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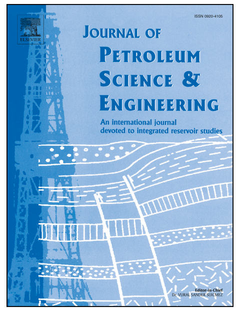

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fThe Effect of Heterogeneity on Hydraulic Fracturing in Shale

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Abstract
Modelling hydraulic fracturing processes in shale oil and gas development remains a major challenge for industrial applications. The omission of heterogeneity inherent in the shale matrix may be one of the causes for the divergence between simulated fractures and those in reality. To elucidate the effects of heterogeneity on hydraulic fracturing, a workflow is developed for generating heterogeneous fields of hydraulic and geomechanical properties based on relatively easily available compressional wave velocity and shear wave velocity. After that, the workflow is implemented in our thermo-hydro-mechanical simulator for hydraulic fracturing. With the integrated simulator, the following are investigated: the effect of heterogeneity and the interactive effects of heterogeneity with other factors, i.e., *in-situ* stress gradient and stress shadow, the significance of different levels of heterogeneity, and the impact of various injection rates. The simulation results showed that these factors could have either synergetic or competitive effects under different circumstances. Also, different levels of heterogeneity result in different patterns of fractures' geometry. According to our study, a heterogeneity field with a large coefficient of variation (CV) and medium correlation length (CL) turns out to develop fractures of the most complex patterns. Moreover, the high injection rate leads to neutralization of the influence of heterogeneity through the averaging effect of intense fracturing. The study leads to better understandings in the mechanism of hydraulic fracturing process under complicated factors such as heterogeneity, interactive effects, fracturing strategies, and both modes of rock failure. This study may shed light on future research on hydraulic fracturing and possible applications in practice as well as some improvements in designing hydraulic fracturing simulator.

Introduction
Hydraulic fracturing (HF) is one of the most important reservoir stimulation technologies for the recovery of oil and gas from shale, as well as development of geothermal systems. Due to the ultralow permeability of shale (nano-darcy for matrix), successful performance of hydraulic fracturing can dramatically enhance the recovery rate of shale gas and oil. Thus, simulation of hydraulic fracturing requires accurate representations of the geometry and trend of hydraulic fractures underground. However, current studies (Hofmann et al., 2014; Li et al., 2016; Li et al., 2017; Suarez-Rivera et al., 2006; Yuan et al., 2015) on simulations of hydraulic fracturing frequently model hydraulic fracturing

Notes for abbreviation: hydraulic fracturing (HF), compressional wave velocity (V_p), shear wave velocity (V_s), Young's modulus (E), Poisson's ratio (ν), tensile strength (T_0), friction coefficient (μ), cohesive strength (C), uniaxial compressive strength (UCS), porosity (ϕ), permeability (k), Sequential Gaussian Simulation (SGSIM), Vertically Transversely Isotropic (VTI), Stonley tube wave velocity ($V_{stonley}$), thermo-hydro-mechanical (THM), conventional linear elastic fracture mechanism (LEFM), two dimensions (2D), three dimensions (3D), coefficient of variation (CV), correlation length (CL), Brittleness Index (BI)