LABORATORY MEASUREMENTS OF ELECTROKINETIC POTENTIAL FROM FLUID FLOW IN POROUS MEDIA

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INTRODUCTION

Electrokinetic potentials, sometimes known as streaming potentials, are generated by fluid-flow through porous media or rock fracture systems. They provide a means for the detection and quantification of groundwater flow, which may then provide hydraulic maps and be used for environmental problems.

However, the electrokinetic potential is very dependent on many parameters such as salinity, hydraulic conductivity, pressure, pH and temperature. Moreover, to use the electrokinetic potential method, determining the zeta-potential (ζ) and electrokinetic coupling coefficient is critical. Laboratory experiments are required to measure the zeta-potential and the electrokinetic coupling coefficient, and also to better understand the petrophysics related to the parameters mentioned above.

In this laboratory work, we used hydraulic head pressure to generate fluid flow. Four different sizes of glass beads as porous media and two different types of solutions are also used. The experiments focused on the interaction of grain surface-charge and fluids, the relationship between hydraulic conductivities and the zeta-potential and the changes of the zeta-potential due to different grain sizes.

EXPERIMENTS

We built an apparatus (Figure 1) to measure the zeta-potential and the electrokinetic coupling coefficient. To generate fluid flow hydraulic head pressure was used, and to simplify calculations we used three steps with a 30 cm height difference between each step. Two manometers were placed at the ends of the 20 mm diameter, 28 cm long column, which was packed with glass beads, to measure the difference of hydraulic head pressure between the two ends. To measure the potential difference two platinum electrodes were inserted at each end of the column, and were connected to a data logger (DT800), which was connected to a computer. A labCHEM-CP instrument was used to measure electric conductivity, pH and temperature of the fluid.

To better understand the basic petrophysical properties we used glass beads as the porous media. This provides the simplicity of standard grain surfaces and can represent all silicate minerals. Four different diameters of spherical glass beads were used, with diameters in the range 106-212 µm, 250-425 µm, 600-850 µm and 1400-1700 µm. For the fluids, we used deionized water and 0.001mol/l NaCl solution within the laboratory temperature (19.1–24.1°C).

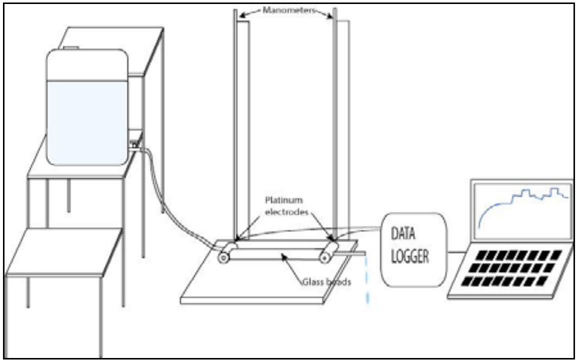

Figure 1: A schematic of the laboratory apparatus.

Before the experiment, the glass beads were washed with deionized water and fully saturated in the deionized water to remove air bubbles. Then, the potential measurements were logged every second by the DT800 and saved directly to flash memory, and were also observed on the computer screen. When the potential values stabilized for a fixed hydraulic pressure, the hydraulic head pressure was changed to the next step (Figure 3). The pH, electric conductivity, and temperature of the fluid were measured at the beginning of fluid flow, at each stable stage of the potential and at the end of an experiment.

The zeta-potentials were calculated with the Helmoltz-Smoluchovsky equation (Overbeek 1952) using hydraulic head pressure following as:

$$\nabla V = \frac{\varepsilon_r \varepsilon_0 \zeta \rho g}{\eta \sigma} \nabla H$$

where ζ is the zeta-potential, ε_r is the relative dielectric constant of the liquid, ε_0 is the dielectric constant of vacuum, η is the viscosity of the fluid, ρ is the density of the fluid (in kg/m^3), g is the normal gravity value (9.81 m/s^2), H is the hydraulic head, σ is the bulk conductivity of the liquid and ∇V is the potential gradient

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normal to the cross section.

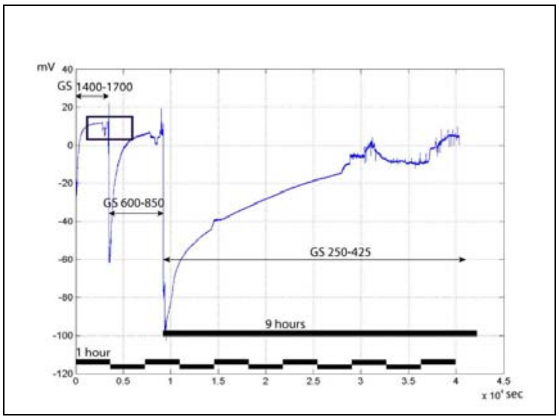

Figure 2: Electrokinetic potential measurements. The figure shows the time dependent effect switching from no-flow to equilibrium flow for three grains sizes.

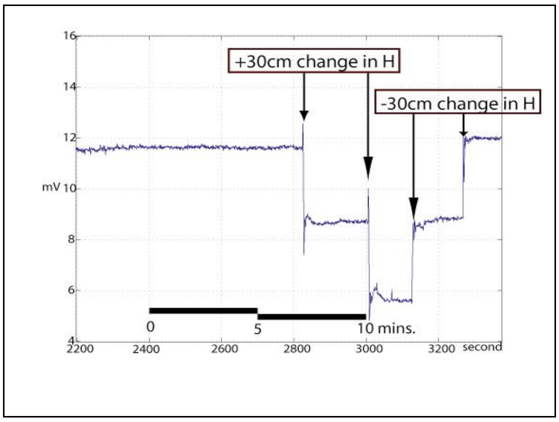

Figure 3: Enlarged picture of the boxed area of Figure 2. The change of electrokinetic potential due to the change of hydraulic head pressure

RESULTS

General results of the laboratory experiments show that:

1. Higher pressure (hydraulic head pressure) produces higher electrokinetic potential (Figure 3);
2. Smaller grain size of glass beads shows a larger magnitude of zeta-potential (Figure 6);
3. Hydraulic conductivity and zeta-potential exhibit a linear relationship (Figure 4);
4. The total surface area of the porous media could be related to zeta-potential values (Figure 5); and,
5. 0.001 mol/l of NaCl solution gives a larger magnitude of zeta-potential value than deionized water.

Figure 2 shows that the electrokinetic potential initially drops as fluid pressure front moves along the column. This may be explained as when the fluid initially reaches the outlet it loses cations from the starting point of the porous medium (column), then as time goes or as the grain surface along the column adsorbs cations, gradually the porous medium is more likely equilibrated. The response curve for 1400-1700 μm glass bead sample takes a much shorter time to reach equilibrium in the electrokinetic potential than smaller grain sizes, and is also more sensitive to the hydraulic head pressure changes. All the glass bead samples show the same phenomena but different magnitudes due to different hydraulic conductivities. On the curve of the 250-425 μm there are some noisy sparks due to fluctuations of fluid flows at the end of the outlet tube. This instrumental error has been corrected and the resolution of signal is 0.1 mV. The representative values from this experimental work are shown in the Table 1.

Table 1: The values from different samples and different solutions

	106-212 μm	250-425 μm	600-850 μm	1400-1700 μm	pH
Zeta-potential (deionized water) (mV)	-11.3	-4.8	-1.0	-0.7	5.6-5.8
Zeta-potential (0.001mol/l NaCl) (mV)	-64.4	-47.7	-18.4	-15.9	6.8-6.9
Hydraulic conductivity (cm/s)	1.45-E04	7.23-E04	3.75-E03	1.4-E02	
Fluid conductivity (deionized water) (μs/cm)	6.6	10.7	1.38	1.36	
Fluid conductivity (0.001mol/l NaCl) (μs/cm)	153.3	146.2	152.8	146.5	

Figure 4 shows the relationship between the hydraulic head pressure and the electrokinetic potential. It shows firstly that high pressure generates a large electrokinetic potential and the bigger grain size porous media gives a larger electrokinetic potential. With the comparison of the results with deionized water the magnitude of the electrokinetic potentials are much smaller for all the samples. The relationship between the zeta-potential and the hydraulic conductivity is shown in Figure 5 and Figure 6. On the log-log scale the relationship shows a good linear relation for both the deionized water and the 0.001mol/l NaCl solution. In Figure 7 the relationship between the zeta-potential and surface area is shown. It is approximately linear but with 0.001mol/l NaCl solution, the magnitudes of the zeta-potential of smaller grain sizes are larger.

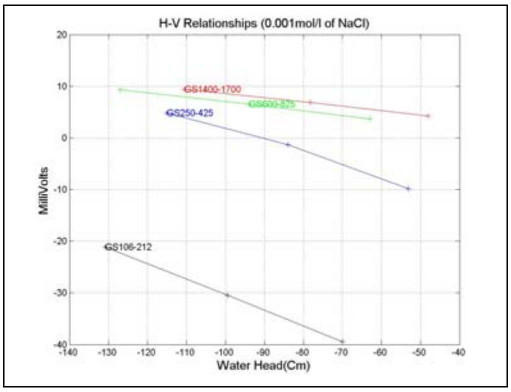

Figure 4: Relationship between hydraulic head pressure and electrokinetic potential

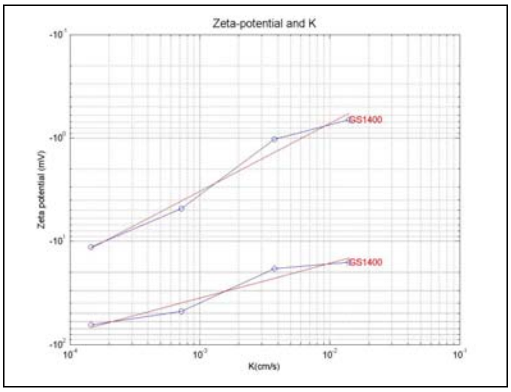

Figure 5: Relationship between zeta-potential and hydraulic conductivity on log-log scale

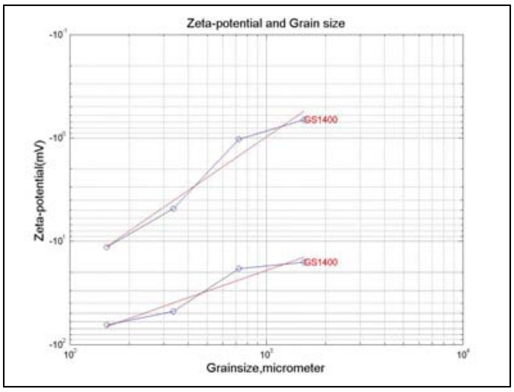

Figure 6: Relationship between zeta-potential and grain-size

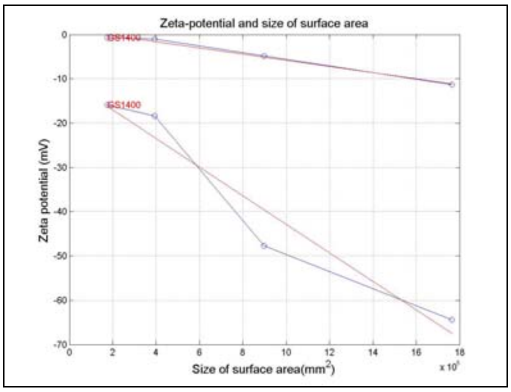

Figure 7: Relationship between zeta-potential and surface area of grains

DISCUSSION

The results from this laboratory work show some clear relationship between the zeta-potential and parameters such as salinity, hydraulic conductivity, pressure and surface area. However, the experimental work needs further investigations on the interactions of zeta-potential with pH and different types of saline solutions because the zeta-potential could dramatically vary with pH, temperature and salinity (Ishido & Mizutani 1981).

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