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Thermoelectric and electrochemical self-potential anomalies induced by water injection into hydrocarbon reservoirs

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Downhole measurements of electrokinetic (EK) streaming potential, using electrodes mounted on the outside of insulated casing, has been shown to be useful for informing production strategies in oil and gas reservoirs. However, spontaneous potentials due to thermoelectric (TE) and/or electrochemical (EC) effects may also be present during production and may contribute to the signal measured at the production well. We present a study of the contribution of these effects based on numerical models of subsurface potentials during production.

We find that the injection of seawater, which typically has a different temperature and salinity to the formation brine, leads to the generation of both TE and EC potential signals in an oil reservoir, which may be measured at the production well along with EK potential signals. In particular, there is a peak in the TE potential before and after the temperature front, with a change in sign occurring close to the midpoint of the front, and the signal decaying with distance from the front. The EC potential has a similar profile, with a change in sign occurring close to the location of the salinity front. In both cases, the absolute magnitude of the signal is related to the overall temperature and/or salinity contrast between the injected fluids and the formation brine, and the magnitude of the TE and EC coupling coefficient.

When we use the maximum theoretical magnitude for the TE and EC coupling coefficients, in the case of a perfect membrane, the lag in the temperature front relative to the saturation front leads to a negligible TE potential signal at the production well until long after water breakthrough occurs. In contrast, the EC potential contributes significantly to the spontaneous potential measured at the production well before the waterfront arrives, as the salinity front and the saturation front approximately coincide.

The dependence of the TE and EC coupling coefficients upon temperature, salinity and/or partial water saturation is still uncertain. We explore the contribution of the EK and EC potential signals to the overall signal measured at the well as a function of salinity and water saturation.

Our results imply that measurements of the spontaneous potential at a production well will combine contributions from both streaming and electrochemical effects, and may be used to detect an advancing waterfront some time before water breakthrough occurs at the well. Moreover, inversion of the measured signals could be used to determine the water saturation in the vicinity of the well, and to regulate flow into the well using control valves in order to maintain or increase oil production.