3D inversion of frequency-domain controlled source electromagnetic data for hydraulic fracturing fluid imaging and well casing's conductivity monitoring

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SUMMARY

Appropriate utilization of steel casings in oil and gas development holds significant promise for enhancing controlled source electromagnetic (CSEM) responses on the surface, particularly in discerning subtle physical property changes within a reservoir. This research introduces a practical approach for performing inversions to map the 3D distribution of injected fluid during hydraulic fracturing operations, even amidst the complex presence of steel casings. Our methodology incorporates steel casings into the conductivity model by introducing edge conductivity—a parameter defined as the product of intrinsic conductivity and the cross-sectional area of the casing pipe. By calibrating edge conductivities to mesh edges and their integration within the finite volume formulation, we capture casing effects without necessitating intricate mesh refinements, simplifying computational processes. We tested our algorithm against a cylindrical mesh and validated its effectiveness in forward modeling using a line current transmitter. For the inverse problem, we work with an objective function comprised of a data misfit and model norm term that imposes constraints on model smoothness. We solve the inverse problem using the Gauss-Newton Method. We illustrate our inversion by considering synthetic scenarios with realistic host rock resistivities, horizontally drilled wells, and a top-casing source. We show that the inversion can recover the trajectory of the injected fluid, and detect if the fluid flow is not symmetric. Our algorithm can also assess the integrity of steel casings by setting the edges of the cells where the casing is active and allowing the inversion to estimate those edge conductivities. This study underscores the potential of integrating steel casing data into electromagnetic modeling, facilitating enhanced reservoir characterization and informed decision-making in oil and gas exploration and production.

Keywords: 3D Inversion, CSEM, Steel casing, Hydraulic fracturing