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DC Electro-Kinetic Coupling Coefficient of Porous Samples in the Laboratory: Experimentation and Modelling

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Introduction

Electro-kinetic properties of rocks allow the generation of an electric potential by the flow of an aqueous fluid through a porous media. The electrical potential is called the streaming potential, and the streaming potential coupling coefficient C_s is the ratio of the generated electric potential to the pressure difference that causes the fluid flow. The streaming potential coupling coefficient for rocks is described in the steady-state regime by the well known Helmholtz-Smoluchowski equation, and is supported by a relatively small body of experimental data. However, electro-kinetic measurement is a powerful tool to characterise a rock with one simple measurement (*Glover and Walker, 2009*). This simple characterisation of a rock on field could induce further development of different area of expertise such as oil and gas exploration, reservoir prospection and monitoring, volcano and earthquake monitoring, the underground sequestration of CO_2 .or borehole geophysics (*Glover and Jackson, 2010*)

Theory

When fluid is flowed through a porous rock at a constant rate (DC regime), a shear plane develops at the fluid-rock interface within the pore. The fluid on the matrix side of the shear plane remains stationary, while that on the pore side flows. Because the shear plane generally falls inside the diffuse layer, the flow will tend to displace more anions or cations, depending on the fluid and the rock surface (i.e., equal numbers of anions and cations in the free electrolyte, but more anions or cations in that part of the diffuse layer that flows because the diffuse layer is depleted in anion or cations.). The flow separates charge and creates a so-called streaming potential, which leads to a secondary streaming current. It should be noted that the electrical potential on the shear plane is called the zeta potential, ζ (in volts), and is an extremely important parameter in the characterisation of the electro-kinetic properties of porous media.

The electro-kinetic phenomenon are described by the Helmholtz-Smoluchowski equation

$$\Delta V = -\frac{\varepsilon\zeta}{\eta\left(\sigma_f + \frac{2\Sigma_s}{\Lambda}\right)}\Delta P$$

where σ_f is the fluid conductivity (S/m), ε the fluid dielectric constant, ζ is the zeta potential (V), η is the fluid viscosity (Pa.s), ΔP is the fluid pressure variation (Pa), ΔV is the variation of the electrical potential (V), Σ_s is the specific surface conductance (S) and Λ is a characteristic length scale for the process.

The Coupling coefficient we want to measure in this study is the ratio of the measured electrical streaming potential developed across the sample divided by the fluid pressure difference that drives flow through the sample (i.e., $C_s = \Delta V / \Delta P$).

Conception, construction and testing of the apparatus

We have designed, constructed and tested a new experimental cell that is capable of measuring the DC streaming potential of consolidated and unconsolidated porous media. The new cell is made from stainless steel, Perspex and other engineering polymers (Figure 1).

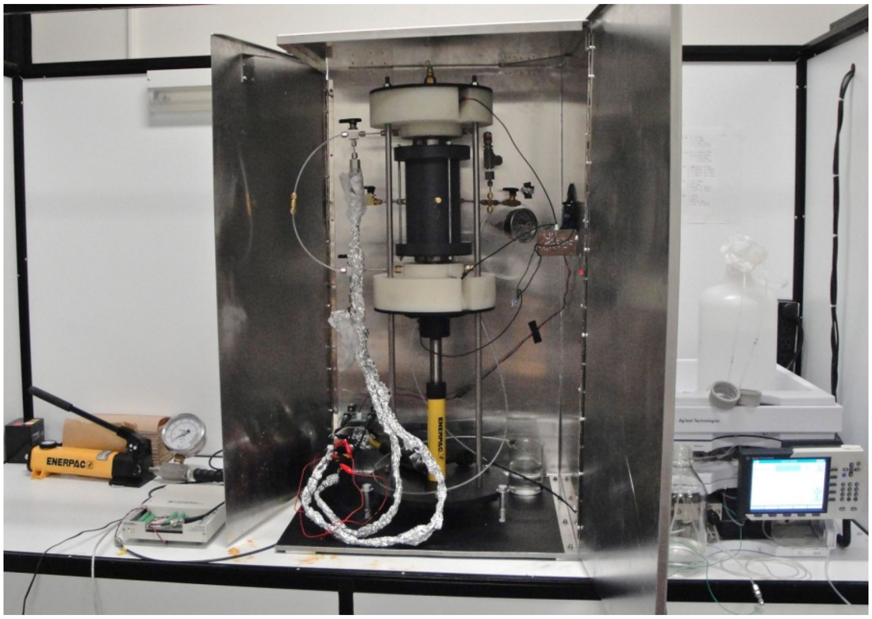

Figure 1: Picture of the apparatus for measuring the DC coupling coefficient of porous sample in the laboratory of petrophysics, Université Laval, Canada. The main cell is in an aluminium Faraday cage. At the left of the cell, you can see the axial pump and the logging card. At the right of the cell, the quaternary fluid pump

Cylindrical samples of 25.4 mm can be placed in a deformable rubber sleeve and subjected to a radial confining pressure of compressed nitrogen up to 4.5 MPa. Actively degassed aqueous fluids can be flowed by an Agilent 1200 series binary pump (2 to 10 mL/min). A maximum input fluid pressure of 2.5 MPa can be applied, with a maximum exit pressure of 1 MPa to ensure sample saturation is stable and to reduce gas bubbles. The pressures each side of the sample are measured by high stability pressure transducers (Omega PX302-300GV), previously calibrated by a high precision differential pressure transducer Endress and Hauser Deltabar S PMD75. The streaming potentials are measured with Harvard Apparatus LF-1 and LF-2 Ag/AgCl non-polarising miniature electrodes. An axial pressure is applied (1 to 6.5 MPa) to counteract the radial pressure and provide additional axial load with a hydraulic piston (Figure 2).

It is our intention to complete the testing of the cell and to use it to measure the electro-kinetic properties of porous rocks in the DC regime in order to provide sufficient data to improve the theories and models of DC streaming potentials.

Modelling

We have carried out fundamental theoretical modelling of the streaming potential coupling coefficient as a function of pore fluid salinity, pH (Figure 3) and temperature. The model requires the calculation of the electrical conductivity, dielectric permittivity and dynamic viscosity of the bulk fluid, the Debye screening length, the Stern plane potential, the zeta potential and the surface conductance of the rock.

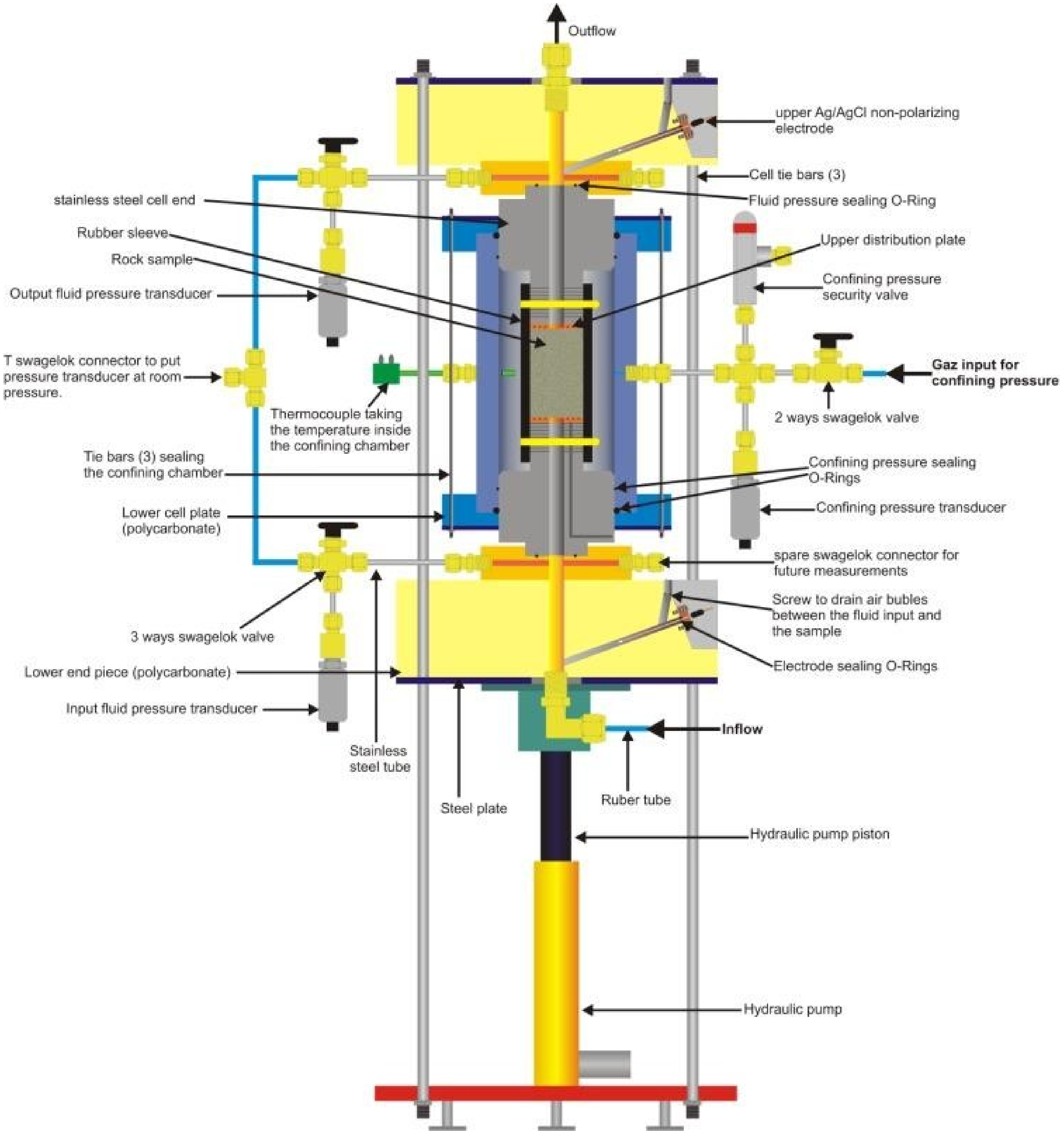

Figure 2: Schematic representation of the central cell from the electro-kinetic measurement apparatus of the Université Laval Petrophysics Laboratory.

These parameters are then combined with parameters that describe the rock microstructure. The resulting model have been compared with a compilation of data from different rocks, from 29 publications, and we found out that the model describe well most of the data. Our model allowed us to conclude that the low salinity regime was controlled by surface conduction and rock microstructure, and was sensitive to changes in porosity, cementation exponent, formation factor, grain size, pore size and pore throat size as well as specific surface conductivity. The high salinity regime was found to be subject to a zeta potential threshold that allows the streaming potential coupling coefficient to remain significant even as the saturation limit is approached.

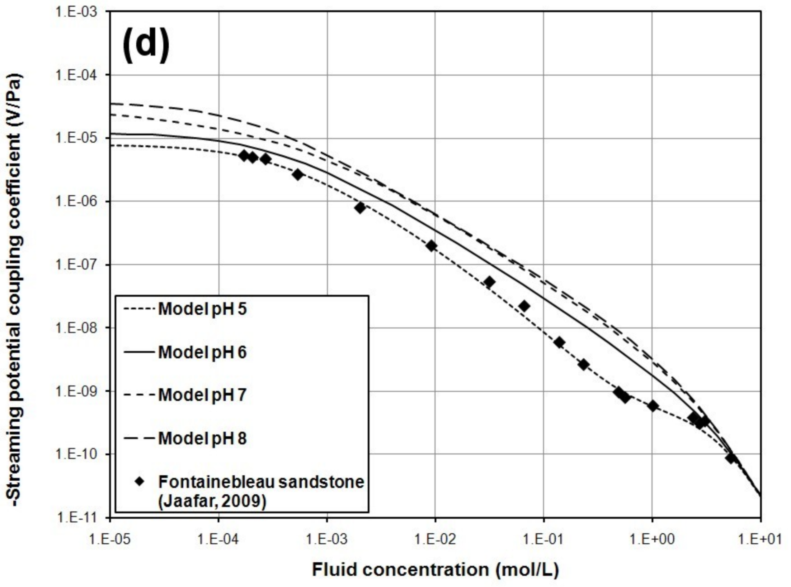

Figure 3 : Modeled streaming potential coupling coefficient (curves) as a function of pore fluid salinity and pH, compared with Fontainbleau Sandstone data from *Jaafar (2009)*.

This model could prove itself a powerful tool to characterize a rock from simple electro-kinetic measurements in the laboratory. Our goal is then to apply this model to our set of data from the new cell for a wide range of rocks.

Conclusions

Having an entire set of DC electro-kinetic measurement in the laboratory under exactly the same conditions and with an totally controlled environment could lead to understand better what electro-kinetics measurements we could make in the field. Measurements of electro-kinetic measurement in the field has been shown to have direct link with all types of rock properties, from porosity and permeability, to grain and pore sizes, and capillary pressure. Hence, the fuller understanding of the electro-kinetic properties of rocks could lead to major developments in drilling, downhole petrophysics, reservoir characterisation, understanding the onset of earthquakes and the monitoring underground flows.

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