SEISMO-ELECTRIC PHENOMENA FROM GRANITE CRACK CONTAINING CRUDE OIL

(A small scale laboratory experiment)

by

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ABSTRACT

Seismo-electric phenomena gained more attention from geophysicists over the last decade. The development of theoretical background and the success of laboratory experiments as well as limited field applications give a lot of opportunities and hope as a means for providing exploration and production data. Seismo-electric effect accommodates any phenomena which links seismic and electrical energy including seismic to electric conversion as well as electro kinetic in origin.

Experiment has been conducted to prove that free ions can be considered to accumulate inside a granite crack containing crude oil which in turn can generate stream oscillatory electric current when a seismic wave hit the fracture. As a result, electric potential can be detected at the mouth of the fracture which intersects the borehole. The environmental nature of the mouth which is full of fluid facilitates the detection of high resolution seismo-electric signal by simple electrodes which is made of metal.

Key words: seismo-electric, seismic exploration, reservoir characterization, fracture.

1. INTRODUCTION

The words seismo-electric or electro-seismic can be used with regard to any phenomena which links seismic and electrical energy, but they imply an effect that is electrokinetic in origin. This effect include electric to seismic conversion or electric signal created by seismic energy. It is the seismic to electric conversion caused by electrokinetic effect during the passage of seismic wave that will be referred to the term seismo-electric phenomena reported in this paper.

The first paper on seismo-electric phenomena was written by Thompson(1936) and then followed by Ivanov (1939). Thompson reported that there is a changes in electrical conductivity caused by propagation of seismic waves in subsurface rock while Ivanov observed that there is concentration of electrical field during the passage of a seismic wave. These reports then triggered the completion of theoretical work by Frenkel (1944) which studied the phenomena related to interaction of molecular energy and electromagnetic filelds. Russell *et al* (1977) identified four distinct phenomena corresponding the inter-relationship between seismic and electrical energy :

1. The change in electrical conductivity caused by the pressure (stress) changes during the passage of seismic wave.
2. Piezoelectric effect in quartz grain.
3. The electric signals produced by massive sulfide.
4. The electric signal caused by electrokinetic effects related to the motion of pore fluid relative to the grain matrix.

This experiment try to show the existence of electric signal caused by crude oil bearing fracture in the granite. This laboratory work has been design to simulate a small scale natural condition of a fracture basement reservoir. If the experiment is successful we expect that there will be a hope of implementing it in the real field.

Seismo-electric phenomena has several advantages compared to pure seismo-elastic wave phenomena used in oil and gas exploration. One of the

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Figure 1
A physical model comprises granite crack containing crude oil simulating fracture basement reservoir

advantages is its resolution which is much more higher than ordinary seismic wave, especially when recording can be carried out in fluid environtment. In this case the receiver for detecting seismo-electric effect is simpler than the receiver for detecting seismic wave. Because its resolution is much more higher than ordinary seismic method, it opens new possibility for investigating fracture reservoir using similar technique used in borehole seismic method. Seismo-electric effect here can be viewed as a change of apparent resistivity induced by seismic excitation.

II. BASIC THEORY

When seismic wave passes through a medium in which a borehole exists, it will cause vibration along the borehole. There will be a vibration along the hole which is referred to as the tube wave or the Stoneley wave. If a crack containing fluid intersects the borehole, the fluid inside the crack will be expelled to the borehole. Ions in the fluid which is caused by the dissolve of minerals will be driven to move in oscillatory manner. When the crack is permeable,this motion will create electrical current streaming into the outlet or the mouth of the crack.

An important feature which will be proved in this experiment is that whether granite crack containing crude oil exhibits seismo-electric phenomena as does fracture basement containing water. The result of this experiment is very important because its implications is that the seismo-electric measurement can be exploited to characterize the permeability and porosity of an oil bearing granite crack normally found in fractured basement.

Theoretically, a Stoenley wave of angular frequency *w* propagating with a phase velocity of c(*w*) around a borehole in a homogenenous permeable formation induces oscillation of fluid pressure Pb in the borehole. The fluid pressure oscillation can be expressed as Tang *et al.* (1991):

$$P_b(r,z,t) = P_0 \frac{I_0\left(r\frac{\omega}{c}\right)}{I_0\left(R_b\frac{\omega}{c}\right)} \exp\left(-i\omega t + \frac{i\omega}{c}z\right) \quad (1)$$

Here r and z are expressed in cylindrical coordinate (z axis pointing down), t is time, rb is tha borehole radius, Po is the scalar amplitude of the pressure oscillation. Io is the zero order modified Bessel function of the first kind.

The fluid pressure oscillation created is the formation by Stoneley wave is:

$$P_f(r,z,t) = P_0 \frac{k_0\left[r\sqrt{-\frac{i\omega}{D}+\left(\frac{\omega}{c}\right)^2}\right]}{k_0\left(R_b\sqrt{-\frac{i\omega}{D}+\left(\frac{\omega}{c}\right)^2}\right)} \exp\left(-i\omega t + i\frac{\omega}{c}z\right) \quad (2)$$

Here, D is the pore fluid dynamic diffusivity defined by Tang *et al* (1991), Ko is the zero order modified Bessel function of the second kind.

The fluid pressure mentioned above creates pore pressure gradient which causes a flow of the pore fluid. If the pore fluid is electrically charged this movement will create streaming electrical current which in turn induces an electric field. Following Mikhailov *et al* (2000) we may write that the total electrical current density in the formation is the sum of the conduction current and the streaming current densities.

J total = J conductive + J streaming

$$= E - L \ \nabla P_f \quad (3)$$

Where:

E is the electrical field vector
is the electrical conductivity

L is the streaming current coupling coefficient derived by Pride (1994)

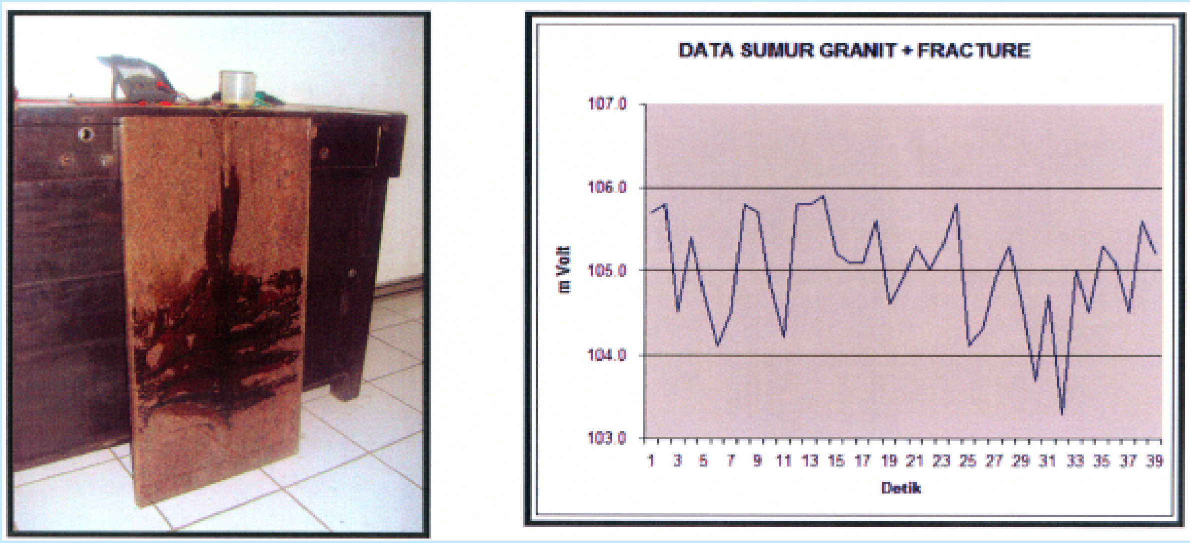

Figure 2
Set up of the experiment (left) and the recorded seismo-electric signal (right)

$$L = -\frac{\phi \, \zeta \, \varepsilon \, f}{a \quad \mu}\left(1 - \frac{i\omega}{\omega_c}\frac{4}{M^2}\right)^{-\frac{1}{2}} \qquad (4)$$

$$\nabla = \vec{i}\,\frac{\partial}{\partial x} + \vec{j}\,\frac{\partial}{\partial y} + \vec{k}\,\frac{\partial}{\partial z} \qquad (5)$$

α is the pore space turtoisity,
is the zeta potential which represents electro-chemical interaction between pore fluid and the rock,
is the pore fluid permittivity.

III. EXPERIMENTAL SET UP AND METHODOLOGY

The small scale laboratory experiment described in this paper is a physical model which tries to simulate naturally basement fracture reservoir in the field. The objective of this experiment is to answer the curiosity of whether granite crack containing crude oil may contain sufficient amount of ions for generating detectable electrical field potential.

The small scale model has been constructed using the materials available for building purposes. The form of the physical model is depicted in Figure 1, where a well is simulated by a vertical hole and several small fractures (cracks) intersect this hole.

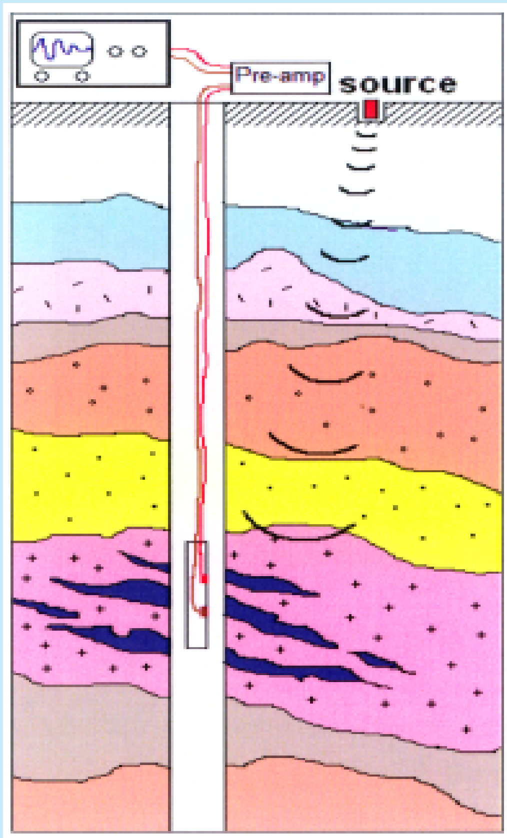

Figure 3
The expected real field application of seismo-electric phenomena

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To give the actual size of this physical model, imagine that the height of the table is 75 cm.

We deliberately fill this fractures by crude oil taken from an oil well. As for the seismic wave source we use a small hammer striking softly on top of the simulated surface. At the mouth (outlet) of the fracture we put two electrodes which are made of copper. These electrodes are connected to a millivoltmeter which is placed on the surface (simulated surface). To facilitate the movement of the ions a DC voltage of 105 mV is given between the electrode. By striking the hammer on the surface manually an elastic waves will propagate into the granite body. According to the theoretical back ground described in Section 2, this elastic wave propagation causes fluid pressure oscillation which pushes ions moving outward from the fractures, as a result streaming current arises. Since electrodes are placed at the outlet of the fractures, this streaming current can be detected.

VI. RESULT AND DISCUSSION

The result of this small scale experiment is given in Figure 2.

Although it is still very preliminary, it answers a very fundamental and important question that sufficient amount of ions do exist not only in granite crack bearing crude oil as does in granite crack bearing water. This fact is very promising from the point view of seismic exploration and reservoir characterization.

To underline the result of our experiment, the following items can be exposed :

1. Seismic wave propagates across a granite crack containing crude oil does generate streaming electric current.
2. Considering that this phenomena is caused by excitation which is generated softly and manually by a small hammer, we can expect that in the real field applications stronger signal will be obtained.
3. The surface of the fractured granite must adsorb ions of a certain polarity leaving on excess of ions of the opposite polarity in the solution (crude oil) otherwise, streaming electric current cannot be observed.
4. The fact that seismic wave excited on the surface can create seismo-electric phenomena in the borehole may inspire further practical application (for example see Figure 3). This kind of field set up can be used for characterizing permeable formation of the fracture basement reservoir.
5. Not only does the seismo-electric phenomena can be used for characterizing permeable formation, but also can be used to estimate the porosity of the reservoir, since according to Mikhailov *et al* (2000) the amplitude of the seismo-electric signal can be related to porosity, while the magnitude spectrum of the seismo-electric signal can be related to the permeability of the fracture reservoir.

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