Tight Gas Reservoir (TGR) Fracture Model

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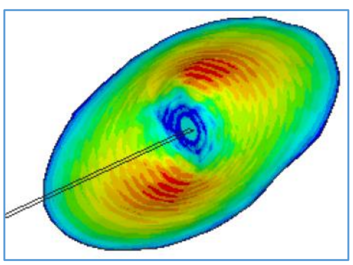
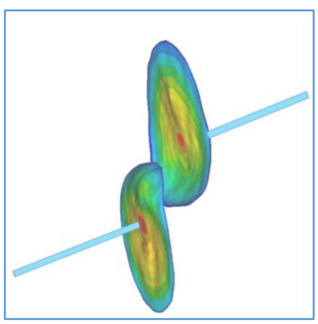
Method

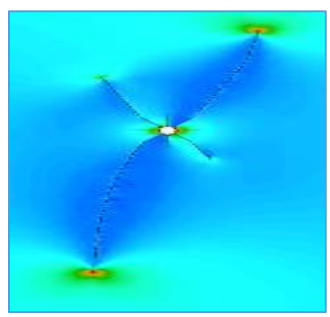
The work outlined here follows a combined Finite Element-Discrete Element (FE/DE) approach and allows complex hydraulic fracture network growth simulations through the use of a novel geometry based fracture insertion algorithm. The new approach lies in the fact that hydraulic fractures can follow arbitrary fracture paths in 2D/3D simulations; as dictated by stress state, material properties and heterogeneity rather than the topology of the finite element mesh. Further to this, only regions near the hydraulic fracture tip are adaptively re-meshed which ensures that stress concentrations can be effectively captured without the need for a computationally expensive global re-mesh. The models are poro-elasto-plastic, fully coupled with fluid flow and proppant transport/embedment. The computational modelling employs a nonlinear coupled finite element system that comprises of a quasi-static explicit solution scheme for the update of mechanical stresses and discrete fracturing of the quasi-brittle rocks based on continuum damage mechanics. An implicit solution scheme is used to simulate flow/transport inside the hydraulic fracture as well as porous flow within the formation. The fully numerical methodology allows simulation of: (i) 3D hydraulic fracture propagation with curved paths; (ii) multi-stage & multi-well fracture interference (with proppant transport, stress shadows, flow back, fracture closure/embedment and production); (iii) discrete fracture network (DFN) stimulation with synthetic microseismicity and hydraulic fracture interactions; (iv) mixed mode discrete tensile and continuum shear formation damage (v) hydraulic fracture propagation under the influence of near wellbore stress field. Figures below illustrate some of the capabilities outlined and within the framework of the methodology as described above.



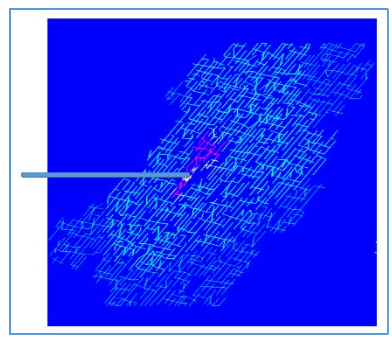
Fracture curving in 3D (contours showing aperture)



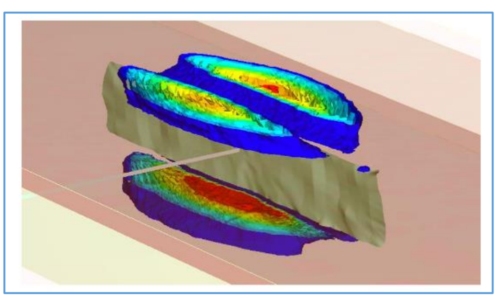
Frac-Frac interference in 3D



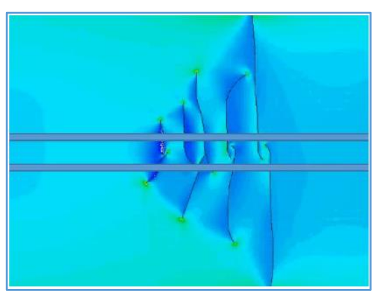
Frac propagation under the effect of wellbore stresses (plan view) (least compressive stress contours)



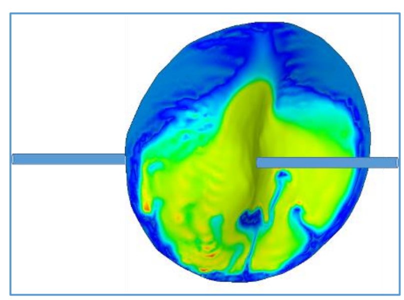
DFN Stimulation (Plan view) (HF pressure contours)



Iso-contours of HF induced formation shear damage in over/under-burden layers



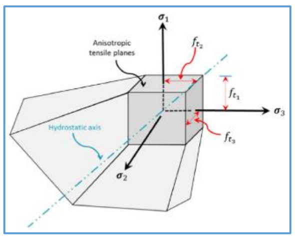
Multi-well fracture interference (plan view)



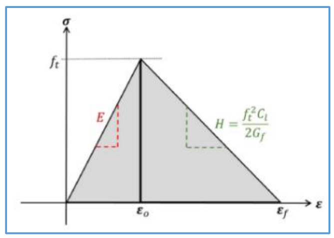
Proppant distribution inside a curving fracture (assuming gravity)

Propagation Criteria

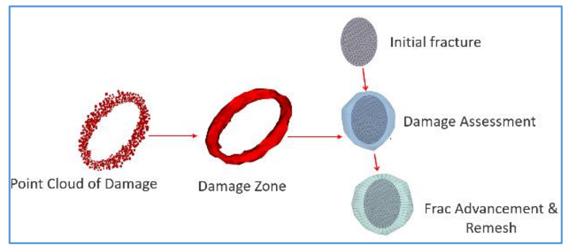
The material model combines Mohr-Coulomb shear and Rankine tensile failure criteria. For the tensile behavior, a typical continuum extensional uniaxial stress-strain response for a brittle material is considered. The pre-yield response is governed by elasticity parameters such as the Young's modulus E. Only 2 parameters are necessary to characterize the post-yield material response, its tensile strength f_t and fracture energy G_f. To ensure objective energy dissipation in arbitrary meshes the softening slope H is regularized for any element size. Once the material has reached its tensile strength, it softens and fails as the fracture energy is released and Mode-I damage front propagates in a direction perpendicular to the most tensile principal stress. In 3D, this requires a multi stage fracture insertion process. A prediction stage determines the length and direction based on accumulated damage and strain softening that the elements have gone through. A collection of all damaged elements (point cloud of element integration points) then form the damage zone. By using the geometry based predictions from the damage analysis/assessment (i.e. extent and direction) remeshing and discrete fracture insertion is performed as the fracture advances and propagates from multi wells/stages in 3D.



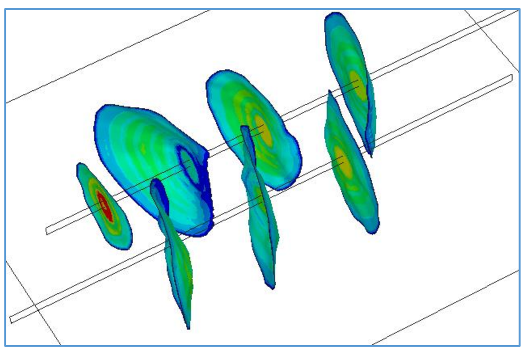
Mohr Coulomb with Rankine Tensile Corner



Softening and Failure for Rankine Fracture



Fracture Insertion in 3D



Fracture propagation & interaction in 3D between multiple horizontal wells

Unique Features

Elfen tgr technology combines advanced rock constitutive models and continuum damage mechanics with discrete fracturing in arbitrary 3D directions; offering true 3D fracture interaction and propagation capabilities. Models are poro-elasto-plastic, fully coupled with fluid flow within the propagating fractures as well as within the matrix. This allows simulating full cycle of stimulation-production-refracturing-production operations. Stress shadows, hydraulic-natural fracture interactions (DFN stimulation), fracture closure, proppant transport, multi-well interference, formation damage, flow back, mixed mode failure are all accounted for in the analysis to provide a unique and realistic representation of the subsurface hydraulic fracture network growth.

References

1. Profit M., Dutko M., Yu J.,Armstrong J., and Parfitt D. (2016) "Application of the state of the art hydraulic fracture modelling techniques for safe-optimized design and for enhanced production" ARMA Paper No: 16-792
2. Profit M., Dutko M., and Yu J. (2015) "Developing a Framework to Simulate the Hydraulic Fracturing of Tight Gas Reservoirs Based on Integrative Adaptive Remeshing and Combined Finite/Discrete Element Approach" ARMA Paper No: 15-293