Monitoring and Imaging the Dynamics and Extent of Hydraulic Fracturing Fluid Movement Using Ground-Based Electromagnetics, with Application to the Eagle Ford Shale

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Abstract

Hydraulic fracturing enables more effective production of hydrocarbons from poorly- or non-producing, low-permeability formations. An important property in hydraulic fracturing, that directly affects well performance, is the distribution of proppant within the formation along the well path. Sufficiently sensitive controlled-source electromagnetic (CSEM) induction techniques are ideal for imaging this distribution due to the conductivity of the fracturing fluid which carries the proppant, and its contrast with that of the surrounding geological medium. We present both modeling and real-world data from the application of CSEM to the monitoring of fluid migration during hydraulic fracturing. First, to predict the expected response using CSEM exploration techniques, we present results from a 1-D numerical model and a 3-D finite element model. The 1-D and 3-D models generate frequency domain responses using Lorentz and Coulomb-gauged potentials, respectively, to solve Maxwell’s equations. We have run multiple scenarios for the 1-D and 3-D cases and show that with current technology it is possible to detect the movement and extent of hydraulic fracturing fluid at practical depths. Finally, real-world data from the Eagle Ford formation in Texas are presented which demonstrate CSEM imaging of migration of hydraulic fracturing fluid into the formation. The transmitter and receivers are located on the surface, eliminating the possibility of interference with fracturing operations due to down-hole instrumentation. The ability to image the areal extent and movement of hydraulic fracture fluid makes high-resolution CSEM an efficient tool to directly assess the effectiveness of a hydraulic fracture stage. Near-real-time processing and delivery of results in the field enables data-informed decision-making before the remaining well stages are fractured.

Introduction

The controlled-source electromagnetic (CSEM) method has a long history in geophysical exploration. It has been used in its inductive mode for application including ore detection in mining and discrimination and classification of unexploded ordnance in munitions response. Much of the CSEM now routinely used in hydrocarbon detection is performed offshore to detect and monitor resistive reservoirs based on galvanic mode excitation. Adapting CSEM technology for onshore oilfield applications presents new challenges.

CSEM works best when there are large conductivity or resistivity contrasts between the target and the surrounding medium. Hydraulic fracturing presents a promising area for CSEM technology. There is a known depth interval and a confined volume into which conductive fluids are injected into the surrounding rock. The resulting fluid invasion changes the bulk conductivity of the volume, producing a measureable change in the CSEM response at the surface. It is desirable to model the change in CSEM response and thereby estimate the magnitude of signal change. After modeling, this knowledge is applied in the field and actual signal changes are recorded which, along with other datasets, can be used to interpret the extent of the fracture fluid invasion.