Cracking pattern of shale reservoirs by water, CO_2 and nitrogen fracturing

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Abstract

Waterless fracturing technology as an alternative solution in hydraulic fracturing is important to the development of unconventional gas resources such as shale gas and coalbed methane, but the mechanism of gas-fracturing-induced damage evolution in shale gas reservoirs has not been well studied. Particularly, the impacts of the interactions between solid deformation and fracturing fluid, in-situ stress state, and bedding plane or pre-fractures on the fracture initiation and propagation as well as fracture pattern are not clear. This paper proposes a numerical simulation model to investigate the damage evolution and fluid flow of shale reservoirs during water, CO_2 or nitrogen fracturing process. This numerical model considers the heterogeneity of shale, the mechanical properties of bedding plane and different damage modes through the mechanical-seepage-damage coupling analysis. A microcrack-based damage criterion is developed to judge the propagation and interaction of cracks until shale element failure. After failure, the fractured element is isotropic and the variations of its mechanical property and permeability are expressed by a reduction coefficient. The shale bedding is expressed by the strength and fracture toughness of this shale bedding element. Energy is calculated in each loading step and is divided into volume expansion energy and shear deformation energy. This model is verified by shale fracturing experiments and used to explore the combination impacts of stress ratio and bedding angle as well as the energy evolution in the fracturing process. The numerical simulations show that tensile damage is the major cause for fracturing crack initiation and propagation. The damage evolution, deformation anisotropy and energy evolution are related to microcrack growth. Permeability is associated with damage evolution and increases significantly after shale failure. Both stress ratio and bedding plane have significant impacts on the damage evolution and mechanical responses of shale and nitrogen flow. The impacts of bedding angle on water, CO_2 or nitrogen fracturing vary with stress ratio and fluid type. The fracturing process of shale can be analyzed through the energy accumulation and release.

Keywords: Shale reservoirs, Waterless fracturing, Damage evolution, Bedding plane, Energy evolution.