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Monte Carlo simulation for determining gas saturation using three-detector pulsed neutron logging technology in tight gas reservoir and its application

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HIGHLIGHTS

- A new method proposed to determine gas saturation in tight gas reservoir.
- The new method has high sensitivity to determine gas saturation than traditional logging method.
- Influence factors of the new method determining gas saturation were studied.

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ABSTRACT

A new method to accurately determine gas saturation in the tight gas reservoir using a three-detector pulsed neutron logging tool was proposed. Formation porosity is varied from 2% to 15% to simulate the distribution of thermal neutron under different borehole and formation conditions by using Monte Carlo method. The study result shows that the difference of three detectors counts can be used to determine gas saturation and have higher sensitivity than counting the ratio of different detectors.

1. Introduction

Unconventional resources, including tight gas, shale gas, tight/shale oil, and coal bed methane, become a significant source of hydrocarbon production and offer remarkable potential for reserves growth and future production (Ilk et al., 2010). The National Petroleum Council of American (Raymond et al., 2007) reported that there are an estimated 4024 Tcf of global natural gas resource in tight gas reservoirs and 8225 Tcf in coal bed methane reservoirs (McCracken and Fitz, 2008). Tight gas reservoir, which is referred to gas reservoir with low porosity and low permeability (Holditch, 2009), is one of crucial items of unconventional reservoir. Therefore, the study on tight gas reservoir is significant for meeting the world's growing demand for energy.

However, as the tight formations are extremely complex, including complex matrix mineralogy, detrital clays and great heterogeneity, the analysis of tight gas reservoir is one of most difficult petrophysical problems needed to be solved (Hamada et al., 2007, Merkel and Gegg, 2008 and Elshafei and Hamada, 2009). Be that as may be, an amount of achievements are still received in the research of tight gas reservoir. Trcka et al. (2006) built the relationship of the ratio of inelastic gamma counts at different detectors and gas saturation with RPM logging data; the hydrocarbon monitoring in gas sandstone reservoir using TDT and CHFR techniques was discussed by Hamada et al. (2007). Hamada and Hegazy (2007), Merkel and Gegg (2008) made use of NMR logging data to solve some problems in tight gas reservoirs, such as porosity calculation, model building, permeability estimation, etc.

In this paper, we release a new method to quantitatively determine gas saturation of tight gas reservoir using a three-detector pulsed neutron logging technology. The logging response

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of gas saturation and the effect of influential factors were simulated by Monte Carlo method. And we have applied this new method to process log data from two wells in an oilfield, yielding reliable interpretation result from the data.

2. Methodology

Through the elemental component of natural gas is similar to oil, the density and hydrogen content of natural gas is far less than that of oil. Therefore, the distribution of thermal neutron would change because of the low hydrogen content in tight gas reservoir, and then the gas properties can be reflected by using the thermal neutron counts of different detectors (Zhang et al., 2010).

According to the spatial distribution of thermal neutron (Longji, 2000), the ratio of thermal neutron count of near and far detector and that of middle and far detector can be expressed as:

$$R_{13}=N_1/N_3=\frac{r_3}{r_1}e^{-(r_1-r_3)/L_f} \quad (1)$$

$$R_{23}=N_2/N_3=\frac{r_3}{r_2}e^{-(r_2-r_3)/L_f} \quad (2)$$

where, r_1, r_2 and r_3 is respectively short and middle and long spacing; N_1, N_2 and N_3 is respectively thermal neutron counts of near, middle and far detector; L_f is slow-down length of fast neutron.

The difference of the ratio of thermal neutron count of near and far detector and that of middle and far detector is obtained:

$$\mathrm{D}=R_{13}-R_{23}=N_1/N_3-N_2/N_3=\frac{r_3}{r_1}e^{-(r_1-r_3)/L_f}-\frac{r_3}{r_2}e^{-(r_2-r_3)/L_f} \quad (3)$$

D is related to L_f which is dependent on porosity and gas saturation. Then gas saturation can be determined by using porosity and D value.

3. Monte Carlo simulation

Monte Carlo simulation is employed to study the method determining gas saturation quantitatively and different influential factors in reservoir with low porosity, which can provide theoretical basis for the logging interpretation in tight gas reservoir.

3.1. Computational model

In order to study the response of quantitatively determining gas saturation in tight gas reservoir, the computational model is built using Monte Carlo N-Particle Transport (MCNP) Code (Briesmeister, 2003), shown in Fig. 1 and specifications are:

- Borehole is filled with fresh water and diameter is 20 cm.
- Cement is composed of $CaSiO_3$ with thickness is 3 cm and density is 1.95 g/cm^3.
- Thickness of casing is 0.7 cm.
- The radial radius and height of formation is 10~70 cm and 140 cm, respectively.
- The neutron logging tool with 20 μs pulse width is placed sidewall. In addition, short, middle and long spacing is 22.5 cm, 42.5 cm and 72.5 cm, respectively.

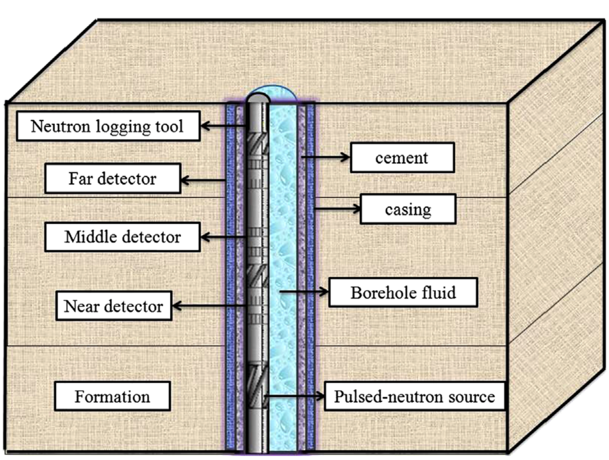

Fig. 1. Monte Carlo simulation model.

3.2. Logging response characteristic

3.2.1. Gas saturation response

Using the computational model mentioned above, formation pore is filled with water and gas. The density of methane gas is 0.2 g/cm^3. When the porosity is 2%, 5%, 8%, 10%, 15%, respectively, the gas saturation is set to 0, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100%, respectively. Thermal neutron counts at near, middle and far detector are recorded and the relationship between D and gas saturation with identical porosity can be obtained, which is shown in Fig. 2. On the other hand, when gas saturation is 0, 20%, 40%, 60%, 80%, 100%, respectively, the porosity is set 2%, 4%, 5%, 6%, 8%, 10%, 12%, 13% and 15%, respectively. The relationship of D and porosity with identical gas saturation is illustrated in Fig. 3.

From Figs. 2 and 3, it can be seen that D is related to porosity and gas saturation. When porosity is identical, D decreases with increasing of gas saturation and the smaller porosity is, the more acute curve changes; when gas saturation is identical, D increases with increasing of porosity and the curve change acutely when gas saturation is small. Therefore, gas saturation can be quantitatively determined by using D combined with porosity data. That is, gas saturation can be quantitatively evaluated in tight gas reservoir using this new method.

3.2.2. Response sensitivity

Formation pore is water-saturated and natural-gas-saturated under the condition of borehole filled with fresh water and natural gas, respectively. The thermal neutron counts are recorded by different detectors under nine porosities (2%, 4%, 5%, 6%, 8%, 10%, 12%, 13% and 15%).

The sensitivity of gas saturation is defined as:

$$S=(R_w-R_g)/R_w \quad (4)$$

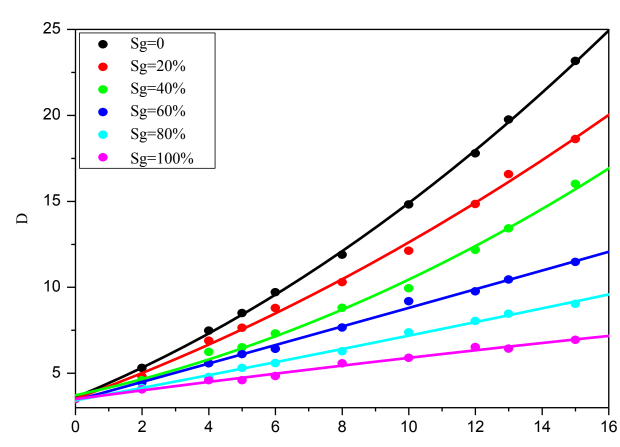

Fig. 2. The relationship of D and S_g with identical porosity.