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DFIT Before Closure Analysis in Naturally Fractured Rocks: Implementing FDEM-DFN Approach

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Summary

Pressure diagnostic analyses such as G-function and log-log plots are used to better understand rock mass in actual field conditions and provide key hydraulic fracture design model and formation parameters. Wellbore pressure available from pre-frac tests such as diagnostic fracture injection tests (DFITs) can be used for this purpose (Barree, 2019). During DFIT a few cubic meters of fresh water is injected to well over a short period of time to induce representative hydraulic fractures (HFs) within the formation. After shut-in, the opened fractures tend to close back because of the induced elastic stresses and most importantly pressure decline driven by leak-off process. Careful analyses of wellbore pressures after shut-in can be used to first estimate fracture closure pressure p_c, as the datum pressure, which divides the pressure diagnostic analysis into before closure analysis (BCA) and after closure analysis (ACA). Hydraulic parameters of formations such as reservoir pressure and transmissibility are estimated through ACA, which demand an unreasonable long falloff times for establishing the associated flow regimes in low permeability shale rocks (Barree, 2019). Here, we merely focus on BCA typically utilized to infer rock fracturing process, fracture dimensions, formation critical pressures, net pressure, ISIP, leak-off coefficients etc. (Nolte and Smith, 1981, Economides and Nolte, 2000, Barree et al., 2009).

Most of the diagnostic pressure relations are based on some limiting assumptions, linear elastic homogenous rock, symmetrical bi-wing fracture propagation with constant compliance after shut-in or normal leak-off process (Barree and Miskimins, 2016, Mohamed et al., 2019). Such ideal behaviours, however, are not necessarily the case in shale rocks since they contain natural fractures (NFs), which make up a discrete fracture network (DFN) within rock formations. DFNs are key geological structures determining the hydro-mechanical characteristics of rock mass under various conditions (Hopkins et al., 1987, Pyrak-Nolte and Nolte, 2016). As a fluid-driven propagates in a naturally fracture rock it may deviate from the preferred propagation direction, be arrested or cause shearing along the critically oriented NFs (Warpinski and Teufel, 1987), that influence pressure response of wellbore during pumping and after shut-in (McClure et al., 2015). Also, the interactions between HFs and NFs can derive the establishment of abnormal fluid-loss processes such pressure dependent leak-off (PDL) or as transverse/transferred storage during hydraulic pressurizing of the formation (Economides and Nolte, 2000, Liu and Ehlig-Economides, 2015).

In this paper the applicability of standard pressure diagnostic analyses for use in naturally fractured rocks is investigated by producing synthetic pressures by implementing a fully coupled numerical method. Output from the numerical study will be used to better analyse post-frac production, optimize stimulation plan, calibrate log data, assess the risk of induced seismicity among others.

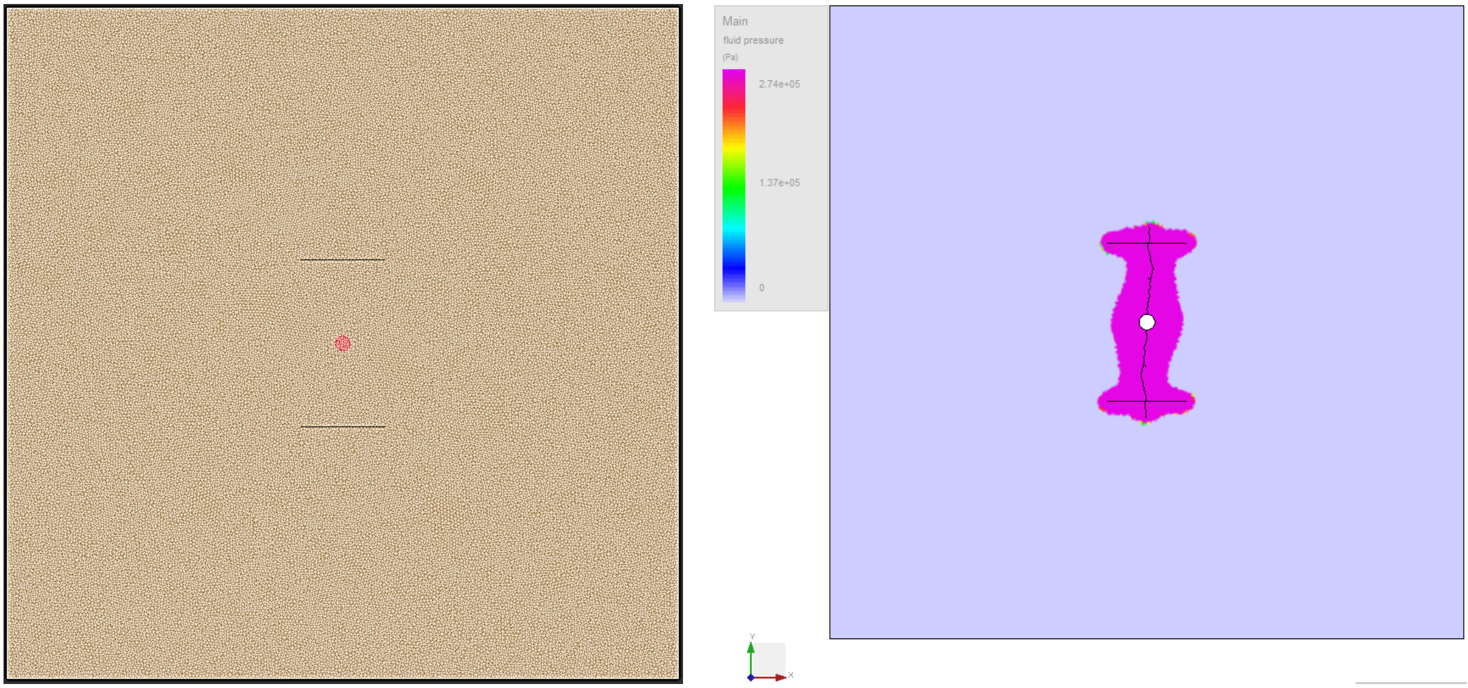
FDEM–DFN

The hybrid Finite-Discrete Element Method (FDEM) and Discrete Fracture Model (DFN) implemented in IRAZU software are utilized to simulate pressure response of shales during DFITs. The FDEM method, developed by Munjiza et al. (1995), combines the elastic finite element stress analysis with the discrete element method, that enables the evolution of rock fracturing processes to be tracked. In a 2D FDEM simulation, the modelling domain is discretized into a mesh consisting of three-node triangular finite elements. Four-node interface elements are embedded between the edges of all adjacent triangle pairs to model fluid flow and fracturing process in a quasi-brittle porous rock. In additional, pre-existing fractures can be defined using a DFN capability, that is composed of crack elements with mechanical properties that differ from the surrounding rock. Two type of mechanical discontinuities can be specified: (i) features with degraded strength and stiffness parameters; (ii) purely frictional discontinuities. A hydraulic discrete fracture network can be incorporated where flow channels between elements have different hydraulic properties compared to the surrounding rock. Also, fluid flow through DFNs can be allowed to model the condition of rough fracture surfaces, or deactivated to replicate fluid flow condition through mineralized NFs (Geomechanica-Inc., 2020).

In recent years, FDEM–DFN has been used for a variety of rock mechanics applications (Lisjak et al., 2014, Latham et al., 2013, Lei et al., 2014, Lei et al., 2015, Lei et al., 2016, Gao et al., 2016). AbuAisha et al. (2017) and AbuAisha et al. (2019) used the FDEM–DFN approach to investigate in more detail the interaction between fluid-driven fractures and pre-existing fractures and induced microseismicity.

Results and discussions

Complex fracturing processes influence the determination of closure pressure, net pressure, fracture dimensions among others from pressure diagnostic analyses. Furthermore, leak-off processes in naturally fracture rocks deviate from normal trend where pressure-dependent leak-off (PDL), in case of rough fracture surfaces, or fissure-dependent or accelerated fluid loss, for mineralized NFs might occur (Economides and Nolte, 2000). In this paper, various NFs configuration and hydro-mechanical characteristics are incorporated into the numerical modelling, e.g., see Figure 1, to study NFs influences on DFIT interpretation and check the validity of standard pressure diagnostic relations.



(a) (b)

Figure 1. (a) Configuration of NFs in the vicinity of wellbore; (b) The evolution of HF and crossing through NFs.

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