



Electrokinetics in Porous Media

L.D. Thành

Summary

This thesis presents the PhD research on electrokinetics in porous media. Electrokinetic phenomena are induced by the relative motion between a fluid and a solid surface and are directly related to the existence of an electric double layer between the fluid and the solid grain surface. Electrokinetic phenomena consist of several different effects such as streaming potential, electroosmosis, electrophoresis. The thesis only focuses on streaming potential and electroosmosis effects in porous media. Below is the summary of the research.

Chapter 1 introduces the applications of electrokinetic phenomena in geophysical applications and environmental applications, physical chemistry of the interface between solid grains and fluids, and the theoretical backgrounds of streaming potential and electroosmosis effects happening in porous media saturated by fluids. This chapter also presents definitions of microstructure parameters used throughout the thesis to describe porous media such as the porosity, permeability, tortuosity, formation factor and solid density. Some interesting ideas that deserve more research are also shown in this chapter.

The coupling coefficients of conversion between seismic wave and electromagnetic wave depend strongly on the fluid conductivity, porosity, permeability, formation factor, pore size, zeta potential of porous media and other properties of the rock formation. Therefore, determining these parameters is very important in studying electrokinetics in general and to model seismoelectric and electroseismic conversions. Chapter 2 presents an approach to characterize porous media using dc measurements of streaming potential and electroosmosis effects. The experimental results are in good agreement with the theoretical model. In particular, the approach works in particular well for very small pore samples.

Permeability is one of the most important physical parameters to describe reservoir rocks. In theory, the streaming potential coupling coefficient depends not only on the zeta potential but also on the permeability of the rocks that partially

determines the surface conductivity of the rocks. However, in practice it is hard to show the permeability dependence of streaming potential coupling coefficients because of the variation of zeta potential from sample to sample. In chapter 3, we study permeability dependence of streaming potential including the effects of the variation of the zeta potential and surface conductance due to the difference in mineral compositions between samples. We perform measurements on 12 consolidated samples including natural and artificial samples saturated with 7 different NaCl solutions to determine streaming potential coupling coefficients. The results have shown that the coupling coefficients strongly depend on permeability of the samples for low fluid conductivity. When the fluid conductivity is larger than 0.13 S/m (0.01M NaCl solution), the coupling coefficient is independent of permeability. This observation is quantitatively explained by a theoretical model.

In chapter 2 and chapter 3, the streaming potential coupling coefficient is experimentally measured and the zeta potential is deduced from that. That is the most commonly used approach to obtain the coupling coefficient and the zeta potential of electrolyte saturated rocks. Glover et al. [27] developed a theoretical model to calculate the zeta potential and streaming potential coefficient of reservoir rocks and other porous media. The authors have compared the theoretical results to an experimental data set from available published data. The comparison shows that the theoretical model can reproduce the main features of the experimental data. However, the existing experimental data sets are based on samples with dissimilar fluid conductivity, pH of pore fluid, temperature and sample compositions. All those dissimilarities may cause the observed deviations. To critically assess the model, in chapter 4 we have carried out streaming potential measurement as a function of electrolyte concentration and temperature for a set of well-defined consolidated samples. The results show that the theoretical model is not in good agreement with the experimental observations when varying the electrolyte concentration. If we use a modified model in which the zeta potential is considered to be constant over the electrolyte concentration, the model fits the experimental data well. Also for temperature dependence, the comparison shows that the theoretical model is not fully adequate to describe the experimental data, but does describe correctly the increasing trend of the coupling coefficient as function of temperature.

In chapter 2, chapter 3 and chapter 4, all streaming potential measurements are carried out for NaCl solution only. In reality most reservoir rocks are saturated or partially saturated by natural waters that normally contain monovalent and divalent electrolytes. Therefore, in chapter 5 we study the dependence of the zeta

potential on types of electrolytes systematically using streaming potential measurements. The experimental results show that the coupling coefficient and the zeta potential depend not only on the mineral compositions but also on types of electrolyte (mainly types of cation). The experimental results also show that the zeta potential for monovalent electrolytes is higher than that for divalent electrolytes. The reservoir rocks made of silica have the highest zeta potentials when saturated by the same type of electrolyte. The experimental results are explained by theoretical models. For monovalent electrolytes, we use a theoretical model that is available in literature. For divalent electrolytes, we develop another model to explain the experimental data. The results shows that the theoretical models can explain the main behavior of the zeta potential against types of electrolyte and types of sample. For a given electrolyte, the difference in the zeta potential can be explained by the difference in the surface site density and disassociation constant for different kinds of porous rocks (mineral compositions). For a given sample, the difference in the zeta potential can be explained by the difference in binding constants of cations and in types of cations.

In previous chapters, aqueous electrolytes have been used to study the streaming potential. In chapter 6, we carry out the streaming potential measurements for an artificial sandstone sample saturated with a binary mixture of triethylamine-water with three different mass fractions. The results show that the zeta potential changes with compositions of TEA and temperature. Interestingly, an anomaly of the zeta potential has been predicted near the critical point for the critical composition. Therefore, there may be an anomalous change of the electric double layer and the Debye length near the critical point.

In Appendix A, we present the approaches and setups to determine parameters of porous media such as the porosity, density of grains, tortuosity, formation factor and steady-state permeability. Those parameters are already used and mentioned in previous chapters. In addition, we also determine the frame and shear modulus of the consolidated samples.

In Appendix B, we derive an expression to calculate the zeta potential for divalent electrolytes that is applied in chapter 5 to explain the experimental data.