UWB ELECTROMAGNETIC BOREHOLE LOGGING TOOL

M.I. Epov[1], V.L. Mironov[2,3], K.V. Muzalevskiy[2,3], I.N. Yeltsov[1]

[1]Trofimuk Institute of Petroleum Geology and Geophysics SB RAS, Russia
[2]Kirensky Institute of Physics, SB RAS, Russia
[3]Reshetnev Siberian Aerospace University, Russia
rsdkm@ksc.krasn.ru

1. INTRODUCTION

When oil-saturated rock is developed with horizontal boreholes, well placement technology helps optimize horizontal well position in order to minimize construction cost and risk [1], [2]. Geosteering electromagnetic logging tools are widely used for well placement technology [3], [4]. Unlike previous investigation [5]-[9], in this paper is considered a borehole logging tool based on ground-penetrating radar approach. It aims at detecting location of bed boundaries in the oil-gas collector. The geosteering borehole logging tools considered operate nanosecond pulses using one transmitting and two receiving dipole antennas with resistive elements. The antennas are packed in an infinite cylindrical dielectric shell which provides for waterproof sonde housing. The borehole radar math model developed takes into account the processes of emitting and receiving by the finite size antennas, wave scattered by a sonde housing and borehole wall, alongside with the contribution of the wave field reflected at the bed boundary.

To model a voltage at the output of the receiving antenna, a method of auxiliary sources (MAS) [9] is applied. This model can also be developed using the method of moment (MoM) [8]. But as following from [14], the MoM is more time-consuming one as compared with the MAS. We generalized [10]-[13] the MAS to make it applicable to time domain analysis of the pulse waveforms propagating through a frequency dispersive medium. Based on the proposed version of MAS, the pulse shape distortion and pulse power attenuation were numerically simulated and analyzed. Especially, the reflection of pulse from the oil-water boundary was studied, using the refractive mixing dielectric model introduced in [12] for the complex dielectric constants of the drilling fluid and media present in the oil-gas collector [1].

2. METHODOLOGY

The chart of borehole logging tool considered is shown in fig.1.

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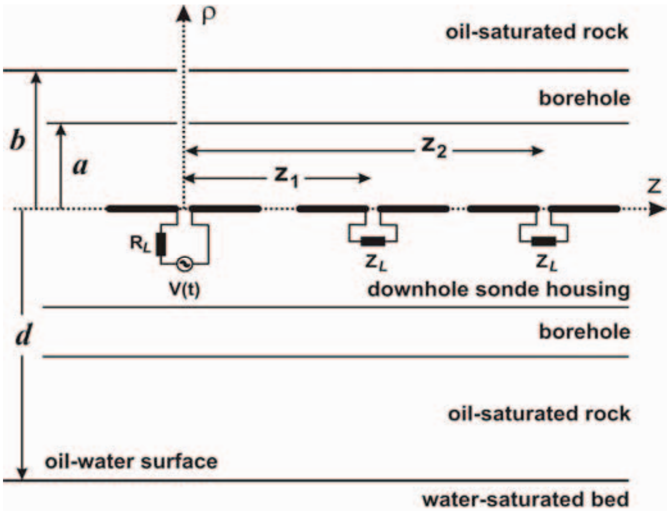

Fig. 1. Logging tool in a borehole placed above the oil-water boundary.

Both the transmitting and receiving antennas are taken to be perfectly conducting Hertz dipoles, of 0.1 m in length with their diameters being of 0.005 m. A source of pulse voltage, having internal resistance R_L=50 Ohm is connected to the transmitting antenna at the gap with a delta-function width. Voltage pulse shape is a time derivative of Blackman-Harris window function [15] having duration of T=5 ns. Two receiving antennas are located at the distances of Z1 and Z2 from the transmitting one, each being connected to a resistive load of Z_L=50 Ohm.

The housing of downhole sonde is made of dielectric material with relative permittivity of ε_1=2, and its radius is equal to a=0.06m. The borehole has radius of b=0.0825m and is filled with drilling fluid composed of brine, sand, clay and crud oil, with volumetric contens being of 90%, 1%, 8% and 1%, respectively. The oil-saturated rock was taken to be a mixture of sand (65%), oil (16%), clay (12%), brine (6%) and methane (1%) where percentages denote volumetric content. The water-saturated bed is located under a planar oil-water contact. It is considered to be a mixture of sand (65%), clay (12%), and brine (23%). The dielectric constants of sand, clay, methane and oil were assigned to be of 2.9, 4.3, 1 and 2.2, respectively [12]. The complex dielectric constant of brine can be calculated using the formulas given in [16] and the well-known Debye relaxation equation. The mineralization of water mud and formation water were assigned to be of 5 g/m^3 and 15 g/m^3, respectively. The temperature of borehole environment was taken to be of 58°C. The petrophysical parameters of the oil-gas collector given above are characteristic to the Fedorovskiy oilfield (West Siberian oil and gas province).

A theoretical model for the thin dipole antennas in air can be derived with the use of the MAS. For this purpose, applying the methods proposed in [8], [9], [17], and [10], first, there was found the Green function taking into account presence of the housing cylinder, cylindrical layer of water mud, oil-saturated rock, water-saturated bed, and oil-water boundary. Second, there was set up an ensemble of auxiliary dipole sources located along the axis of the three Hertz dipole antennas. The total field exited by the auxiliary sources was calculated on the surface of the three Hertz dipole antennas and the boundary condition was implemented on the surfaces of the Hertz dipole antennas to yield a system of algebraic equations. Third, this system was numerically solved to provide for the unknown amplitudes of auxiliary sources. Given this amplitudes and the Green function found earlier, we calculated voltage at the outputs of the receiving antennas. In the case of a 1.0 ns duration of the voltage pulse exciting the transmitting antenna, the pulse shapes registered by the receiving antenna are given in. Fig. 2. Here, by symbols a and b, are designated the time intervals characteristic to the signals formed by near zone field interference and by the field of the wave reflected from the oil-water contact, respectively. On the right panel in Fig. 2, is also shown the pulse shape accounted for by only the reflected wave, with the distance from the logger to the oil-water contact being greater. As seen from Fig. 2, detection of the signal reflected from an oil-water contact appeared to be quite feasible. The amplitude of the pulse, reflected from the oil-water contact located the distance of 3 m, was found to be 64 dB as small compared to the amplitude of the near field interference pulse.

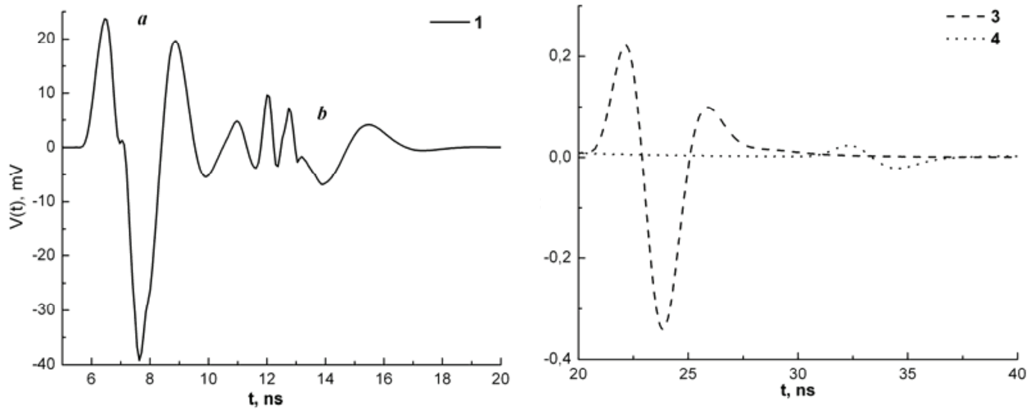

Fig. 2. Voltage at the output of the receiving antenna located at z_1=1m. The distance from the logging tool to the oil-water boundary: 1 – 1m, 3 – 2m, 4 – 3m.

3. CONCLUSION

The feasibility of developing of a geosteering borehole logging tool based on the UWB electromagnetic sensing pulses was theoretically analyzed. This device uses a ground penetrating radar principle to navigate drilling process in the course of oilfield exploration. We found it feasible for such a logging tool to register a pulse reflected from the oil-water contact located at the distance of 3 m, with its receiver dynamic range being on the same order as that of the contemporary ground penetrating radars.

4. REFERENCES

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