Analysis of seismoelectric effects via tank experimental observations

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Abstract. The purpose of the present research is to experimentally confirm the seismoelectric effects of the second type on the physical model, which is represented by a tank filled with sand (2.1 x 1.32 x 3.2 m). Analysis of the current state in the field of hydrocarbon search using seismoelectric effects was carried out. Physical modeling of microseismic and natural electromagnetic field was performed applying acoustic emitter and grounded electrodes at the tank edges; registration was carried out with the help of three axial seismic receivers manufactured by GS and grounded dipole using non-polarizing electrodes of VIRG design. The results show that the maximum of the cross-correlation function is highly noisy, and recording seismoelectric effects on physical models of such sizes using the existing element base is not possible, thus, it is necessary to either increase the sensitivity of the receiving equipment along with an increase in the size of physical models or increase the signal accumulation time from 20 minutes or more.

1. Introduction
The first works devoted to seismoelectric effects were offered by J. I. Frenkel and M. Bio [1-2], which had been experimentally discovered by A. G. Ivanov in 1939 [3]. These models are high frequency and consider seismoelectric effects at frequencies above 10 kHz. These effects appear on porous structures, described using the Helmholtz-Smoluchowski-Frenkel ratio [1], and supplemented by Bio theory for a porous fluid-saturated medium. Further research was carried out by B. S. Svetov and V. P. Gubatenko [4-7], who developed a lower frequency model of 0-100 Hz, which is used to analyze and evaluate various kinds of seismoelectric effects. Analysis of recent patents shows [8-11] that this technology is vigorously developing; theoretical research in this field and also experimental observations at real oil and gas fields are carried out.

Authors of this article have already done field experimental observations on gas condensate deposits [12-13]. The results obtained in these works show that the passive seismoelectric method is consistent with the proposed mathematical model, as well as with the results of classical seismic exploration and borehole drilling [12]. Applying active sources of seismic field allows to apply seismoelectric method along with seismic survey, avoiding increase of field works labor costs.

To analyze seismoelectric effects in this work, physical modeling was carried out on a sand tank with a hydrocarbon reservoir simulator (HDS), modeling the passive seismoelectric method.
2. Methods and materials

For tank tests a laboratory tank with sand (2.1 x 1.32 x 3.2 m) was employed using a hydrocarbon reservoir simulator (HDS). Measurement diagram and appearance are given in figures 1-2. To make measurements in the Matlab software environment uncorrelated implementations of noise-like signals were generated to simulate microseisms and the Earth natural electromagnetic field. Applying grounded electrodes at the edges of the tank and a power amplifier, potential difference was created between the electrodes which ultimately led to the flow of current through the sand wetted with water. Excitation of microseisms was simulated with an acoustic emitter. The signal accumulation time was 20-180 s, the diving depth of the HDS was 0.3 m. The hydrocarbon reservoir simulator was a clay pot filled with a mixture of sand, water and oil refining products (motor oil). In order to make comparison, measurements were given, both with and without the presence of HDS. Physical modeling was also carried out under the influence of acoustic pulse. The acoustic emitter was installed at three different points, as shown in figure 3 of the application file.

Receiving sensors (a grounded electric dipole using non-polarizing electrodes and a three-axis seismic receiver) were installed directly above the HDS, as shown in figure 1. To record the measured signals, specialized band-pass amplifiers with a gain of 2500-5000 and a 24 bit ADC were used. The data was stored on a personal computer.

![Figure 1. Diagram of laboratory tank measurements.](image-url)
Thus, the passive seismoelectric method was simulated. For analysis the cross-correlation function was used applying the following expression:

$$R(0) = \frac{1}{2T} \int_0^T \bar{E}(t) \bar{S}(t - \tau) dt,$$

where $E(t)$ and $S(t)$ are dispersion normalized signals of electrical and seismic noise. This expression describes calculation of the cross-correlation function between seismic and electromagnetic fields. Of interest is the maximum of this function, the size of which shows the force of seismoelectric effect.

3. Results and discussion

In the process of physical simulation, it was found that the maximum cross-correlation function for a HDS of this size is at the level of natural noise or less, even using modern low noise amplifiers and 24 bit ADCs with a quantization step of 200 nV, which suggests that this kind of physical modeling is unlikely to be possible or it is necessary to construct a measurement scheme with HDS dimensions of magnitude larger, which will be expensive. Measurements carried out by other authors and those at existing deposits show that these seismoelectric effects are observed at the edges of the deposits and are determined apparently by the size of the deposit itself. Figure 3 shows a typical cross-correlation function obtained during physical simulation with a seismic emitter installed at the bottom of the tank.
Analysis of the graph shows that the maximum of the cross-correlation function is highly noisy and shifted in time by about 0.3 s, which can primarily be associated with the dimensions of the physical model, and, according to the author those measurements are carried out on a sand tank, where re-reflection of acoustic waves, standing waves and other factors are possible. Changing the accumulation time to 180 s and/or the noise band does not qualitatively change the shape of the cross-correlation function. The best results for recording the maximum cross-correlation function were obtained when installing the acoustic emitter below the tank. Thus, laboratory physical simulations have found that the size of the physical model is incommensurably small with the recorded effect and, therefore, to obtain more stable results in a laboratory it is necessary to carry out studies on much larger physical models, as well as with a more accurate construction of geo cross-section structure and HDS.

4. Conclusion
This work shows that the use of tank models to simulate the seismoelectrical effects of the second type is possible only employing ultra-sensitive equipment, including ADCs, low-noise amplifiers, etc. Implementation of the model itself should be carried out in an industrial impulse interference-proof place and spectrum-focused (50 Hz), which can make a significant contribution to the resulting observed coefficient. In order to achieve valid results, it is desirable to carry out physical modeling using crude oil rather than its refined products.

Further line of research in this area is related to the implementation of field works on real oil or gas condensate fields alongside with standard seismic exploration, which will allow more accurately interpret the results of observations and compare them with methods that are widely used in exploration geophysics.

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