Geosteering Technology of Drilling Tool in a Layered Medium Oil and Gas Reservoir

M.I. Epov, V.L. Mironov, *Member, IEEE*, K.V. Muzalevskiy, *Member, IEEE*, I.N. Yeltsov

Abstract — **In this paper, the geosteering technology of drilling tool, relatively bottom of oil horizon in oil and gas reservoir was proposed. A theoretical model of borehole logging tool, transmitting and receiving ultra-wideband (UWB) electromagnetic pulses was proposed. The pulsed voltage at the output of the receiving antenna of borehole electromagnetic logging tool (BELT), located near the oil-water contact (OWC) was simulated, used experimentally tasted models of complex dielectric permittivity (CDP) of oil-saturated rock.**

The principal possibility of detecting the reflected pulse from transition layer which separates the oil-saturated rock from water-saturated rock and determine the distance to OWC was shown.

Index Terms — **Geosteering, borehole logging tool, oil-water contact, oil-saturated rock, UWB pulse, dielectric dispersion, broadband electromagnetic logging.**

I. Introduction

Effective extraction of hydrocarbons is one of the most importance problems of energy supply and resources conservation. In particular, this problem is solved with the use of drilling a horizontal well in the oil-saturated reservoir [1] [2]. Horizontal wells essentially improves the development of oil-field. However, horizontal drilling requires high-accuracy navigation of drilling tool in order to avoid penetration the drilling tool into a water-saturated or gas-saturated layers, which can lead to the destruction of wells due to the breakthrough of formation water or gas. Currently, for geosteering of horizontal wells using high-frequency (10 kHz – 14 MHz) induction logging isoparametric sonde [1]. Sensing range of the like sonde is less than 1 m, and the relative error in determining the distance from the borehole to the OWC as high as 50 % or more.

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Currently activities turn to improve these characteristics. In particular, use of UWB radar [3] seems promising for the development of new geosteering technologies for high accuracy geosteering of drilling tools in horizontal wells.

In this paper, in addition to the results obtained in [3], built a superior model of BELT, which takes into account the effect of sonde design, layers of mud and a smooth transition layer from oil-saturated rock to water-saturated rock.

II. Formulation of the Problem

To construct a theoretical model of BELT, we use the design proposed by the authors in [4]. BELT consists of transmitting and receiving dipole antennas spaced by a distance z_r and located in a cylindrical waterproof insulator (see Fig. 1).

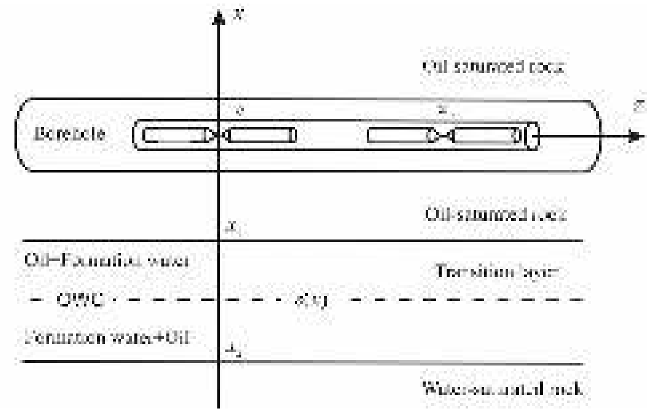

Fig. 1. BELT sounding of the layered oil-saturated rock.

Transmitting and receiving antennas were made in the form of cylindrical perfectly conducting dipoles length of 0.15 m and a radius of 0.02 m. Antennas are spaced by a distance z_r=0.5m and placed in a waterproof cylindrical insulator diameter of 0.1 m. The relative permittivity of the insulator is 14. BELT located in the oil-saturated rock at a distance x_1 above the upper boundary of the transition layer between the oil-saturated and water saturated rock.

Transmitting antenna was linked through the gap width of 0.01m by means of 50 Ohm coaxial cable to the voltage generator (GIN-2-02, company "FID-Technology", St. Petersburg). Pulse voltage shape at the output of the generator and its spectrum are shown in Fig. 2.

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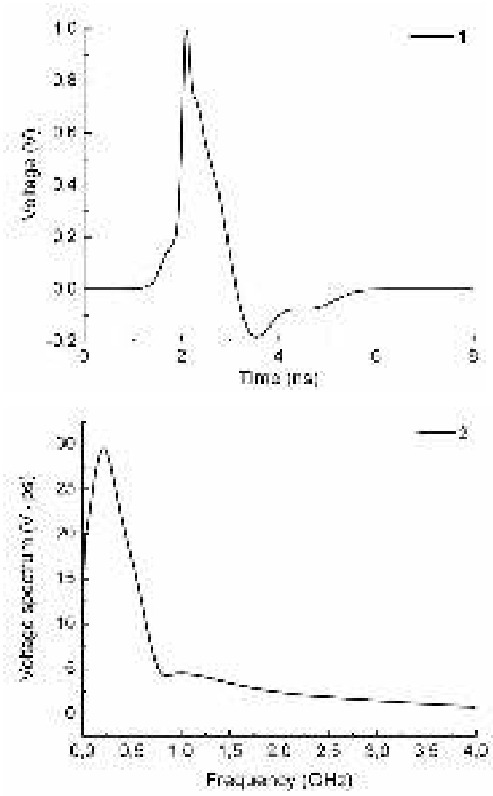

Fig. 2. Pulse voltage (1) and its spectrum (2) at the output of the pulse generator.

Spectra of the dielectric constant of the oil-saturated was calculated using the refraction mixture dielectric model (RMDM) [3]. Input data of this RMDM are the dielectric constant of quartz, oil, brine, saline and porosity of formation (set equal to 23 %) and volume fraction of oil $W_o(x)$ and formation water $W_o(x)$. Volumetric content of oil and formation water were assigned W_w=23 % и W_o=0; W_w=7 % и W_o=16 %, respectively. The mineralization of formation water were assigned 17 g/l The temperature in the formation was taken to be of 22°C. The Fermi distribution [5] used to describe the transition profile of formation water $W_w(x)$ and oil $W_o(x)$ from oil-saturated rock to water-saturated rock:

$$\begin{aligned} W_w(x) &= W_{w,os} + (W_{w,ws} - W_{w,os}) \cdot \\ &\{1 - 1/(1+\exp[(x_{ow} - x)/\Delta_{ow}])\}, \\ W_o(x) &= W_{o,os} + (W_{o,ws} - W_{o,os}) \cdot \\ &\{1 - 1/(1+\exp[(x_{ow} - x)/\Delta_{ow}])\}, \end{aligned} \tag{1}$$

where $W_{w,os}$ and $W_{w,ws}$ are the volumetric content of formation water in oil-saturated rock and water-saturated rock, $W_{o,os}$ and $W_{o,ws}$ are volumetric content of oil in oil-saturated rock and water saturated rock, $x_{ow} = (x_1+x_2)/2$ is the centre of transition layer, Δ_{ow} is the effective thickness of transition layer. Transition layer boundaries defined as $x_1 = x_{ow}+d_{ow}/2$, $x_2=x_{ow}-d_{ow}/2$, where $d_{ow}=2\Delta_{ow}\, ln\, 9$ is a thickness of layer between $(W_{w,ws}+W_{w,os})/2 \pm 0,4(W_{w,ws}-W_{w,os})$ or $(W_{o,ws}+W_{o,os})/2 \pm 0,4(W_{o,ws}-W_{o,os})$.

Profiles of volumetric content of oil and formation water in the transition layer, calculated on the basis of (1) with d_{ow}=0.64 *м*, are shown in Fig. 3.

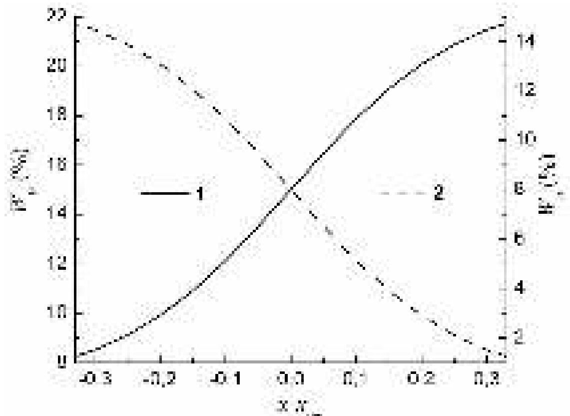

FIg. 3. Profile of volumetric content of 1) formation water , W_w, 2) oil, W_o in transition layer.

In the numerical modeling, transitional layer is divided by 20 discrete layers, each of which the volumetric content of oil and formation water were averaged.

III. Numerical Modeling

Numerical simulation of the output voltage at the receiving antenna was carried out using the finite difference time domain method [6]. In numerical calculations, the distance between the transmitting and receiving antennas was set equal to z_r= 0.5m. In case of placing BELT in a homogeneous oil-saturated rock and the excitation of the transmitting antenna by a voltage pulse (which is depicted in Fig. 2) a voltage pulse is recording at the receiving antenna is shown in Fig. 4. Pulse duration (see Fig. 4) at the level of 0.1 relative to maximum of amplitude is approximately 6 ns.

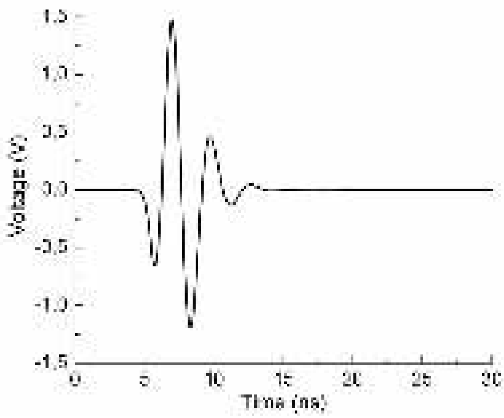

Fig. 4. The output voltage at the receiving antenna with the BELT placed in a homogeneous oil-saturated rock.

As seen from the calculation shown in Fig. 4, the pulse propagating in a homogeneous oil-saturated rock has a bandwidth of 0.25 GHz is approximately equal to the central band of 0.33 GHz. In this case, the pulse delay time, defined as a maximum of the envelope was found to be about t_d= 7 ns. The pulse shift at the output of generator (3 ns) was taken into account (see Fig. 2). As a result, the pulse velocity V along the axis oz at a distance z_r = 0.5 m was equal to V/c = 0.42, where c – velocity of light in a vacuum. It follows that the apparent refractive index is equal to $n_a=c \cdot t_d/z_r$=2,4. This value is close to the refractive index of oil-saturated rock, n=2.2, at the central band of the propagating pulse (0.33 GHz). Therefore, the field wave propagated from the transmitting antenna to the receiving antenna was concentrated mainly in the oil-saturated rock, not in the medium that fills the insulator (n=3.7) and the drilling fluid in the layer between the insulator and the borehole wall (n=9.3). Further studied the reflectivity of the transitional layer between the oil-saturated and water saturated rock, which is located at a distance x_{ow}=1 м+d_{ow}/2 from the axis of the borehole, with thickness in the range of 0,08 m ≤ d_{ow} ≤ 0,64 m. The results of this simulation are shown in Fig. 5. As seen from Fig. 5, when the thickness of transition layer within the bounds of 0.08 m to 0.32 m the amplitude of the reflected signal significantly reduced (4.7). Further increase the thickness to a value d_{ow}=1,0 m and more practically no effect on the level of the received signal. In addition, with increasing thickness of transition layer no significant increase the delay of the pulse reflected from OWC. This means that the time delay of the reflected pulse corresponds to the upper boundary of transition layer and slightly depends on its thickness. When the transition layer thickness over 0.32 m, the level of the reflected signal from the transition layer, in comparison with the signal caused by wave propagated from the transmitting antenna to the receiving on (time interval of the pulse in Fig. 5 is in the range of 4 ns to 15 ns) is equal to -48.8 dB.

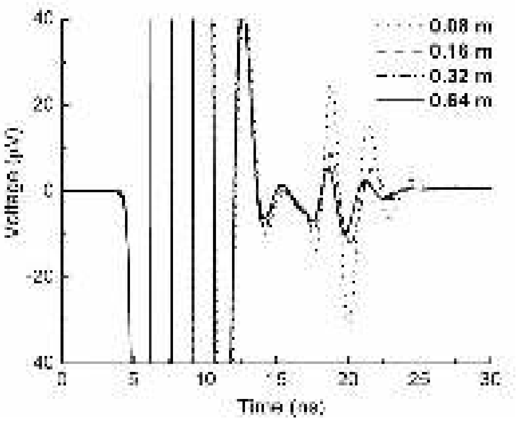

Fig. 5. The voltage at the output of the receiving antenna when BELT sounding transition layer of varying thickness.

Modern GPR have a dynamic range of more than 70 dB. Therefore useful to consider the range at which can be recorded the signals reflected from the transition layer. Fig. 6 shows simulated voltage at the output of the receiving antenna, the transition layer located at a distance of 1.1 m ≤x_{ow} ≤ 2.4 m from the borehole axis, the thickness of transition layer was taken to d_{ow}=0.64 m. The level of the reflected signal from the transition layer, in comparison with the signal level caused by wave propagated from the transmitting antenna to the receiving antenna along the axis oz, equal to -38.0 dB, -48.8 dB, -57.3 dB, -67.8 dB for distances x_{ow} equal to 1.1 m, 1.4 m, 1.9 m, 2.4 m, respectively. Note that the background signal caused by the wave propagated from the transmitting antenna to the receiving one (see Fig. 6) when the duration of sounding pulse (6 ns), it is impossible to resolve the pulses reflected from the transition layer, located at a distance x_{ow} < 1,1 m. Based on the measured time delays (see Fig. 6) t_d=14.5 ns, t_d=16.7 ns, t_d=25,9 ns, t_d=33,4 ns (taking into account the shift pulse of 2 ns in the generator) For pulses reflected from the OWC, at the distance to the center of the transition layer is 1.1 m, 1.4 m, 1.9 m and 2.4 m estimated the distance to the reflecting boundary was 1.14 m, 1.45 m, 1.95 m, 2.46 m, respectively. The velocity of reflected pulse was assumed to be the phase velocity of the wave at a frequency of 0.33 GHz, corresponding to the center frequency of a pulse propagating in this medium.

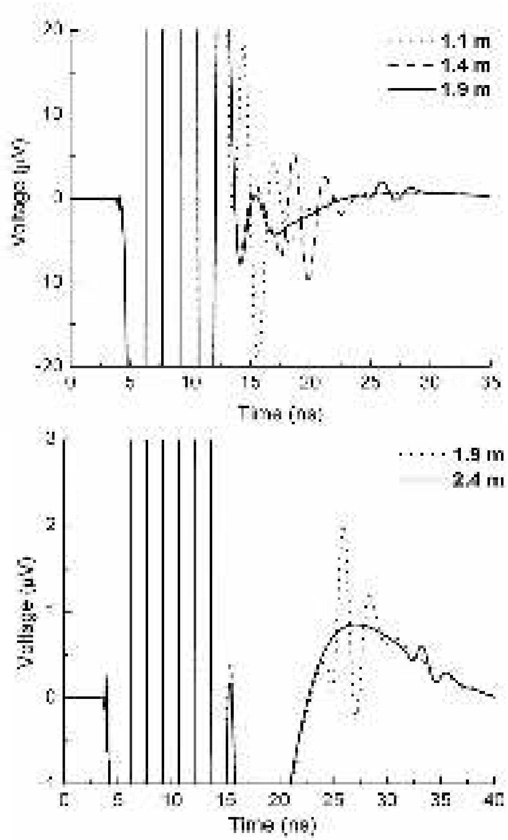

Fig. 6. Voltage at the output of receiving antenna when BELT sounding transition layer thickness of 0.64 m at difference distance x_{ow}.

IV. Conclusion

Based on numerical simulation of ultrawideband electromagnetic logging tool proved the principle possibility of measuring the reflected signal from the transition layer (with smoothly varying dielectric constant) which separates the oil-saturated rock from water-saturated rock. The analysis shows that the maximum sounding range to the transition layer thickness of more than 0.64 m with a dynamic range of the transceiver BELT 70 dB does not exceed 2.4 m. The minimum distance at which the reflected signal from the transition layer can be identified, for a duration pulse (~ 6 ns) is about 1.1 m.

Based on the pulse delay time data, when placing BELT in a homogeneous oil-saturated rock was estimated the apparent refractive index n_a= 2.4. This value is a relative error of 9.1 % coincided with a refractive index of oil-saturated rock. Therefore, we can assume that the sounding pulse is mainly propagated outside the borehole. The latter allows the use of BELT to sounding the apparent refractive index of inclosing rock, including the vertical drilling, to determine the content of fluid components.

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