IOP Conference Series: Earth and Environmental Science

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To cite this article: V F Yanushkevich *et al* 2023 *IOP Conf. Ser.: Earth Environ. Sci.* **1231** 012068

Hydrocarbon exploration technique based on the ratio coefficient measurement of two-frequency amplitudes

V F Yanushkevich*, D A Dauhiala, A L Adamovich, T V Maladzechkina and A S Vershinin

Department of Energy and Electronics, Euphrosyne Polotskaya State University of Polotsk, Belarus

*E-mail: v.yanushkevich@psu.by

Abstract. The paper presents a hydrocarbon field exploration technique based on the ratio coefficient measurement of two-frequency amplitudes. The study establishes electronic plasma resonance frequencies. The anomalous measurement values show a large range when receiving the reflected signal at the station line measurement points. The technique test proved an increase in the accuracy of hydrocarbon field boundaries by 20-30 %. The findings can be implemented in prospecting geophysics to improve the accuracy of hydrocarbon boundaries applying the ratio coefficient measurement of two-frequency amplitudes within a wide frequency range. The study also proved that it is possible to increase the deposits location resolution using the coefficient measurement ratio of three-frequency amplitudes of the range covered.

1. Introduction

The relevance of the problems considered in the paper lies in the development of exploration techniques for new gas and oil (hydrocarbons) deposits in all potentially oil-bearing horizons and their further geological survey to determine a commercial oil accumulation area, expand geophysical, geological, and geochemical studies of the poorly explored parts of crystalline basement and thus assess the hydrocarbon potential [1-3].

The purpose of the research is to improve the reliability of hydrocarbon detection and accuracy of hydrocarbon (HC) accumulation boundaries.

The analysis of interaction of electromagnetic waves (EMW) with an anisotropic medium above an HC field, which results in electro-physical and electrochemical processes, helps to differentiate between hydrocarbon deposits. The differentiation is more precise if the characteristics of the signals used can be varied [4, 5]. Currently, the interaction of two-frequency electromagnetic waves with anisotropic media over hydrocarbon fields is normally analyzed to more accurately determine the field boundaries. In most cases, the behavior of the real constituent component of a dielectric constant tensor is investigated. The signal characteristics depend on different sources of electromagnetic wave radiation that have amplitude and frequency ratio coefficients in the modes of powerful low-frequency and high-frequency signals [5]. In 2008 and 2010, large multi-client 3D CSEM surveys were conducted in the Barents Sea. In rounds of license applications in Norway, oil companies used the CSEM data to support their geological models and prospects. The findings were drawn from case studies when 3D resistivity models obtained by inverting CSEM data helped to identify areas of interest and update prospective risks [6]. The thorough analysis of seismic and well-log data and detailed modeling with 22 layers looks impressive [7]. The study [8], registered a total of 32 station lines for mapped surface texture and faults.

The fast iterative method for the automatic interpretation of Schlumberger and Wenner sounding curves bases itself on interpreted depths and resistivities from shifted electrode spacings and adjusted apparent resistivities, respectively. The seabed logging method (SBL) uses a horizontal transmitter over a horizontal receiver. It measures a large EMW amplitude directly through seawater and a smaller signal from an underlying rock [10]. There is also a vertical-vertical electromagnetic method with a controlled source which uses a large and powerful vertical dipole transmitter and arrays of electric field receivers with vertical and horizontal dipole sensors. It relies upon its own tools and data collection procedures, which differentiate this technique from other electromagnetic methods with a controlled source [11]. Three-dimensional anticline structures with a horizontal aspect ratio of more than two can be adequately interpreted using two-dimensional inversions [12]. Researchers have set up equations for components of electric and magnetic fields created by a vertical electric dipole in a one-dimensional layered medium. The equations apply to modelling fields of resistive layers [13]. There should be sufficient contrast between the regional background resistivity and the oil and gas reservoir to make a correct discrimination possible [14]. Geomagnetic variation profiling is traditionally used to study the deep structures of the Earth's crust, along with the generally recognized method of magnetotelluric sounding [15].

2. Hydrocarbon electrical exploration technique based on ratio coefficient measurement of two-frequency amplitudes

Consider the interaction of EMW with a HC field in the exposure mode to the signals:

$$\begin{aligned} \vec{e}_1(t) &= E_1 \cos \omega_1 t, \\ \vec{e}_2(t) &= E_2 \cos \omega_2 t, \\ \vec{e}_3(t) &= E_3 \cos \omega_3 t, \end{aligned} \qquad (1)$$

where, $E_1, E_2, E_3, \omega_1 = 2\pi f_1, \omega_2 = 2\pi f_2, \omega_3 = 2\pi f_3$ the amplitudes and frequencies of the three EMW, respectively.

We introduce the amplitudes ratio coefficients of two waves and their frequencies

$$k_{E21} = \frac{E_2}{E_1}, k_{E31} = \frac{E_3}{E_1}, k_{E32} = \frac{E_3}{E_2} \qquad (2)$$

$$k_{\omega 12} = \frac{\omega_1}{\omega_2}, k_{\omega 13} = \frac{\omega_1}{\omega_3}, k_{\omega 23} = \frac{\omega_2}{\omega_3} \qquad (3)$$

and consider the effect, caused by EMW with different parameter ratios, on the medium over the HC field.

Electronic plasma resonance frequencies were established, whose anomalous measurement values showed a large range when receiving the reflected signal at the station line measurement points.

Thus, if we determine the plasma circular frequency from the formula

$$\omega_{\Pi i} = q_i \left(\frac{N_i}{m_i \varepsilon_0} \right)^{\frac{1}{2}} = 2\pi F_n \qquad (4)$$

where q_i, N_i, m_i, F_n are the charge, concentration, mass of particles and frequency of electronic plasma resonance, ε_0 is the dielectric constant, and irradiate the station line with an electromagnetic wave at fixed frequencies with vertical polarization it is possible to increase the measurements accuracy.

3. Results and discussion

The technique was tested at the Osipovichi underground gas storage facility and the Rechitsky, Yuzhno-Ostashkovsky HC fields in Gomel region.

During testing, a device was used that included a fixed transmitter with an antenna and a receiver with an antenna. Electromagnetic radiation from a fixed transmitter with vertical polarization of the frequencies f_1, f_2, f_3 (selected equal *to* F_n according to formula (4) for the range from 1 to 30 MHz) was directed by the antenna to the area of the proposed deposit. The reflected radiation via the receiver antenna entered the receiver. The height and spacing of the antennas depended on the measurement procedures and ensured electromagnetic compatibility of the device. The electric field intensity was defined at the station line measurement points. An abnormal change in the magnitude of the electric field indicated a HC accumulation. We used vibrator antennas 1 m long.

The EMW station line under study was irradiated at fixed frequencies f_1 = 1 MHz, f_2 = 10 MHz, f_3 = 20 MHz with vertical polarization of EMW. Having received the reflected radiation, we measured the magnitude of the electric field intensity at the station line measurement points. Then, a reference point was set, with regard to which the ratio of two-frequency amplitudes was measured along the station line. The measurement points were selected with a sampling of 10 m for the Osipovichi underground gas storage, 50 m for the Rechitsky HC field, and 100 m for the Yuzhno-Tishkovsky HC field along a straight line passing through the reference point and across the proposed boundary.

When the measuring point of the two-frequency amplitudes ratio (figure 1) lies on the boundary of the field (station 550 for the Yuzhno-Tishkovsky HC field), the two-frequency amplitudes ratio k_{E21} increases to 0.65, the two-frequency amplitudes ratio k_{E31} increases to 0.43. For station 1030 (Yuzhno-Tishkovskoye HC field), the two-frequency amplitudes ratio k_{E21} decreases to 0.25, the two-frequency amplitudes ratio k_{E31} decreases to 0.24. The measurements were made at f_1 = 1 MHz, f_2 = 10 MHz, f_3 = 20 MHz.

For measurements at f_1 = 2 MHz, f_2 = 15 MHz, f_3 = 30 MHz, when the measuring point of the two-frequency amplitudes ratio (figure 2) is on the boundary of the field (station 550 for the Yuzhno-Tishkovsky HC field), there is an increase in the ratio k_{E21} to 0.73, in the ratio k_{E31} to 0.48. For station 1030 (Yuzhno-Tishkovskoye HC field), the two-frequency amplitudes ratio k_{E21} decreases to 0.38, the two-frequency amplitudes ratio k_{E31} decreases to 0.20. The HC field boundary was determined according to the anomalous values of the two-frequency amplitudes ratio.

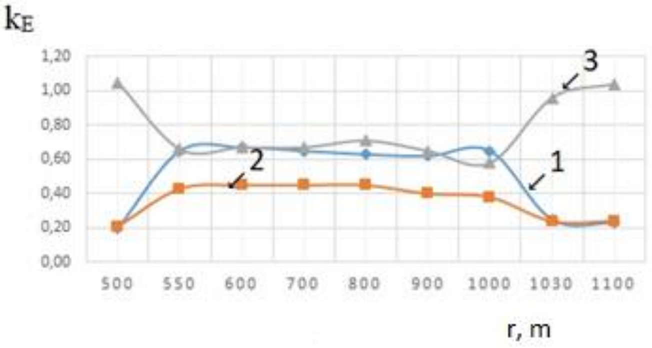

Figure 1. Change in the two-frequency amplitudes ratio for the Yuzhno-Tishkovsky HC field at f_1 = 1 MHz, f_2 = 10 MHz, f_3 = 20 MHz: 1 – k_{E21}, 2 – k_{E31}, 3 – k_{E32}.

When the measuring point of the two-frequency amplitudes ratio (figure 3) lies on the boundary of the field (station 250 for the Rechitskoe HC field), the two-frequency amplitudes ratio k_{E21} increases to 0.95, the two-frequency amplitudes ratio k_{E31} increases to 0.68. For station 500 (Rechitsky HC field), the two-frequency amplitudes ratio k_{E21} decreases to 0.32, the ratio of the amplitudes of two frequencies k_{E31} decreases to 0.25. The measurements were made at f_1 = 1 MHz, f_2 = 10 MHz, f_3 = 20 MHz.

For measurements at f_1 = 2 MHz, f_2 = 15 MHz, f_3 = 30 MHz, when the measuring point of the two-frequency amplitudes ratio (figure 4) is on the boundary of the field (station 250 for the Rechitsky HC field), the two-frequency amplitudes ratio k_{E21} increases to 1.07, the two-frequency amplitudes ratio k_{E31} goes up to a value of 0.78. For station 500 (Rechitsky HC field), the two-frequency amplitudes ratio k_{E21} decreases to 0.35, the two-frequency amplitudes ratio k_{E31} decreases to 0.28. The HC field boundary was determined according to the anomalous values of the two-frequency amplitudes ratio.

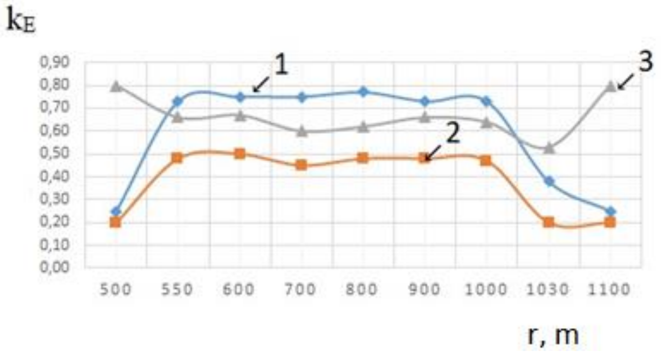

Figure 2. Change in the two-frequency amplitudes ratio for the Yuzhno-Tishkovsky HC field at f_1 = 2 MHz, f_2 = 15 MHz, f_3 = 30 MHz: 1 – k_{E21}, 2 – k_{E31}, 3 – k_{E32}.

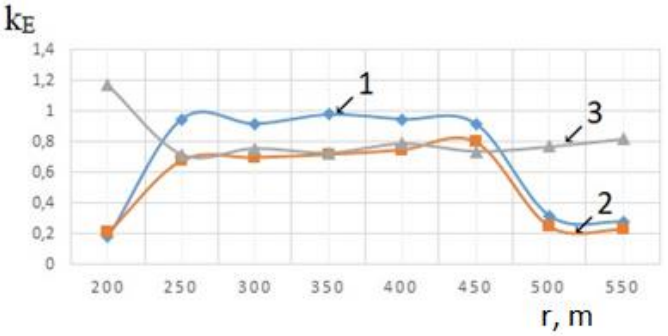

Figure 3. Change in the two-frequency amplitudes ratio for the Rechitsky HC field at f_1 = 1 MHz, f_2 = 10 MHz, f_3 = 20 MHz: 1 – k_{E21}, 2 – k_{E31}, 3 – k_{E32}.

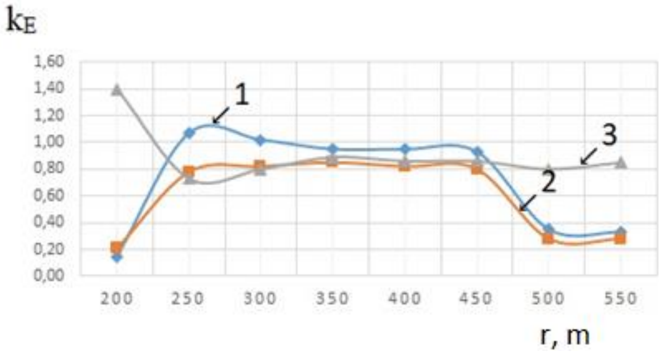

Figure 4. Change in the two-frequency amplitudes ratio for the Rechitsky HC field at f_1 = 2 MHz, f_2 = 15 MHz, f_3 = 30 MHz: 1 – k_{E21}, 2 – k_{E31}, 3 – k_{E32}.

When the measuring point of the two-frequency amplitudes ratio (figure 5**)** lies on the field boundary (station 170 for the Osipovichi underground gas storage), the two-frequency amplitudes ratio k_{E21} increases to 0.84, the ratio of the amplitudes of two frequencies k_{E31} increases to 0.76. The measurements were made at f_1 = 1 MHz, f_2 = 10 MHz, f_3 = 20 MHz.

For measurements at f_1 = 2 MHz, f_2 = 15 MHz, f_3 = 30 MHz, when the measuring point of the two-frequency amplitudes ratio (figure 6**)** is on the field boundary (station 170 for the Osipovichi underground gas storage), the two-frequency amplitudes ratio k_{E21} increases to 1.02, the two-frequency amplitudes ratio k_{E31} – up to a value of 0.97. The HC field boundary was determined according to the anomalous values of the two-frequency amplitudes ratio.

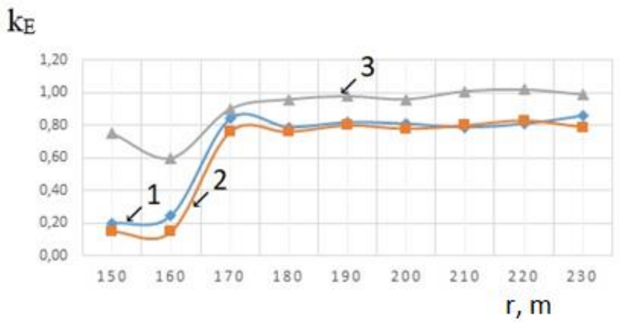

Figure 5. Change in the two-frequency amplitudes ratio for the Osipovichi underground gas storage at f_1 = 1 MHz, f_2 = 10 MHz, f_3 = 20 MHz: 1 – k_{E21}, 2 – k_{E31}, 3 – k_{E32}.

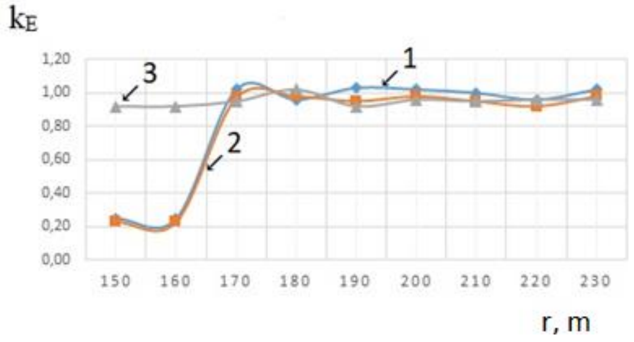

Figure 6. Change in the two-frequency amplitudes ratio for the Osipovichi underground gas storage at f_1 = 2 MHz, f_2 = 15 MHz, f_3 = 30 MHz: 1 – k_{E21}, 2 – k_{E31}, 3 – k_{E32}.

4. Conclusion

As a result of the study:

- A technique based on the ratio coefficient measurement of two-frequency amplitudes within the range of (1–30) MHz has been developed for hydrocarbon detection.
- An increase in the deposits location resolution has been achieved by measuring electronic plasma resonance frequencies. The anomalous measurement values show a large range when receiving the reflected signal at the measuring points of the station line.
- Efficiency of geological exploration is increased.

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