Observational statistics analysis of seismoelectric effects in a gas condensate reservoir

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Abstract The article considers the observational statistics analysis of seismoelectric effects of the second kind at the Bystryanskoye gas condensate reservoir in Krasnoyarsk Territory. The measurements were carried out by the passive method from 2014 to 2019 on one exploration profile. The authors obtained an averaged profiling curve. Its analysis showed that there exists the repeatability of measurement results, as well as the convergence with the results of mathematical modeling. The collected statistics on the observation points shows the possibility of this method application in carrying out industrial field work in conjunction with the standard seismic exploration.

1. Introduction

Nowadays, the hydrocarbons exploration requires the introduction of new exploration methods since new reservoirs are mainly localized in hard-to-reach areas and, as a consequence, modern exploration methods cannot always cope with the problem (weight and size indicators, etc.). The hydrocarbons exploration, like any other geophysical problem, requires the solution of the inverse problem that does not have an unambiguous solution. Therefore, scientists try to apply several exploration methods together to obtain more reliable results. The directions that are currently considered as promising ones are methods based on seismoelectric effects of the first and second kind. They were discovered experimentally by AG Ivanov in 1939 [1], later the theory was developed by Ya. I. Frenkel and M. Bio [2-3]. The model of interaction of seismic and electromagnetic fields described in [2-3] is high-frequency (frequencies above 1 kHz). The studies connected with these effects were reduced to experimental and theoretical studies on porous structures at frequencies of 10 - 100 kHz. In [4], the authors adapted the models proposed above [2-3] for low frequencies. The evaluation showed that the registration of a seismoelectric effect of the second kind over a hydrocarbon reservoir has maxima at its vertical boundaries.

The following articles [5-6] proposed different between methods and tools for these effects application for the exploration for hydrocarbon deposits. A lot of authors in their articles indicate that the frequency range is from 0.1 - 100 Hz, which goes against the classical theory of seismoelectric effects. However, the experimental data given in various articles [7-9] suggest that these effects are recorded on a wide range of reservoirs (oil, gas).

Nowadays, there exist several basic methods for the for hydrocarbons based on the registration of such effects: active, which use active sources of the seismic and electromagnetic field, passive - the natural seismic and electromagnetic fields of the Earth are recorded, and various variations of combining these two methods, when there is only one source of seismic or electromagnetic field.
According to the opinion of the authors, the application of an active method with the generation of seismic and electromagnetic exploration is expensive and its application is justified only in operating in shelf zones. The authors of this article have already presented the results of the work applying both the passive method [10] and the external impulse non-explosive source of seismic waves [11].

The application of the passive method is associated with the registration of noise-like oscillations of both fields. It leads to the minimum measurement time at each point for about 3 minutes. An important task is also to observe the repeatability of results at different moments of the observation time applying different receiving equipment. This article provides data communication of the results obtained for 2014-2019 observations during field works at a gas condensate reservoir (Russia, Krasnoyarsk Territory) applying various kinds of hardware solutions.

2. Materials and methods
The measurements were carried out using a grounded electric dipole (200 m) recorded the horizontal component of the electrical component of the Earth's natural electromagnetic field; the seismic field was recorded with a standard geophone produced by the GS company. The specially developed equipment was used to match the resistances and amplify the received signals. That made it possible to set the required frequency range using bandpass filters, filter out industrial noise 50 Hz (suppression up to 40 dB) and amplify signals (up to 60 dB). The signals were recorded for 180 seconds and stored in the non-volatile memory of a laptop.

The software product was written to analyze the results obtained in the field conditions, using the Matlab programming language. That made it possible to carry out all calculations in real time to visualize the received signals, their spectra, as well as a calculated coefficient characterizing the magnitude of the seismo-electric effect. This coefficient was calculated as the maximum of the cross-correlation function between the seismic and electromagnetic fields of the Earth using the following formula:

$$R_{ES}(\tau) = \frac{1}{T} \int_0^T \tilde{E}(t) \cdot \tilde{S}(t-\tau) dt$$

where $\tilde{E}(t)$ and $\tilde{S}(t)$ are signals received by a grounded electric dipole and a seismic receiver, respectively; T is time of recording signals to the seismic station, 180 seconds, $R_{ES}(\tau)$ is correlation function; its value at $\tau = 0$ was used to evaluate the seismo-electric effect.

**Figure 1.** Scheme of measurements with the help of specialized equipment developed by the authors of this work in 2014-2019.
Figure 2 shows the observation profile measured during the period from 2014 to 2019. According to the data obtained during exploration drilling, the reservoir is located approximately at a depth of 2000 m (or, according to seismic data, $\approx 1.5$ s). The deep-hole well 15-P, marked in the figure, has a gas outline. At present it is currently suspended. This reservoir is well studied. It is a test site for developing new methods of hydrocarbon exploration, as it has good transport accessibility.

![Figure 2. Profile of observations during the period from 2015 to 2019 at the Bystryanskoye reservoir, Krasnoyarsk territory, Russia.](image)

The theoretical foundations of this passive method were given by the authors in the following articles [10, 11]. According to the experience, the edge of the reservoir is almost always noted with a large value of the normalized value of the maximum of the cross-correlation function (1). Thus, the generalization of the data obtained during the field works will make it possible to evaluate the convergence of the results obtained in different years.

3. Result and discussion

Figure 3 shows the data obtained in the course of generalization and the calculated curve obtained in [11].
In the course of the data generalization it was revealed that the maximum of the cross-correlation function marks the edges of the reservoir. The data were obtained in different years applying the passive seismoelectric method, presented in the Figure 3. The dotted line denotes the line of interpolation by the averaged values; it repeats the shape of the curve obtained at calculating the amplitude values of the horizontal component of the E component \[ 10, 11 \]. Apparently, the local peaks on the curve indicate the features of the reservoir structure. Its analysis when comparing with the results of standard seismic exploration, will let them be interpreted.

This is the first attempt to process data obtained in different years of observation. On the basis of the experience \[ 10, 11 \] it can be concluded on this profile, that the amplitude value of the observed cross-correlation coefficient on the Earth's surface depends on many factors. Thus the absolute value of this coefficient cannot be used for the evaluation, and, therefore, the shape of the resulting curve is more important. Therefore, it is necessary to include additional measurements in the method of work by the passive seismoelectric method before starting the field works. These measurements are carried out at a predetermined point where, according to the explored data, there are no productive anomalies. It will make it possible to compare the evaluated parameter above the prospective reservoir and at the point where it is not present.

4. Conclusion
The analysis of the data obtained in different years showed that there exist repeatability of the measurement results, as well as the convergence with the results of mathematical modeling. This indicates the adequacy of the previously proposed mathematical model of a hydrocarbon reservoir for the passive seismoelectric method.

The passive alternative of the seismoelectric method helps to register the boundaries of the reservoir, i.e., to carry out its delineation. Active seismic methods are required to analyze the reservoir structure.
However, this method can save money in exploring for minerals even in such a limited application. The application of passive methods is advantageous for operating in hard-to-reach areas, such as swampy or mountain-taiga areas, where the use of large-sized equipment is impossible.

Thus, the collected statistics on observation points shows the possibility of using this method in carrying out industrial field works in conjunction with standard seismic exploration, since the implementation of the passive seismoelectric method requires about three grounded electric dipoles. It can be implemented in conjunction with the magnetotelluric sounding method, where it will be necessary to add a seismic receiver to the measurement scheme, in order to register the seismic field. The authors assume the further development of this method in the direction of finding the optimal algorithm for extracting information from the natural electromagnetic and seismic noise of the Earth.

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