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Advancements in Hydraulic Fracturing Simulation Considering Complex Natural Fracture Distributions

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Hydraulic fracturing, involving the injection of highly pressurized liquid into a well to break up bedrock formations, is a widely employed method for stimulating unconventional reservoirs, such as shale oil, shale gas, and enhanced geothermal systems (Gandossi & Von Estorff, 2013). Natural fractures play a crucial role in shaping stimulated reservoir volume and significantly impacting subsurface liquid production. Due to the scarcity of details on natural fractures, most research primarily focuses on regularly distributed fractures and their influence on the hydraulic fracturing process. However, these regular patterns differ significantly from actual fracture systems.

This study employs a lattice Boltzmann-discrete element method (LBM-DEM) (Galindo-Torres, 2013) to simulate the hydromechanical behavior during hydraulic fracturing (Chen & Wang, 2017, Chen et al., 2020). Additionally, we delve into the intricacies of natural fracture systems through the discrete fracture network method, incorporating these fractures into the LBM-DEM scheme. We consider two key geometrical parameters of discrete fracture networks: mean orientation and position clustering. Natural fractures are mimicked by adjusting the relative bond strength between particles. From the previous study (Zhu et al., 2023), we found that the heterogeneity of fracture strengths, injection rate, and viscosity is essential for the fracture initiation and propagation process. Therefore, in this work, we also consider different degrees of heterogeneity and injection rates under low viscosity conditions. A Taguchi design is adopted to perform orthogonal numerical tests to reduce computation time.

Preliminary observations yield several conclusions: i. Heterogeneity of bond strengths profoundly influences fracture formation and the complexity of resulting fracture systems, specifically their intensity. Extremely low bonding strength can lead to many local fractures disconnected from the primary hydraulic fracture, which, however, cannot contribute equally to production compared to the primary hydraulic fracture initiated from the perforation. ii. Higher injection rates, coupled with low viscosity, intensify fluid leakage, potentially generating extensive local fracture clusters. iii. Connectivity of hydraulic fractures increases with their propagation, positively correlating with production rates. However, production rates are more closely tied to the total area of the primary fracture cluster. iv. In the studied cases, the geometries of fractures exhibit weak correlations with connectivity and final production rates. The clustering effect tends to enhance the connectivity of formed fracture networks and, subsequently, the final production rate.

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