Postprint: Numerical Simulation of Acid Fracturing Stimulation in Carbonate Geothermal Reservoirs Based on THMC Multi-physics Coupling

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Abstract

Reservoir stimulation is a complex physical process involving thermal-hydraulic-mechanical-chemical (THMC) interactions. Due to the effects of high underground stress and temperature, this process is difficult to observe directly. Numerical simulation provides powerful assistance for revealing its reaction laws and kinetic mechanisms, yet existing numerical studies seldom consider full coupling of all physical fields, particularly rock damage induced by hydraulic fracturing in the near-wellbore region. This study proposes a novel numerical model that simulates acid transport and reaction, fracture initiation and propagation, and heat conduction processes through fully coupled THMC multiphysics and rock damage. The chemical field is primarily coupled with the seepage field and stress field by altering natural fracture aperture, while the damage field is characterized through tensile or shear failure based on the Mohr-Coulomb criterion. The model is validated against analytical solutions, previous experimental studies, and numerical investigations. By comparing with conventional hydraulic fracturing simulation results, the influence of acid-etching-induced changes in natural fracture aperture on the heat extraction performance of injection wells is investigated. The results demonstrate that acid etching effectively enhances heat exchange efficiency; rock damage increases permeability and porosity around the wellbore, which creates a larger heat exchange region, thereby expanding the heat acquisition range and improving heat extraction temperature. Additionally, this study conducts sensitivity analyses on parameters including natural fracture number, injection temperature, and in-situ stress difference. The research findings can provide scientific guidance for the stimulation and enhancement of carbonate geothermal reservoirs.

Full Text

Preamble

Modeling Research of Acid Fracturing in Carbonate Geothermal Reservoir Based on a Coupling THMC Simulation

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Abstract

Reservoir stimulation is a complex physical process involving coupled thermal-hydraulic-mechanical-chemical (THMC) interactions. Due to the influence of high underground stress and temperature, this process is difficult to observe directly. While numerical simulation provides a powerful tool for revealing its reaction patterns and dynamic mechanisms, existing numerical studies rarely consider full-physics field coupling, particularly rock damage induced by fluid fracturing in the near-wellbore region. This study proposes a novel numerical model that simulates acid transport and reaction, fracture initiation and propagation, and heat conduction through fully coupled THMC multiphysics and rock damage. The chemical field couples with the flow and stress fields primarily by altering the aperture of natural fractures, while the damage field is characterized by tensile or shear failure based on the Mohr-Coulomb criterion. The model is validated against analytical solutions, previous experimental data, and numerical studies. By comparing with conventional hydraulic fracturing simulation results, we investigate the influence of acid-etching-induced changes in natural fracture aperture on heat extraction performance from injection wells. The results demonstrate that acid etching effectively enhances heat exchange efficiency; rock damage increases permeability and porosity around the wellbore, creating a larger heat exchange zone, thereby expanding the heat source capture range and improving extraction temperature. Furthermore, this study conducts sensitivity analyses on parameters including natural fracture density, injection temperature, and in-situ stress differential. The research findings provide scientific guidance for stimulation and enhancement of carbonate geothermal reservoirs.

Keywords: acid fracturing; multiphysics coupling; rock damage; numerical simulation

Note: Figure translations are in progress. See original paper for figures.