HF propagation with Proppant injection using the FEM with zero-thickness interface elements.

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Hydrocarbon recovery from unconventional reservoirs consisting of deep low-permeability rock layers, often relies on the technique of Hydraulic Fracture. In this technique, wells are usually drilled vertically down to the desired depth and then turned 90˚ to a horizontal section which develops within the target layer in the direction perpendicular to the lowest principal stress. It is in this horizontal section that vertical hydraulic fractures are created along planes perpendicular to the well axis. This is achieved by first perforating the well lining and surrounding rock in several directions around the well axis (“cluster“), then installing packers, normally encapsulating a group of clusters at a time (“stage“), and finally injecting the fracturing fluid. In order to maintain the fractures open after the end of the injection, once the fractures have started propagating sand or similar proppant particles may be mixed with the injection fluid. Proppant will then spread over the opening fractures with the intention that it remains as evenly distributed as possible within the fractures. The definition of parameters such as cluster spacing, number of clusters in a stage, distance between wells, injection sequence, duration and intervals of proppant injection, particle sizes, etc. is normally supported by numerical calculations using commercial software fully integrated within the workflow of the O&G industry. However, these tools may be sometimes based on simplifications [1] and often not fully transparent about the underlying asumptions and methodologies.

This motivates the development of in-house codes based on rigurous mechanical principles for solid, fluid and proppant transport in a full 3D environment. In this paper, a model is presented which is based on the FEM with zero-thickness interface (“cohesive”) elements, which are pre-inserted along the potential fracture paths. Their mechanical behavior is governed by a fracture-based constitutive model integrating normal (mode I) and shear (mixed mode + frictional) behavior. Fluid flow takes place through the porous continuum, but especially along fractures, the transmissivity of which is drastically affected by opening via the cubic law [2,3]. Proppant transport within the rock mass takes place exclusively along the fractures which are open beyond a threshold related to particle diameter, and is governed by a non-linear advection-diffusion equation, combined with the gravity effect (Stokes deposition velocity). The numerical implementation is based on massive MPI parallelization using PETSC libraries and HDF5 i/o files, with very good scalability.

In the presentation, the main aspects of the model are briefly described, and examples of application are shown including single and multiple fracture with stress shadow interaction. If the clusters are too close, fractures cannot develop freely and show alternate patterns in vertical and horizontal directions. Proppant distributions depend heavily on particle density and size, as well as on proppant injection strategies. The overall model therefore turns out a valuable tool to understand complex field observations and help Engineering design.

References

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