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A novel coupled mechanical, fluid-thermal approach to modelling of hydraulic fracturing in rocks

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Abstract:

Hydraulic fracturing is a stimulation technique to increase the productivity of petroleum, gas, or heat reservoirs in which rocks are fractured by a pressurized fluid. The economic production from petroleum, gas, and heat reservoirs greatly depends on the effectiveness of hydraulic fracturing stimulations that are affected by a realistic description of brittle crustal rocks with fractures. Rocks are very complex heterogeneous and anisotropic structures due to naturally existing pre-discontinuities, such as joints, faults, veins, and bedding planes which are different in dimensions, evolution, and arrangement. The formulation of a realistic numerical model is crucial to describing the key coupled phenomena in the development process of hydraulic fracturing and to optimize it (e.g. pumping rate/cycles and fluid viscosity) for magnifying a gas extraction from deep shale layers, which is now at about 5% and rarely exceeds 15%.

The innovative mechanical-fluid-thermal model based on the coupled DEM/CFD approach[1] was developed to track in detail the liquid/gas fractions in pores and fractures with respect to their different geometry, size, location and temperature. Although the multiphase fluid flows along the fluid flow network[2], a very extending mesh of both domains was generated: the discrete (constant) domain and the continuous fluid domain. Due to a coherent mesh (grid) of both domains, the finite volume method (FVM) was used to solve the energy conservation equation. The conservation of energy equation was supplemented with cubic state equations (Peng-Robinson) for each of the phase. The Peng-Robinson equation of state was suitable to describe behavior of gas phase that behaved as super-critical fluid for so high pressures (over 70 MPa). The liquid phase for pressures applied in hydraulic fracturing was still below the critical point. The impact of different temperatures of the injection fluid on the hydraulic fracture initiation and propagation was studied. Local fluid temperature variations were observed. The fluid temperature lower than the average temperature of the rock matrix, a local increase of the fluid temperature (even above rock matrix temperature) was obtained due to rapid volume changes of pores and very intensive advection, typical for very high pressure differences.

[1] Krzaczek, M., Kozicki, J., Nitka, M. and Tejchman, J. (2020) Simulations of hydro-fracking in rock mass at meso-scale using fully coupled DEM/CFD approach. *Acta Geotechnica* 15(2), 297-324.

[2] Krzaczek, M., Nitka, M. and Tejchman, J. (2020). Effect of gas content in macro-pores on hydraulic fracturing in rocks using a fully coupled DEM/CFD approach. *Int J Numer Anal Methods Geomech*. 1–31, https://doi.org/10.1002/nag.3160.