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Transient Streaming Potentials Associated with Brine Flow in Rock Salt

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Abstract

Preliminary experimental data collected in falling-head permeameter tests using brine flow through crushed rock salt are presented. The brine was obtained by recirculating what was initially deionised water through a column of crushed rock salt until saturation (specific gravity = 1.203) was attained. The column was then repacked with fresh crushed salt. Brine flow through the salt was then monitored with a pressure transducer and silver-silver chloride (Ag/AgCl) electrodes, measuring the pressure and voltage drops, respectively, across the length of the salt column. The measurements are reported. Preliminary analysis of the data is performed with a recently developed model for transient streaming potentials in falling-head permeameters.

Background

Streaming potentials arise during fluid flow in porous media due to the existence of a surface charge at the mineral grain surface and the consequent formation of an electric double layer in the fluid phase to counter the mineral grain surface charge. The fluid phase, usually groundwater, is typically a dilute electrolyte. Increasing fluid phase solute concentration is known to decrease the magnitude of streaming potentials generated by flow. Hence, the question arises whether measurable streaming potentials can be generated by flow of brine (solute saturated electrolyte) through rock salt (mineral grains comprising porous medium). Experiments were performed in a falling head permeameter with brine and rock salt in an attempt to answer this question. The salt was collected in the Waste Isolation Pilot Plant (WIPP) underground from the Salado formation of the Permian Basin in southeastern New Mexico near Carlsbad. The experiments are described in the following.

Permeameter Experiments

Materials

Permeameter comprising a plexi-glass sample holder and a fluid reservoir, one Druck pressure transducer, four biomedical silver/silver chloride (Ag/AgCl) electrodes, crushed rock salt (impure halite) collected in the WIPP underground, brine made by dissolving the rock salt in deionized water until saturation (specific gravity = 1.203), fine mesh cloth, and a high impedance voltmeter. PVC tubing with a control valve was used to connect the sample holder and fluid reservoir. The fluid reservoir can be connected to a pressurized gas line for constant head or higher (than pressure differential due to fluid column only) pressure falling head tests.
Rock salt of the Salado formation is composed of halite and clayey halite, with the latter containing detrital debris, chiefly quartz and clay (Powers et al., 1978).

Figure 1: Permeameter showing sample holder, fluid reservoir, pressure transducer, and electrode ports.

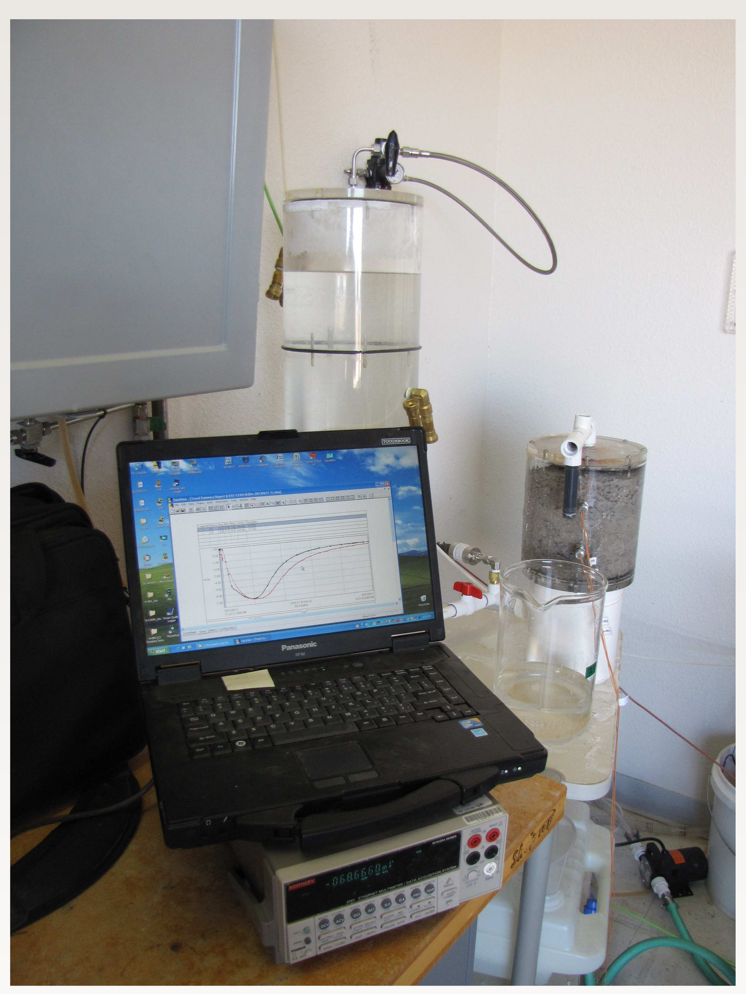

Figure 2: Experimental setup and data acquisition system during a flow experiment.

(a) (b)

Figure 3: (a) Sample of crushed rock salt used in flow test. (b) Typical electrode placement on top of sample in permeameter.

Procedure

Crushed rock salt was tightly packed into the sample holder filled with brine under saturated conditions to minimize air entrappment. Fine mesh cloth was used to hold salt in place. Brine was used in the flow experiments to avoid salt dissolution. Two biomedical (Ag/AgCl) electrodes were placed at the top and and two at the bottom of the crushed rock salt column. Voltage differentials between the top and bottom electrodes (across the packed salt sample) were measured. After a period of background measurements, brine flow through the sample was initiated by openning a control valve. These were falling head tests under brine head only. For the results presented here no pressure data were collected given the simple objective of determing whether measurable signals can be generated by brine flow through crushed salt. Experiments ran for 24 hrs

Observations

- No salt dissolution was observed during fluid flow.
- Relatively low flow rates ($\sim$ 600 mL/hr initially) compared to those observed in experiments on sand.
- Salt build-up was observed at brine out flow port due to the low flow rates and evaporation.
- Voltage differentials showed appreciable transient change from background and outside the noise range.

Results

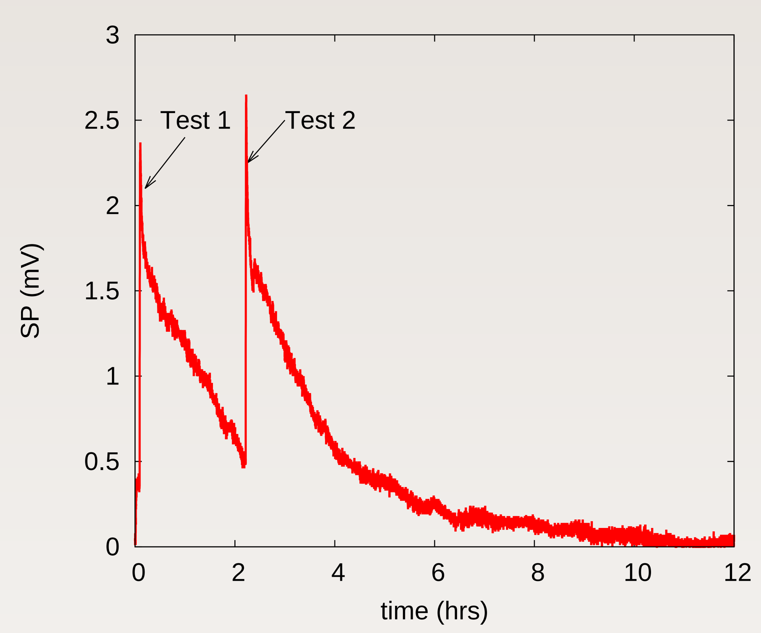

Figure 4: SP response measured during falling head permeameter brine tests in rock salt.

- Figure 4 shows the response observed in two flow tests performed on rock salt.
- Peak SP responses of $\sim$ 2.5 mV were recorded followed by slow decay to preflow state.
- Early-time response is gradual (evident in semi-log plot in Figure 5) transient rise (on order of minutes) to peak differential perturbation due to flow initiation. For permeable soils, this phase is near instantaneous.

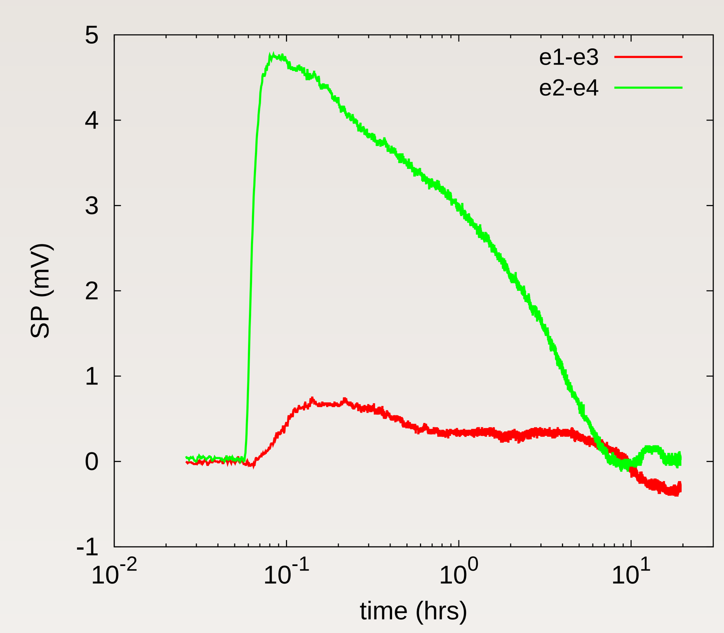

Figure 5: Semi-log plot of measured SP response show gradual early-time rise to peak differential SP.

- Data show an intermediate phase with an inflection in the temporal SP variation.
- Late-time decay to pre-flow equilibrium is much slower than the early-time response, taking several hours. Late-time response is associated with fluid flow through the sample.
- The two electrode pairs gave very different results suggesting local effects.

Empirical model for soils

Falling head permeameter flow in porous media is modeled with the classical lumped-parameter model

$$\frac{dh}{dt} = -\beta h \Rightarrow h(t) = h_0 e^{-\beta t} \qquad (1)$$

where $h_0 = h(t=0)$, $\beta = (K/L)(d_c/d_t)^2$, K is sample hydraulic conductivity, L is sample length, d_c diameter of the column housing the sample, and d_t is falling-head tube diameter.

The corresponding SP model is obtained from (Malama and Revil, 2013)

$$\frac{d\phi}{dt} = -\beta\phi_1 e^{-\beta t} \Rightarrow \phi(t) = \phi_0 + \phi_1 e^{-\beta t} \qquad (2)$$

where $\phi_1 = h_0 C_\ell$ and $C_\ell = d\phi/dh$ is the electrokinetic coupling coefficient.

An additive exponential decay function is introduced to account for post-flow relaxation, leading to the semi-empirical model

$$\begin{aligned}\phi(t) &= \phi_0 + \phi_1 e^{-\beta t} + \phi_2 e^{-\beta_2 t}\\ &= \phi_0 + C_\ell h(t) + \phi_2 e^{-\beta_2 t}\end{aligned} \qquad (3)$$

where ϕ_2 and β_2 characterize post-flow relaxation.

Model does not describe observed early-time behavior, and predicts instantaneous decrease to a much lower SP value than observed upon flow initiation.

It was applied to data collected in experiments (see Figure 6) on sand yielding hydraulic conductivity values equal to those from Equation (1) with head data (Malama and Revil, 2013).

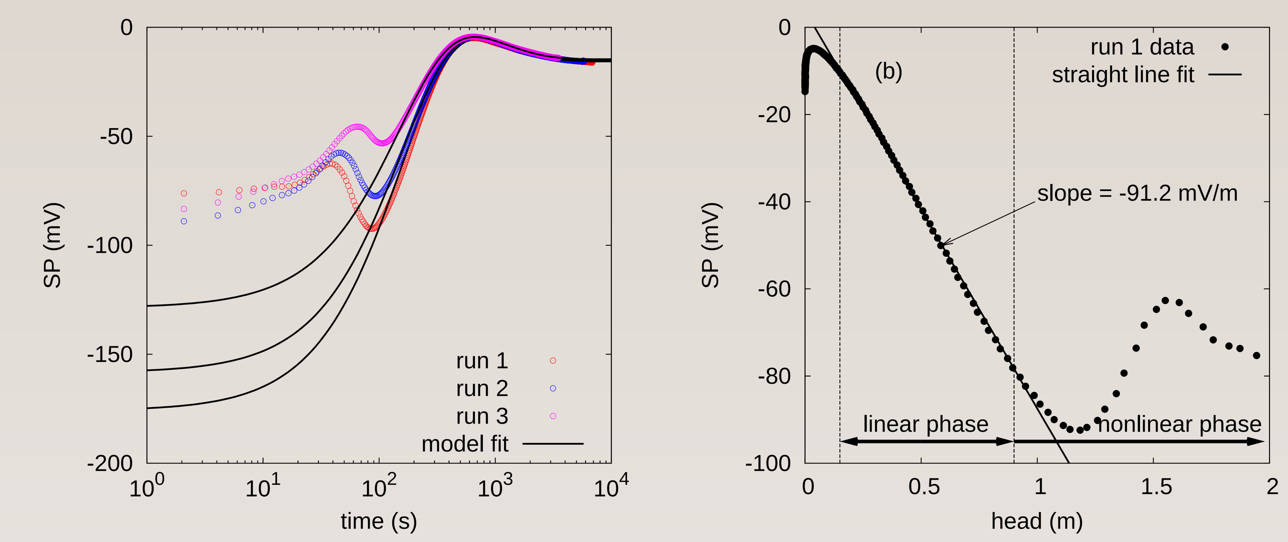

Figure 6: (a) Model fit to SP data vs. time and (b) straight-line ($d\phi/dh = C_\ell$) fit to SP vs. head data. These data were obtained in flow tests using silica sand.

Model application to brine flow in rock salt

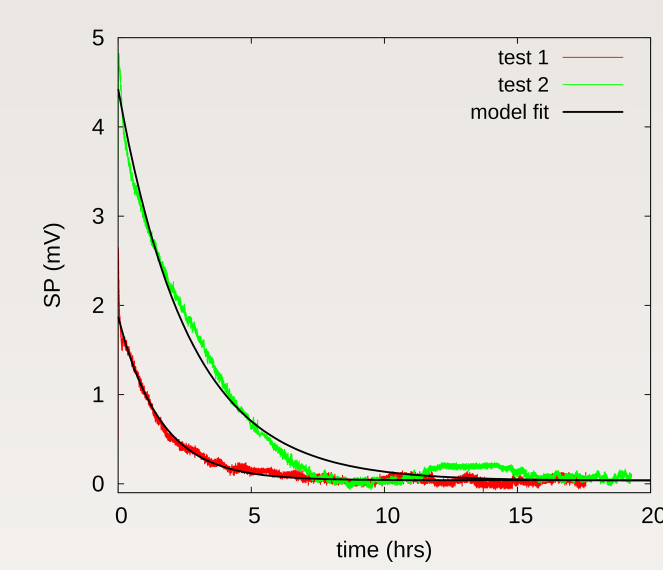

Figure 7: Model fit to permeameter test data from brine flow experiments through rock salt.

Assuming Equation (3) is applicable to brine flow through rock salt, it was fitted to SP data collected in the experiments reported here.

Plots are shown in Figure 7 showing good fits to data. Parameters estimated from the tests are in Table 1. Sample and reservoir diameters are equal ($d_c = d_t$) and sample length is $L = 20$ cm.

Table 1: Parameters estimated from SP data.

Run	h_0 (m)	$\lvert\phi_0\rvert$ (mV)	$\lvert\phi_1\rvert$ (mV)	β (hr^{-1})	K (m/d)	$\lvert C_\ell\rvert$ (mV/m)
1	0.3	0.040	1.83	0.63	3.0	6.1
2	0.3	0.034	4.39	0.38	1.8	14.6

Remarks: It is not the intent of this work to suggest that the electric double layer phenomenological relations applicable to soils and other such porous media are directly extendable to brine flow in rock salt. The primary objective was simply to demonstrate that measurable SP may be generated by brine flow in rock salt. The causal mechanisms of the SP in this instance present an opportunity for further research.

References

Malama, B., Revil, A., 2013. Modeling transient streaming potentials in falling-head permeameter tests. Groundwater, online.

Powers, D. W., Lambert, S. J., Shaffer, S.-E., Hill, L. R., Weart, W. D., December 1978. Geological characterization report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico. Technical Report SAND 78-1596, Sandia National Laboratories, Albuquerque, NM.

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