EGU21-13704, updated on 26 May 2022
https://doi.org/10.5194/egusphere-egu21-13704
EGU General Assembly 2021

Modelling hydraulic fracturing with the J-integral

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Hydraulic fracturing plays a central role in engineering fractured reservoirs. To simulate the propagation of “dry” fractures, the J-integral has been a standard technique. Its superior accuracy at coarser resolutions make it particularly attractive, especially for reservoir-scale simulations. However, the extension of the J-integral to hydro-mechanical simulations of fluid-driven fracturing has not received the same attention or success. In particular, while several studies have highlighted the capacity of the method in simulating viscosity-dominated propagation, detailed investigations into the performance of the method are still missing. In this work, we find that the extent of hydraulic fracturing is typically overestimated by the J-integral in the viscosity-dominated propagation regime. A finite element analysis is conducted which sheds light on the source of the error. The case is put forward that the inaccurate numerical solution for fluid pressure is *exclusively* responsible for the loss in accuracy of the J-integral. With this new understanding, the J-integral is reformulated to minimise its dependence on inaccurate fluid pressures, bypassing the aforementioned sources of error. The reformulation, termed the J_V-integral, is both simple to implement, and general to the numerical method. Within the framework of finite elements, a propagation algorithm using the novel J_V-integral is subsequently constructed with two distinct abilities compared to the original J-integral. The first is an increased ability to capture the viscosity-dominated regime of propagation at significantly coarser resolutions. Finite element simulations conducted at various levels of refinement detail the promising results relevant to hydro-mechanical simulations at reservoir scale. The ability of the method in simulating the toughness regime remains as performant as the original J-integral. The second, is the ability of the J_V-integral in extracting the propagation velocity of the fracture; a feature particular to methods arising from hydraulic fracture mechanics. Consequently, the method demonstrates an inherent advantage when converging on the fracture length, requiring significantly fewer iterations compared to the original formulation. Fundamentally, the velocity obtained via the J_V-integral has the potential to be used in combination with front-tracking schemes like the implicit level set method. As a result, the J_V-integral appears to be a promising method when simulating hydraulic fracturing in geoenergy applications and beyond.