Journal of Applied Geophysics 132 (2016) 229–233

Contents lists available at ScienceDirect

Journal of Applied Geophysics

journal homepage: www.elsevier.com/locate/jappgeo

Convolution effect on TCR log response curve and the correction method for it

Q. Chen [a], L.J. Liu [a,*], J. Gao [b]

[a] School of Electrical and Electronic Engineering, Huazhong University of Science and Technology, Wuhan 430074, China
[b] College of Geophysics and Information Engineering, China University of Petroleum, Beijing 102249, China

ARTICLE INFO

Article history:
Received 6 June 2015
Received in revised form 27 May 2016
Accepted 14 July 2016
Available online 16 July 2016

Keywords:
TCR logging
Vertical resolution
Convolution function of TCR logging tool
Modified Lyle-Kalman deconvolution

ABSTRACT

Through-casing resistivity (TCR) logging has been successfully used in production wells for the dynamic monitoring of oil pools and the distribution of the residual oil, but its vertical resolution has limited its efficiency in identification of thin beds. The vertical resolution is limited by the distortion phenomenon of vertical response of TCR logging. The distortion phenomenon was studied in this work. It was found that the vertical response curve of TCR logging is the convolution of the true formation resistivity and the convolution function of TCR logging tool. Due to the effect of convolution, the measurement error at thin beds can reach 30% or even bigger. Thus the information of thin bed might be covered up very likely. The convolution function of TCR logging tool was obtained in both continuous and discrete way in this work. Through modified Lyle-Kalman deconvolution method, the true formation resistivity can be optimally estimated, so this inverse algorithm can correct the error caused by the convolution effect. Thus it can improve the vertical resolution of TCR logging tool for identification of thin beds.

1. Introduction

Acquisition of through-casing resistivity (TCR) measurement was first proposed by Alpin (1939), and several studies have been performed concerning on TCR measurement. The simulations of TCR measurement are most by using *hp* finite-element method for both 2D (Pardo et al., 2006) and 3D (Pardo et al., 2008) model. The forward calculation of the TCR logging response by transmission line equation was used to investigate the effect of non-uniform formation in both vertical and radial direction (Liu et al., 2007; Gao et al., 2008). The effect of higher resistivity formation on the stability of measurement was investigated by Liu et al. (2013). Based on Kaufman's theory (Kaufman, 1993), the vertical resolution is determined by the potential electrodes interval of the instrument, and the measured resistivity of the instrument is the resistivity of formation between the potential electrodes. Kaufman's theory has pointed out that the measured resistivity of the instrument is closely associated with the formation resistivity between the potential electrodes, and when the formation is uniform the measured resistivity is exactly the formation resistivity. But it doesn't demonstrate a clear relationship between the measured resistivity and the true formation resistivity when the formation between the potential electrodes is non-uniform.

During the last two decades, TCR logging has been successfully used in production wells for the dynamic monitoring of oil pools and the distribution of the residual oil (Chen et al., 2010). In most cases, the measured resistivity can represent the true formation resistivity well, but there are always some distinctions between the measured resistivity and the true formation resistivity especially at location where the formation resistivity changes dramatically. And this distinction can't be eliminated by any efforts in promoting the accuracy of the measurement instrument. Fig. 1 shows an example of comparison of the curves of measured resistivity by TCR logging tool and the true formation resistivity. The true formation resistivity is represented by the dual laterolog which has a higher vertical resolution. The ρ_{LLD} is the resistivity of deep investigation laterolog which was measured at open hole in China (well No: Sha-103). The ρ_{TCR} is the measured resistivity in the metal casing hole by XCRL which is developed by CNPC Xibu Drilling Engineering Company Limited. Fig. 1 shows that, at location of 3008 m the error between the measured resistivity and the true resistivity can reach 30%, but they would agree basically well if the formation resistivity changes slowly. Due to this phenomenon, the formation information of thin beds might be covered up very likely. In order to obtain an more accurate formation resistivity measured by TCR logging tool for identification of thin beds, it's very necessary to analyze what causes this interesting phenomenon and find a method to correct the error caused by this phenomenon.

The phenomenon described above also existed in other well loggings such as induction logging (Thadani and Merchant, 1982), sonic logging (Williams et al., 1984), nuclear logging (McDonald and Palmatier, 1969) and gamma-ray logging (Conway, 1980). From the following analysis in this work it can be found that the reason for this phenomenon for TCR logging is also very similar to other well loggings. It was found that the vertical response of TCR logging tool is also the convolution of true formation resistivity and the convolution function of the well logging tool. So it

* Corresponding author.
E-mail address: liulongjian001@yeah.net (L.J. Liu).

http://dx.doi.org/10.1016/j.jappgeo.2016.07.012
0926-9851/

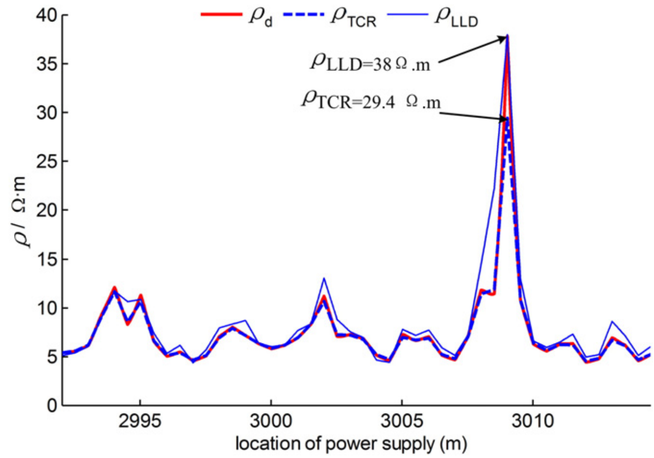

Fig. 1. Comparison of curve of TCR logging and true formation resistivity. ρ_d is the curve processed by deconvolution described in Section 4 of this work.

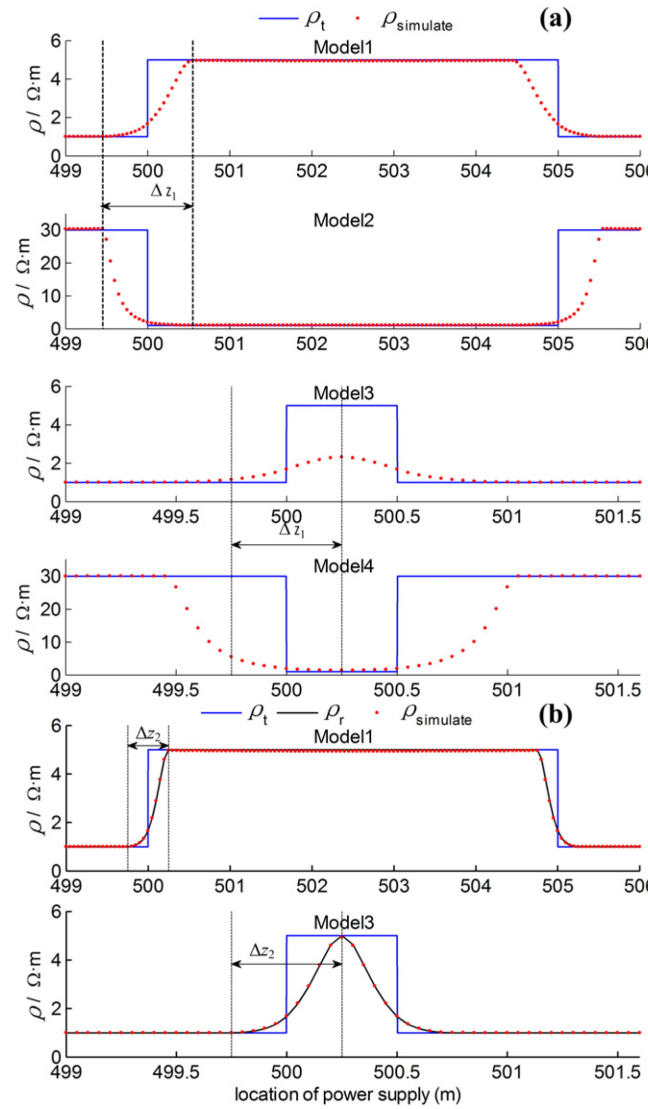

Fig. 2. The simulated TCR response curve. (a) The electrode interval Δz_1 is 1.1 m; here the electrode interval is the distance between the two potential electrodes M_1 and M_2. (b) The electrode interval Δz_2 is 0.5 m and ρ_r is resistivity curve calculated by Eq. (6).

is very likely that the methods of solving this similar problem in other well loggings can also be used in TCR logging. In this work, a modified Lyle-Kalman deconvolution was used to correct the TCR logging curve. To this end, we first analyzed the reason why there exist differences between the measured resistivity by TCR logging tool and the true formation resistivity. Based on this analysis, the convolution function of TCR logging tool was then derived and an inverse algorithm was used to correct the TCR logging curve for identification of thin beds. In addition, an ideal non-uniform formation model and the well log data presented in Fig. 1 were used to verify the analysis and performance of the correcting method proposed in this work.

2. Analysis of formation model with single thin bed

In order to analyze the phenomenon presented in Section 1, four simple formation models with one thin bed were used to interpret it. It was assumed that all the four models have three formation layers with different resistivities, and the lengths of casing are all 1000 m. The resistivities of formation layers of the four models are as follows:

Model 1: 0—500 m, 1 Ω m; 500—505 m, 5 Ω m; 505—∞ m, 1 Ω m.
Model 2: 0—500 m, 30 Ω m; 500—505 m, 1 Ω m; 505—∞ m, 30 Ω m.
Model 3: 0—500 m, 1 Ω m; 500—500.5 m, 5 Ω m; 500.5—∞ m, 1 Ω m.
Model 4: 0—500 m, 30 Ω m; 500—500.5 m, 1 Ω m; 500.5—∞ m, 30 Ω m.

Here the finite element simulation was used to obtain the TCR logging response curves for two cases: the potential electrode intervals are respectively 1.1 m and 0.5 m. The length of middle layer and electrode intervals were chosen as described above was to investigate the response of TCR logging tool at different condition (i.e., the length of the middle layer is larger than the electrode interval, the length of the middle layer is no more than the electrode interval, the effects of electrode interval on response of TCR logging tool). As shown in Fig. 2(a), the simulated resistivity curves represent the response resistivity of TCR logging. As comparison the true formation resistivity curves are also presented. From the comparison between simulated resistivity curves and the true formation resistivity curves, it can be found that when the formation between the potential electrodes is non-uniform there would be difference between the simulated resistivity curves and the true formation resistivity curves. The TCR logging response curve is distorted seriously at place where the formation resistivity changes rapidly. So it can be concluded that the TCR logging response curve can never be consistent with the true formation resistivity curve unless the formation is uniform. It is to say that the TCR logging response curve is the deformation of true formation resistivity curve. From the comparison between model 3 and model 4, it can be found that the formation information of thin bed with high resistivity would be very likely to be covered up. However, for thin beds with low resistivity it is not so. And by comparing model 1 and model 3 or model 2 and model 4, it can be found that the thinner the thin bed is the more likely the formation information of thin bed would be covered up.

3. Theoretical model for interpretation

3.1. Vertical response of TCR logging tool

Kaufman has derived the vertical response of TCR logging based on the analytical result of potential for the model which has a single thin bed (Kaufman, 1993). The analytical result is accurate but too complex and it is very difficult to obtain the analytical result for the model containing many thin beds. Based on measurement model of Kaufman, the resistivity of formation at the location of electrode *N*