochemical log measurements[C].Proceeding of the Ocean Driling Program, Scientific Results, 2000.

[5] Zhou Yinhang, Ma Yugang, Zhao Guangyi Method for detecting natural gas hydrates using carbon oxygen ratio spectroscopy [J]. Offshore Oil, 2006 (1): 47-50.

[6] Liu Juntao, Zhang Feng, Zhang Quanying, Hou Guojing, Zhang Haoping, Ding Fan Method for Improving the Sensitivity of Carbon Oxygen Ratio Logging in Low Porosity Reservoirs [J]. Journal of China University of Petroleum (Natural Science Edition), 2016,40 (06): 57-62.

[7] Li Pengju, Tian Tian, Wei Shuangbao Interpretation model for carbon oxygen ratio logging of natural gas hydrate saturation [J]. Journal of Heilongjiang University of Science and Technology, 2021,31 (03): 289-294.

[8] Ma Shuilong, Shen Fujian, Wu Zhimin, Wang Feng, Zheng Hua The New Application of PNST Pulse Neutron Full Spectrum Logging Tool in Jidong Oilfield [J]. Petroleum Pipe and Instrument, 2018,4 (05): 27-31.

[9] Sun Jianmeng, Luo Hong, Jiao Tao, Chen Hua, Song Liyuan, Xiong Zhu Overview of logging evaluation of gas hydrate reservoir parameters [J]. Progress in geophysics, 2018,33 (02): 715-723.

[10] Tian Tian. Research on Pulse Neutron Carbon Oxygen Ratio Logging Method for Natural Gas Hydrate Reservoirs [D]. Northeast Petroleum University, 2021.

[11] Wang Ruigang Research on New C/O Spectral Logging Data Processing Methods [D]. China University of Petroleum (Beijing), 2018.

[12] Briesmeister J F. MCNP-A General Monte Carlo N-Particle Transport Code[C]. Version 4C, RA-13709-M, Los Alamos: Los Alamos National Laboratory, 2003.

[13] Zhang Feng. Overview of the Development of Pulse Neutron Logging Technology in China [J]. Atomic Energy Science and Technology. 2009, 43 (Supplement): 116-123.