Sensitivity Analysis of Hydraulic Fracture in Open and Cased Holes Using Numerical Mode Matching Method

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Hydraulic fracturing is a widely used well-stimulation technique to enhance the productivity of gas or petroleum in the wells of tight oil and tight gas since it was first introduced in 1947. In the earth formations of low porosity and low permeability, the fracture is commonly induced hydraulically to increase the exposed area of the producing formation, allowing more hydrocarbon to flow into the wellbore, and ultimately improving the production economics. Thus, it is important to obtain the information about fracture, including length, width, thickness and orientation.

Although the microseismic technique is frequently adopted to recover the parameters of fracture, it cannot provide information about effective area and conductivity of proppant filled in the fracture. To overcome this shortcoming, the induction logging tool is proposed to the fracture detection and estimation. To design an excellent logging tool, some numerical solvers based on the method of moment, finite element method and finite difference time domain method are used to compute the response of electromagnetic waves in the presence of fractures. Although all of them have more flexibility to analyze various kinds of fractures, they are suffering from heavy computational complexity. In this study, we first employ the numerical mode matching (NMM) method to efficiently compute the response of a kind of commonly encountered fracture, which is axis-symmetric with respect to the wellbore center.

The NMM method is a powerful semi-analytical solver which combines a one-dimensional numerical implementation of the finite element method (FEM) in the radial direction and an analytical solution in the vertical direction that can fast compute the induction logging response due to an electric or magnetic dipole embedded in the well with fracture. 1) Unlike the conventional three-dimensional full-wave numerical method, the NMM method only requires 1D mesh for FEM solver along radial direction, resulting in great reduction of the computational time. 2) We implement the NMM code to determine the transmitter-receiver spacing and trajectory of logging tool to effectively and efficiently invert the parameters of the fracture. 3) The numerical simulator can also be used for quantifying the response sensitivity of the fracture with different parameters, such as length, width, thickness and conductivity of filled proppant. The normalized scattering field from the fracture with respect to the incident field is computed to evaluate the detectability of the fracture. We also determine the spatial resolution of the logging tool, i.e., the maximum length can be distinguishable, for different configurations. 4) The casing used to withstand the forces is first modeled together with the fracture to investigate the effect of casing for fracture detection. It reveals that at low frequency range, the normalized scattering field will not be weakened, guaranteeing the fracture is still detectable, though the attenuation of electromagnetic field through the casing is significant.