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Theoretical studies of permeability inversion from seismoelectric logs

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Permeability is one of the most important parameters for evaluating the level of difficulty in oil and gas exploitation. A quick, continuous and accurate in-situ estimate of reservoir permeability is highly significant. Stoneley wave logs have been used to determine formation permeability (Tang and Cheng, 1996). However, the inversion errors of this method are too big in low-permeability formations, especially in high-porosity and low-permeability formations resulting from the high clay content in pores.

In this study, we propose to invert permeability by using the full waveforms of seismoelectric logs with low frequencies. This method is based on the relationship of permeability with the ratio of the electric excitation intensity to the pressure field's (REP) with respect to the Stoneley wave in seismoelectric logs.

By solving the governing equations for electrokinetic coupled wavefields in homogeneous fluid-saturated porous media (Pride, 1994), we calculate the full waveforms of the borehole seismoelectric wavefields excited by a point pressure source and investigate frequency-dependent excitation intensities of the mode waves and excitation intensities of the real branch points in seismoelectric logs. It is found that the REP's phase, which reflects the phase discrepancy between the Stoneley-wave-induced electric field and the acoustic pressure, is sensitive to formation permeability.

To check the relation between permeability and REP's phase qualitatively, an approximate expression of the tangent of the REP's argument is derived theoretically as $\tan(\theta_{EP}) \approx -\omega_c/\omega = -\varphi\eta/(2\pi f \alpha_\infty \rho_f \kappa_0)$, where θ_{EP}denotes the arguments of the REP and their principal value is the REP's phase, ω is the angular frequency, ω_c is a critical angular frequency that separates the low-frequency viscous flow from the high-frequency inertial flow, φ is the porosity, α_∞ is the tortuosity, κ_0 is the Darcy permeability, ρ_f and η are the density and the viscosity of the pore fluid, f is the frequency. According to this approximate expression, if porosity, tortuosity and pore fluid properties (density and viscosity) have been measured by some methods or estimated by empirical formulas, permeability can be inverted by calculating $\tan(\theta_{EP})$ and using its corresponding frequency.

To test this method, permeabilities of different sandstones are inverted from the synthetic full-waveform data of the seismoelectric logs. A modified inversion process is proposed based on the analysis of the inversion errors, by which the relative errors are controlled below 25% and they are smaller than those of the permeability inversion from the Stoneley wave logs.

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