Thin bed responses and correction methods for cased hole density logging

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Abstract: The study of the thin bed responses and correction methods in cased hole density logging can provide a theoretical basis for research to improve data processing methods. By using the Monte Carlo program MCNP, the change of detector count from thin beds with the vertical depth was calculated at different casing thicknesses. The calculation showed that with the low density thin bed moving upward, detector count first increased to a maximum then decreased. The responses of a thin bed with a high density were opposite to those of a thin bed with a low density. The change curve was symmetrical, and the maximums or minimums appeared at the midpoint between the detector and source. Besides, detector count increased with increasing thin bed thickness. At a specific thin bed thickness, further increase of thin bed thickness resulted in a slow increase of detector count then the count rate leveled off. In actual logging, the influence of adjacent formations on density log measurements can be ignored. Finally, based on numerical simulation correction methods for the dual influence of casing and thin beds are discussed.

Key words: Density logging in cased hole, thin bed response, casing, MCNP program, correcting

1 Introduction

Over the past several years, logging methods for open hole formation evaluation have been used in cased holes (Bellman et al, 2003; Tan et al, 2003; Li et al, 2006; Qiao and Che, 2005; Shi et al, 2006; Luo et al, 2006; Zhou et al, 2007). A typical example in radioactive logging is cased hole litho-density logging. It can provide formation evaluation parameters for holes that have weak stability before being cased, and provide porosity data for cased holes without porosity data or for old wells with bad data quality. Furthermore, it can identify gas beds and monitor reservoir dynamics in cased holes (Cosentine and Spotti, 1992).

Using the Monte Carlo Neutron and Photo Transport Code (MCNP) (Wolcott and Vittachi, 1994; Quint, 1999), this paper focuses on the thin bed responses and correction methods for density logging in cased holes with the Slim Array Litho-Density Tool (SLDT) of the Schlumberger Company (Stoller et al, 1997; Moake, 1998; Ellis et al, 2004). In this paper, the dots in figures represent calculation results and the curves in figures represent fitting results.

2 Calculation model

Considering the actual conditions, the model is designed to be semi-cylindrical for calculation convenience (Wu and Huang, 2004; Wu and Xiao, 2007a; 2007b). Fig. 1 shows the longitudinal and lateral sections of the model. In the model,

the formation thickness is 225 cm and the formation radius is from 10 cm to 43 cm. The logging tool, which has a ^{137}Cs point source emitting gamma rays of 0.662MeV, is placed against the borehole wall. The semi-cylindrical space between source and detector and above the detector is filled with ideal shielding material, whose thickness changes with the spacing. The space outside the model is also filled with shielding material. A point detector tallies the flux spectrum of photons with energy of above 0.15MeV. The variance reducing techniques have been applied to Monte Carlo simulation without considering the detector effect. Relative calculation error of photon count is limited to 1%.

Fig. 1 Calculation model (D: detector; S: source)

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3 Thin bed responses

3.1 Responses of thin bed location

The calculation method is as follows. Wall rock is pure limestone with porosity of zero and density of 2.710 g/cm^3 ; the thin bed is limestone with porosity of 40% saturated with fresh water and density of 2.026 g/cm^3 . The thickness H of the thin bed is set to 36cm, 45cm and 54cm and the thickness H_c of casing is set to 0, 1.5 cm and 3.0 cm respectively. The radioactive source is placed at the point (9, 0, 54) and the detector with a long spacing of 40cm is placed at the point (9, 0, 94). We calculated only for the long spacing detector in this paper. Curves of detector count changing with the longitudinal position of the thin bed were obtained when the thin bed moved from bottom to top of the model gradually (Fig. 2).

Fig. 2 shows that with the thin bed moving upward, the detector count increases gradually, reaches a maximum and then declines. The detector count curve is symmetrical and its half-width is close to the thickness of the thin bed. The count maximum appears at the point (9, 0, 74), that is nicely the midpoint between source and long spacing detector, which proves theoretically that the sensitive position of density logging is the midpoint between source and long spacing detector. Fig. 2 also shows that when the thickness of thin bed is fixed, the thicker the casing is, the smaller the detector

(a) $H=36\text{cm}$

(b) $H=45\text{cm}$

Fig. 2 Responses of thin bed location at different casing thicknesses

count is. That is to say, the casing will make statistical error increase and weaken the thin bed resolution of density logging. Therefore, appropriate casing thickness must be selected and correction for casing must be done in density logging. The responses of a thin bed with a high density are opposite to those of a thin bed with a low density.

3.2 Responses of thin bed thickness

The thickness H_c of casing is 1.5cm and the thickness H of thin bed is designed as 18 cm, 27 cm, 33 cm, 60 cm and 72 cm. The longitudinal position of the thin bed with a low density is fixed. When the tool moved from bottom to top of the model, the responses of thin bed thickness for long spacing detector were obtained as shown in Fig. 3.

Fig. 3 shows that detector count increases gradually with increasing thin bed thickness. When the thin bed thickness reaches a specific value, the detector count will increase slowly and then level off with further increasing thin bed thickness. The responses of thin bed thickness can be expressed as follows:

$$\Delta\rho = K(1 - e^{-rh}) \quad (1)$$

Fig. 3 Detector count curves changing with thin bed thickness

where, $\Delta\rho$ is the change of density resulting from the thin bed; K is a constant; r is a positive coefficient related to the density tool construction.

3.3 Influence of adjacent formation

In the calculation, two thin beds with thickness H of 36cm and 72cm are fixed one at a time at the midpoint of the model (9, 0, 108). When the tool moved upward from the bottom of the model, the results were obtained as shown in Fig. 4.

Fig. 4 shows that count curves are asymmetric, and the counts below are bigger than those above. The reason is that the material outside of the model is supposed to be ideal shielding, that is to say, a formation with infinite density is placed at the bottom of the model. The photons emitted to the formation are reflected, which results in a high detector count. The influence of adjacent formation is greater with decreasing casing thickness.

In actual logging, the influence of adjacent formation can be ignored because there are no formations with infinite density, so the count curves are symmetrical.

Fig. 4 Influence of adjacent formation

4 Corrections for dual influence of thin bed and casing

For the SLDT tool (Stoller et al, 1997), two compensated density tools can be formed by using the long detector and the short detector or the middle detector and the short detector because SLDT tool has three detectors which are long, short and middle, respectively. Thus, the traditional compensated density method for mud cake can be used to compensate the influence of the casing. The compensated density value ρ_{bL} from the long detector compensated by the short detector and ρ_{bM} from the middle detector compensated by the short detector can be obtained. The formation density ρ_b can be taken as the average of ρ_{bL} and ρ_{bM} .

To study the influence and correction of the thin bed and casing, the casing thickness is set to be 1.0cm, long spacing is 40cm, middle spacing is 28cm, and short spacing is 12cm. The calculation result is shown in Fig. 5. $\Delta\rho$ is the change of density resulting from the thin bed thickness H and $\Delta\rho_{\max}$ is the maximum change of density.

Fig. 5 shows that the three changing curves produce three points of intersection, and the whole area of the figure can be divided into four parts A, B, C and D.

In the area A, there is only casing that influences long spacing, middle spacing and short spacing counts, thus, $\rho_L > \rho_M > \rho_S$. In this situation, the traditional compensated density method for mud cake can be used to correct for the influence of the casing.

In the area B, the long spacing count is influenced by both the casing and the thin bed, and the middle or short counts are only influenced by the casing, thus, $\rho_L < \rho_M > \rho_S$. In this situation, the formation density can be obtained from ρ_M corrected for the effect of the casing.

In the area C, the long spacing and middle spacing counts are influenced by both the casing and the thin bed, and the short count is only influenced by the casing, thus, $\rho_L < \rho_S < \rho_M$. Formation density can be obtained from ρ_M corrected by the thin bed and casing. The equation $\Delta\rho_{ML} = \rho_M - \rho_L$ can be used to correct the thin bed influence for ρ_M and the equation $\Delta\rho_{MS} = \rho_M - \rho_S$ can be used to correct the casing influence for ρ_M .

Fig. 5 Density curves changing with thin bed thickness

In the area D, this situation can be ignored because the thin bed thickness is too small.

5 Conclusions

1) The response curves from the thin bed with changing vertical location in the calculation model are symmetrical, and the half-width is close to the thickness of the thin bed. With increasing casing thickness, the detector count decreases, statistical error increases and the thin bed resolution of the density logging is reduced.

2) The detector count increases gradually with increasing thin bed thickness. When the thin bed thickness reaches a specific value, the detector count will level off with further increasing thin bed thickness.

3) The influence of adjacent formations on density logging results can be ignored.

4) A three-detector density tool can be used to correct the dual influences of the thin bed and the casing.

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