Study of reflectance characteristics for isolation of anisotropic medium over hydrocarbons

V F Yanushkevich, D A Dauhiala, A L Adamovich, S N Abramenka and N Y Fedarovich

Euphrosyne Polotskaya State University of Polotsk, 29, BlokhinStreet, Novopolotsk, Vitebsk Region, 211440, Belarus

E-mail: v.yanushkevich@psu.by

Abstract. The article provides a study of the reflectance characteristics for the isolation of an anisotropic medium over hydrocarbons. An analysis of the reflectance characteristics for two-frequency electromagnetic waves when exposed to prevailing waves of either low or high frequency has been carried out. Experimental studies were carried out on real hydrocarbon fields. The results of these tests confirmed an increase in the level of delineation of oil and gas accumulations by measuring reflectance characteristics at (10 - 20) m. The obtained results of the studies can be used in electrical exploration systems to improve the accuracy of determining the boundaries of the deposit to improve the accuracy of determining the boundaries of the deposit by measuring reflectance characteristics in a wide frequency range and to enhance resolution while determining the location of deposits by measuring reflectance characteristics in two modes.

1. Introduction

The relevance of the tasks considered in this work is to increase the level of delineation of fields and accumulations of hydrocarbon reservoirs [1-3].

The purpose of the research is to solve the problems of interaction of electromagnetic waves (EMW) and hydrocarbon deposits, the development and experimental study of methods and devices for increasing the level of exploration reliability, search and delineation of these deposits.

The method of vertical examination with a controlled source uses a transmitting device with a vertically located dipole antenna, a system of various radio receiving devices with both vertical and horizontal dipole antennas and a data collection procedure [4]. Great attention is paid to field tests [5, 6]. Methods of detection based on variation of characteristics of applied signals are recommended [7-9].

With integrated 3D gravitational modelling applied to salt layers studies, an improved model was obtained [10]. The development of antennas for prospecting geophysics plays an important role [11]. A specialized electromagnetic system is used for tank monitoring and geothermal prospecting [12]. Extremely low frequencies are involved in the method and device for geophysical research by detecting inhomogeneities using electromagnetic fields [13]. The solution to the problems of detecting minerals is based on the use of ground penetration radars [14]. Currently, methods of searching for hydrocarbons based on frequency-modulated signals are recommended to improve the accuracy of boundary determination [15].

2. Method of electric prospecting for hydrocarbons using reflectance characteristics

Reflection from anisotropic medium above the geological profile under the influence of EMW with linear polarization can be estimated by the contrast of reflection coefficients between the anisotropic medium and the underlying surface using the formula:

$$\Delta R = 20\lg|R_p - R_{BB}|, \tag{1}$$

where R_p is the coefficient of reflection from the underlying medium with the final dielectric permittivity of the ε_r and the σ_r conductivity for EMW with vertical polarization, is determined by the formula:

$$\dot{R}_p = \frac{\dot{\varepsilon}_p \sin\theta - \sqrt{\dot{\varepsilon}_p - \cos^2\theta}}{\dot{\varepsilon}_p \sin\theta + \sqrt{\dot{\varepsilon}_p - \cos^2\theta}} = |\dot{R}_p|\, exp\, j\, \varphi_p, \tag{2}$$

where $\dot{\varepsilon}_p = \varepsilon_p - j\frac{\sigma_P}{\omega\varepsilon_0}$ - complex dielectric permittivity of the underlying surface,
θ - angle of EMW incidence,
$|\dot{R}_p|$- modulus of the coefficient of reflection from the underlying medium,
φ_p- phase of the coefficient of reflection from the underlying medium,
ω - circular frequency of the signal,
ε_0- dielectric permittivity of vacuum,

$$\dot{R}_{BB} = \frac{\dot{a}_1\cos\theta + \dot{a}_3(\cos^2\theta - 1)}{\dot{a}_2\cos\theta + \dot{a}_4(\cos^2\theta + 1)} = |\dot{R}_{BB}|\cdot\exp(j\varphi_{BB}),$$

where $|\dot{R}_{BB}|$- modulus of the coefficient of reflection from anisotropic medium,
φ_{BB}- phase of the coefficient of reflection from anisotropic medium,

$$\begin{aligned} \dot{a}_{1,2} &= \sqrt{\dot{\varepsilon}_R\dot{\varepsilon}_L} \mp 1, \\ \dot{a}_3 &= \sqrt{\dot{\varepsilon}_R} + \sqrt{\dot{\varepsilon}_L}, \\ \dot{a}_4 &= \dot{\varepsilon}_R + 2\dot{\varepsilon}_R\dot{\varepsilon}_L + \dot{\varepsilon}_L, \end{aligned} \tag{3}$$

combinational components appear here

$$\begin{aligned} \dot{\varepsilon}_R &= \dot{\varepsilon}_1 + \dot{\varepsilon}_2 = Re\,\dot{\varepsilon}_R + j\,Im\,\dot{\varepsilon}_R; \\ \dot{\varepsilon}_L &= \dot{\varepsilon}_1 - \dot{\varepsilon}_2 = Re\,\dot{\varepsilon}_L + j\,Im\,\dot{\varepsilon}_L. \end{aligned} \tag{4}$$

In expressions (4) there are elements of the matrix:

$$\dot{\hat{\varepsilon}} = \begin{bmatrix} \dot{\varepsilon}_1 - j\dot{\varepsilon}_2 & 0 \\ j\dot{\varepsilon}_2 & \dot{\varepsilon}_1 & 0 \\ 0 & 0 & \dot{\varepsilon}_3 \end{bmatrix}. \tag{5}$$

To generate the EMW in the search and identification device, we are going to select a two-frequency signal of the form

$$\vec{e}(t) = \vec{e}_1(t) + \vec{e}_2(t) = A_1\cos\omega_1 t + A_2\cos\omega_2 t, \tag{6}$$

where A_1, A_2, ω_1, ω_2- the amplitude and frequency of EMW data, respectively.

Measurement modes depend on EMW parameters interacting with the investigated geological profile:

$$k_E = \frac{A_2}{A_1}, k_\omega = \frac{\omega_1}{\omega_2}, \tag{7}$$

When implementing the method, equipment based on stationary radio transmitting and radio receiving devices was used. A two-frequency signal of a radio transmitting device with vertical polarization at frequencies of f_2 = (700-1000) MHz and f_1 = (1-10) MHz when exposed to predominant waves of either low or high frequency is emitted by an antenna over a geological profile. The signal reflected from the ground surface enters the receiver antenna. The location of the antennas and the amount of spacing were taken for measurement reasons and for the sake of providing the required characteristics of the receiver. The angle of incidence of the EMW was selected $\theta = 30^o$. The contrast of reflection coefficients between the anisotropic medium and the homogeneous underlying surface was determined at the measurement points of the profile under investigation. An anomalous change in the contrast value of the reflection coefficients indicates the presence of hydrocarbon deposits. Microstrip antennas were used.

The proposed method was tested on artificial gas accumulation in Osipovichi and at the Rechitsa field of the hydrocarbon deposits of the Gomel region.

Example 1. The dual-frequency EMW profile under study was irradiated at a fixed frequency of f_2 = 700 MHz with the frequency of a low-frequency signal of f_1 = 1 MHz with vertical EMW polarization and exposure to prevailing waves of either low or high frequency. In the prevailing low frequency mode, $k_E = 10^{-1}$, $k_\omega = 1{,}43 \cdot 10^{-3}$. In the prevailing high frequency mode, $k_E = 10^1$, $k_\omega = 1{,}43 \cdot 10^{-3}$. The reflected radiation was received and the contrast of the reflection coefficients was measured at the measurement points of the profile under study. A reference point was specified, with respect to which the contrast of reflection coefficients was measured along the profile under study. Measurements were made relative to the reference point, which determines the value of the contrast of reflection coefficients from the profile surface. At the points located at distances of 10 m for artificial gas accumulation in Osipovichi and at distances of 50 m for the Rechitsa hydrocarbon field, the contrast of reflectance coefficients was determined in a straight line from the reference point.

At the reservoir boundary (reference point of 170 for artificial gas accumulation in Osipovichi and reference point of 250, 500 for the Rechitsa hydrocarbon field) the contrast of reflection coefficients increases to 8.50 dB (exposure to the predominant low frequency signal) and 6.00 dB (exposure to the predominant high frequency signal) at the check point of 170 m. The contrast of reflection coefficients increases to 4.40 dB (exposure to the predominant low frequency signal) and 4.00 dB (exposure to the predominant high frequency signal) at the check point of 250 m. The contrast of reflection coefficients increases to 4.70 dB (exposure to the predominant low frequency signal) and 4.20 dB (exposure to the predominant high frequency signal) at a check point of 500 m (figures 2 - 4).

Example 2. The EMW profile under study was irradiated at a fixed frequency of f_2 = 850 MHz with a low-frequency signal frequency of f_1 = 5 MHz with vertical EMW polarization in the modes of the predominant low frequency signal and the predominant high frequency signal. In the prevailing low frequency mode, $k_E = 10^{-1}$, $k_\omega = 5{,}88 \cdot 10^{-3}$. In the prevailing high frequency mode, $k_E = 10^1$, $k_\omega =$ $= 5{,}88 \cdot 10^{-3}$. The contrast of the reflection coefficients of the investigated geological profile was determined from the value of the reflected EMW.

At the deposit boundary (check point of 170 for artificial gas accumulation in Osipovichi and check point of 250, 500 for the Rechitsa hydrocarbon field) the contrast of reflection coefficients increases to values of 6.30 dB (exposure to the predominant low frequency signal) and 6.20 dB (exposure to the predominant high frequency signal) at a check point of 170 m, up to 4.20 dB (exposure to the predominant low frequency signal) and 4.40 dB (exposure to the predominant low frequency signal) at a check point of 250 m, up to values of 3.80 dB (exposure to the predominant low frequency signal) and 3.80 dB (exposure to the predominant high frequency signal) at the 500 m check point.

Example 3. The EMW profile under study was irradiated at a fixed frequency of f_2 = 1000 MHz with a low frequency signal frequency of f_1 = 10 MHz with vertical EMW polarization in the modes of the predominant low frequency signal and the predominant high frequency signal. In the prevailing low frequency mode, $k_E = 10^{-1}$, $k_\omega = 10 \cdot 10^{-3}$. In the prevailing high frequency mode, $k_E = 10^{1}$, $k_\omega = 10 \cdot 10^{-3}$.

The contrast of the reflection coefficients of the investigated geological profile was determined from the value of the reflected EMW.

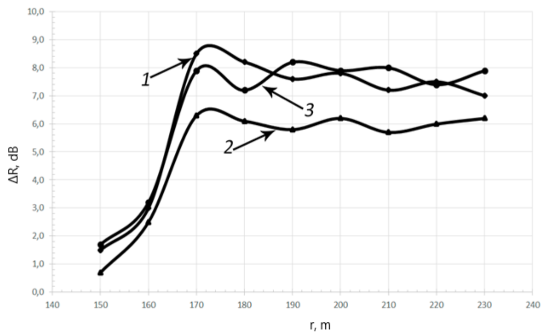

Figure 1. Measurement results of the contrast of reflection coefficients for the Osipovichi artificial gas accumulation, exposure to a predominant low frequency signal: 1 - f_2 = 700 MHz, f_1 = 1 MHz; 2 - f_2 = 850 MHz, f_1 = 5 MHz; 3 - f_2 = 1000 MHz, f_1 = 10 MHz.

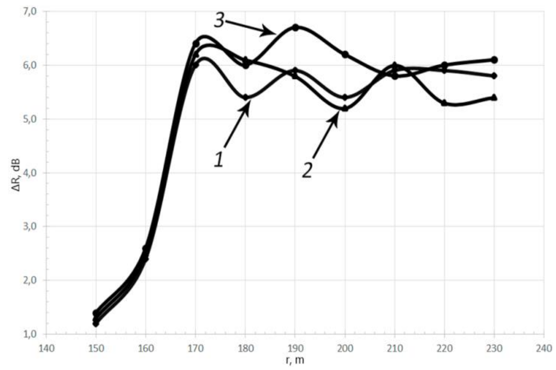

Figure 2. Measurement results of the contrast of reflection coefficients for the Osipovichi artificial gas accumulation, exposure to a predominant high frequency signal: 1 - f_2 = 700 MHz, f_1 = 1 MHz; 2 - f_2 = 850 MHz, f_1 = 5 MHz; 3 - f_2 = 1000 MHz, f_1 = 10 MHz.

At the deposit boundary (check point of 170 for artificial gas accumulation in Osipovichi and check point of 250, 500 for the Rechitsa hydrocarbon field) the contrast of reflection coefficients increases to values of 7.90 dB (exposure to the predominant low frequency signal) and 6.40 dB (exposure to the predominant high frequency signal) at a check point of 170 m, up to 4.70 dB (exposure to the predominant low frequency signal) and 4.50 dB (exposure to the predominant low frequency signal) at a check point of 250 m, up to values of 4.20 dB (exposure to the predominant low frequency signal) and 4.10 dB (exposure to the predominant high frequency signal) at the 500 m check point. The hydrocarbon boundary was indicated by the anomalous values of the contrast of the reflection coefficients.

The measurement accuracy was determined as the difference in the distances corresponding to the deposit boundary (a known value) and those determined using this method, expressed as a percentage.

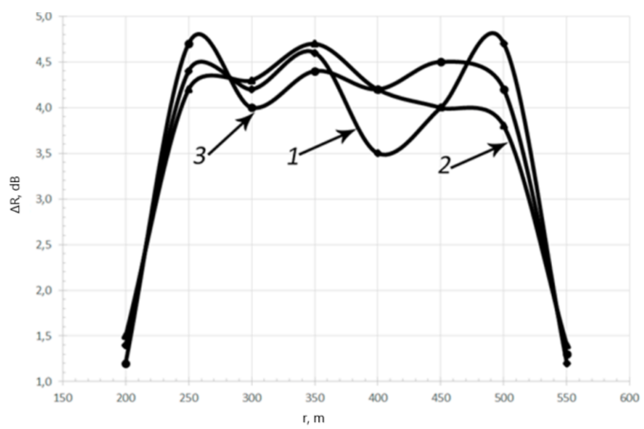

Figure 3. Measurement results of the contrast of reflection coefficients for the Rechitsa hydrocarbon field, exposure to a predominant low frequency signal:1 - f_2 = 700 MHz, f_1 = 1 MHz; 2 - f_2 = 850 MHz, f_1 = 5 MHz; 3 - f_2 = 1000 MHz, f_1 = 10 MHz.

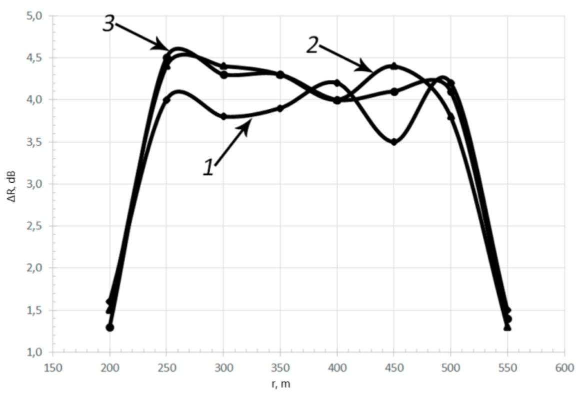

Figure 4. Measurement results of the contrast of reflection coefficients for the Rechitsa hydrocarbon field, exposure to a predominant high frequency signal: 1 - f_2 = 700 MHz, f_1 = 1 MHz; 2 - f_2 = 850 MHz, f_1 = 5 MHz; 3 - f_2 = 1000 MHz, f_1 = 10 MHz.

3. Conclusion

The advantages of the proposed method in comparison with current analogues are:

- Improving the accuracy of deposits positioning by measuring the contrast of reflection coefficients in a wide frequency range.
- Enhancing the resolution capability of deposit location by measuring the contrast of reflection coefficients in two modes.
- Better weight-dimension indicators of antennas
- Improving geological exploration performance.

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