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Transient Matrix-Fracture Flow Modeling for the Numerical Simulation of the Production of Unconventional Plays using Discrete and Deformable Fracture Network Model

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Summary

The use of horizontal wells and and massive hydraulic fracturing operations has become very popular particularly in low permeability unconventional reservoirs. Designing stimulation jobs requires an integrated knowledge of the reservoir (lithology, mechanical properties, fracture properties, PVT, etc), needing calibration and scenario simulation capacities. In this paper we aim to demonstrate the advantages of using an innovative simulation model adapted to fractured unconventional reservoirs and integrating all detailed known information about the reservoir.

Characterization of unconventional reservoirs implies the conciliation of several scales, integrating a potentially large fracture information database. It normally results in the modeling of a large Discrete Fracture Networks (DFN) that include many fracture planes. Coupling of such DFN’s to reservoir modeling packages often use up-scaling methods, resulting in models which in turn are simulated using extensions of classical dual continuum models. Using a realistic example inspired from field data, we show how the construction of a fracture model using a consistent Discrete and Deformable Fracture Networks (DDFN), tractable for multiphase flow reservoir simulations, can help describing a complex fracturing case.

A field natural fracture system and a propagating fracture network corresponding to the hydraulic fracturing process, calibrated on the BHP and microseismic cloud, is input as a specific unstructured dual discretization into a reservoir model.

This explicit description of the fracture geometry is coupled to a non-discretized matrix refinement function accounting for matrix heterogeneities, well-adapted to the dynamic pressure behavior observed in such reservoirs. A generalized multiple interacting continua formulation (named “transient transfer influence function”) is used within the matrix medium, allowing the simulation of a longer transition period, typical of many unconventional reservoirs, thus improving matrix contribution during hydraulic fracturing.

This DDFN approach is able to computationally handle 300,000’s of fractured coupled to a fluid flow simulator. The platform on which it was implemented could be extended to multiphysics problems, essential for unconventional resources (Ricois et al., 2016).

Fracture modeling

Among many methodologies representing observations, the DFN (Discrete Fracture Network) approach has gained popularity, since it naturally resembled natural observations. Current efforts (Mayerhofer et al. 2010; Weng et al. 2014; McClure et al. 2015) concern the development of adapted grid schemes for coupled geomechanical/reservoir models. These models discretize explicitly main flow paths created by fractures instead of using idealized representations such as the universal sugar-box double media representation. (Karimi-Fard et al. 2004-2006; Yan et al. 2013; Ding et al. 2014).

The lack of satisfying methods allowing a compromise between realism and efficiency has inspired our approach, trying to describe and reproduce main observations at reservoir scales in a comprehensive and predictive engineered way. We know that important variables describing fractures (locations and mechanical properties) are uncertain while hydraulic properties during time, such as conductivities and apertures, are not known (inferred at best). Fluid flow production is yet enabled by fractures, which are highly conductive, offering recoveries first, acting as relaying conduits from the porous matrix to the well.

Thus we choose to develop a flow model scheme enabling multiphase flow simulations while preserving the fracture dispositions described and calibrated during characterization and to introduce geomechanical aspects (simple but realistic) to account for fracture creations and reactivations. The resulting Discrete and Deformable Fractured Network DDFN methodology (Delorme et al. 2013, 2016; Baroni et al. 2015; Khvoenkova et al. 2015) is applicable for simulations of both hydraulic stimulation and production of unconventional plays.

DDFN – Gridding, suitable for both production and stimulation.

Within the DDFN, fractures are two parallel tortuous planes of small storativity, defined by an aperture, negligible in comparison to fracture characteristic length. An independent pseudo fracture conductivity accounts for laminar fluid flow, following Darcy formalism. Each fracture doesn't need to be finely discretized as transient flow in the fracture medium will be very rapid (few seconds) at the observation scale. We place unknowns only at fracture intersections (Khvoenkova & Delorme 2011). The idea is to consider each intersection as a source term which is reasonable if intersections reflect enhanced zones. Transmissivities along fractures (only one plane relying 2 intersections) are estimated in each fracture plane respecting the isopressure lines. The final fracture network mesh is K-orthogonal leading to a conforming mesh, which facilitates simulations. The main advantage of the approach is the node number reduction which makes feasible simulations of both the stimulation jobs (Delorme et al, 2016) and well productions using the same discretization.

The heterogeneous porous matrix continuum is less permeable than primary continuous fracture system. Pressure gradient in the matrix space, in the vicinity of each fracture, requires assessing correctly the exchange surfaces, thus using an adapted scale. Our choice is to use an octree delineation whose refinement is conditioned by the fracture density. The final octree is equilibrated at the second order.

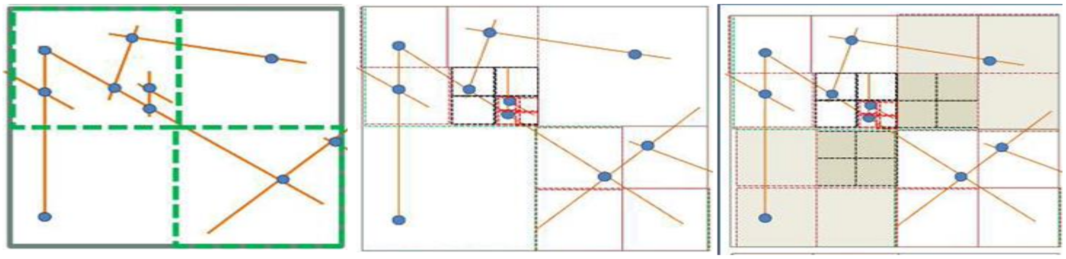

Figure 1 - Schematic description of the matrix mesh. It shows how the octree is spacially adapted to fracture density

Transient transfer influence function.

For unconventional reservoirs producing at a constant flowrate, pressure drawdown starts at the matrix/fracture interface and moves further into the matrix, as time progresses, very slowly. This transient state can last for several hundred days for reservoirs of very low matrix permeability. To improve transient flow simulation, Pruess, (1983, 1993) and Wu et al. (1988) investigated the multiple interacting continuum concepts (MINC). The MINC method treats inter-porosity flow in a fully transient way by computing gradients which drive inter-porosity flow at the matrix-fracture interface. Matrix blocks are discretized into a sequence of nested volume elements, defined on the basis of distance from the fracture faces, named proximity functions. Analytical expressions of proximity functions can be written assuming regularly 2D or 3D shaped matrix blocks.

In our case, the proximity functions or namely the transient transfer influence functions are computed in each cell of the matrix medium octree providing a distribution of matrix volume fractions with respect to the nearest natural fracture face distance. As pressure gradients are very high in the vicinity of fractures, it is very important to finely discretize the matrix surrounding the fracture to capture it accurately. Therefore a logarithmic x-axis is used for the histogram of matrix volume fractions.

We developed a recursive algorithm to compute the transient transfer influence functions. Each matrix octree cell is subdivided (factor of 2) in each direction (8 sub-cells in three dimensions). This procedure applies to each of the subdivided cells until no fracture intersects them or if the length of the largest diagonal of the cell is below a threshold value. If the subdivision stops, the volume of the subdivided cell is associated to the distance between its center of mass and the nearest fracture plan (Fig. 2).

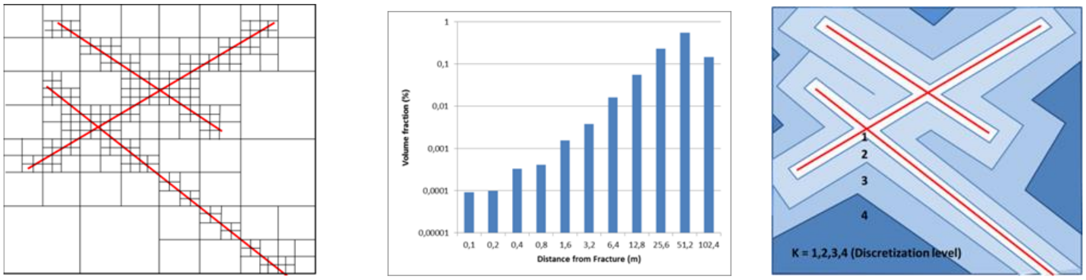

Figure 2 - Transient transfer influence function procedure.

Given a chosen width of each nested interacting continua, the transient transfer influence function of each matrix octree cell is used to compute the numerical discretization scheme. The number and the width of nested interacting continua are chosen independently of the transient transfer influence function discretization.

Application to the Wolfcamp discrete fracture model.

The full DDFN approach has been applied to a real field (Wolfcamp). The initial DFN geometry is set from the known parameters of the field, based on a geological analysis and propagating fracture distribution process governed by the geological model (Khvoenkova et al 2015). The fracturing treatment in Well 7H is simulated, the BHP well pressure and microseismic are both history-matched for one stage of hydrofrac then predicted for the rest. The work-flow underlying the study represents an effort to integrate all information and test the predictibility, leading to a complex DFN best served by the DDFN approach.

The DDFN output of the hydraulic fracturing simulation process gives a comprehensive SRV with updated spatial properties and its dual discretization is directly used to simulate the production of the treated well. The 387446 resulting fracture planes (Fig 3. left) and the surrounding matrix are discretized with 162221 matrix cells (matrix octree of level 6) and 354598 fracture intersection nodes (Fig 3. right). This black-oil reservoir simulation of 1-year production history period takes 8 to 10 hours to complete on a parallel PC cluster.

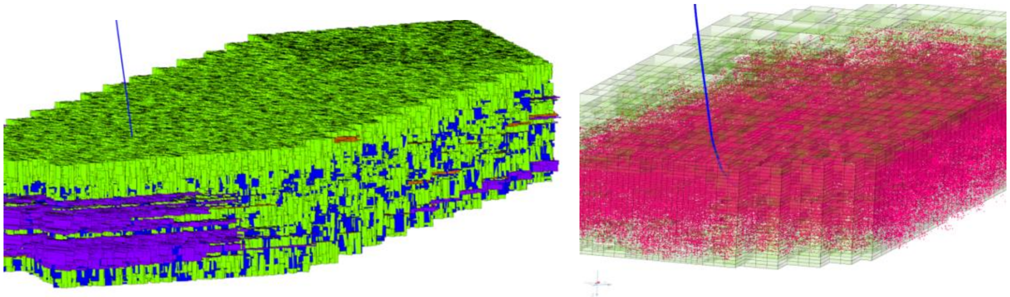

Figure 3 – DFN geometry (left) and dual discretization (right) of the Wolfcamp model.

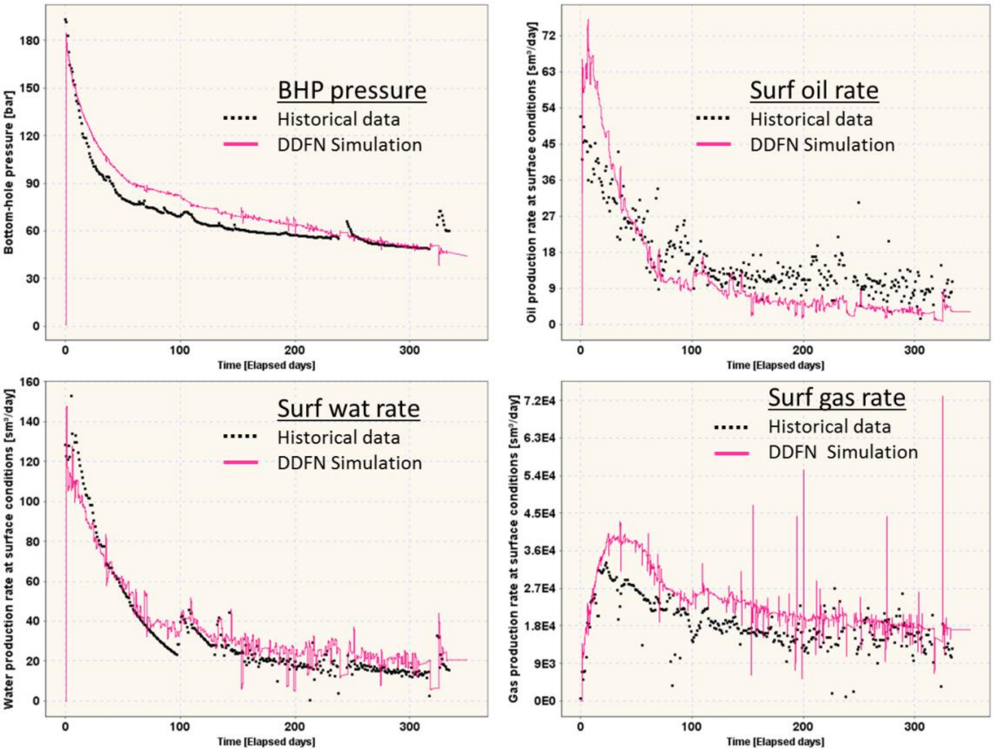

Figure 4 - History match of the Wolfcamp reservoir.

Results and discussion.

The DDFN approach produces satisfying history match results. Matching the gas production can be difficult and would propably require the introduction of corrections for bubble point suppression and non-darcy flow in our model. Capillary effects are also very important as the system is mixed toward oil-wet. The transient pressure affects gas formation and it has a strong impact in this case. The use of transient transfer function is mandatory to accurately model flows between matrix and fractures. In this case, five nested interacting continua were generated, distributed in the following sequence (0,05;0,1;0,2;1;5) away (in meter) from the fracture, thus enabling the simulation of a representative pressure gradient in the matrix medium. As the DDFN model integrate all the knowledge at all scales, once calibrated, it can be use to produce a reliable forecast of the production of unconventional reservoirs. Thus, different scenarii for the stimulation jobs can easily be run to optimise the hydraulic fracture design and improve the ultimate recovery.

Conclusions

The developed DDFN approach fills a gap within the industrial capacity to use DFN models for the design or characterization of hydraulic fracture stimulations. Owing to research performed for almost a decade, we think that the new proposed model can, at a large scale, integrate most information concerning fracture network and natural fracture observations, and thus address the problem of complexity.

The recurrent problem of the transient effects, observed in unconventional reservoirs, and poorly accounted for in classical simulators using classical dual media - structured or unstructured - has been solved, using adapted proximity functions, which doesn't penalize computational times while creating realistic pressure gradients close to the fracture faces.

Computational times for up to 300,000 fractures are very competitive.

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