

Steel casings in controlled source electromagnetic surveys

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SUMMARY

Steel casings are essential infrastructure for energy development. Conventionally, they are considered man-made interference to electromagnetic (EM) surveys. Researchers have been exploring their unique roles in assisting CSEM monitoring in recent years thanks to the extremely high electric conductivity of casing that channels an excessive amount of current to deep reservoirs beyond CSEM's typical depth of investigation. This presentation summarizes the results of our study on the numerical capability and methodological research for steel casings and other similar metallic infrastructures. We also highlight their applications in the development of clean energy and energy transition, as well as in the near-surface and engineering problems.

The backbone of our numerical modeling for steel casings is an innovative concept that assigns conductivity properties to the edges of a 3D mesh. The newly defined physical property, edge conductivity (edgeCon), is the product of steel's intrinsic conductivity and the casing's cross-sectional area. EdgeCon quantitatively preserves the casing's directional current-conducting capability while avoiding mesh refinement for the thin casings. We have implemented the 3D modeling of arbitrary well casing using edgeCon for DC and frequency-domain EM. We also made 3D codes to invert DC or CSEM data with the presence of steel casings. In our recent development, the edgeCon approach was modified to handle more complex casing structures, including cementing and multi-layered casings.

While steel casing's current channeling effect is well-known, we have made some theoretical contributions that have significant implications for monitoring hydraulic fracturing. The most counterintuitive one is that, regardless of where the fracturing occurs on the horizontal well and where the CSEM source is located, the strongest data anomalies on the surface are always around the wellhead. In addition, the top-casing source at low frequencies (galvanic component) is the most effective in utilizing casings as a long electrode and amplifying the anomalous signals from the deep fracturing fluid. We have also demonstrated the advantages of multiple parallel wells in sensing the flow of injected fluid. A deep learning-based inversion scheme was developed for real-time fracturing imaging monitoring with steel casings embedded in the model.

We have applied our numerical and theoretical research results to various scenarios, including synthetic and field data studies on tight oil/gas fracturing, enhanced geothermal system fracturing, and borehole-surface EM monitoring for carbonate reservoirs, in which hydrocarbon is contained in small and deep cavities. We also find potential applications of our tools in urban or industrial environments, where complex metallic infrastructure must be efficiently and accurately simulated.

Keywords: Steel casing, controlled source electromagnetic, 3D modeling, electromagnetic exploration
