A fully coupled fracture model for the accurate analysis of the leak-off phenomenon in hydraulic stimulation

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ABSTRACT

Reservoirs in which hydrocarbons are trapped in rock formations with very low permeability are referred to as unconventional reservoirs. These reservoirs require some form of well stimulation to enable economical recovery rates. One such stimulation technique is hydraulic fracturing, by which highly permeable fracture pathways are created by injecting viscous fluids at high pressures [1]. Although the process of hydraulic fracturing has been well known since 1950s, it has gained traction in recent decades due to the technological advancements such as horizontal drilling, multi stage fracturing, slick-water fracking fluids. Recently, this technique has also been applied to design engineered geothermal systems by creating artificial fracture networks in hot rock formations [2].

Over the years, several models have been presented to analyse the crack growth in rock formations. The Enhanced Local Pressure (ELP) model, which has been developed by Remij et al. [3], uses the partition of unity method to allow for crack propagation in arbitrary directions, irrespective of the underlying finite element mesh. The method has been used to study crack growth near existing fault and the creation of crack formations [4]. A drawback of this approach is that the current model for the leak-off limits its application to near impermeable rocks, such as shales and granites.

In this paper, we present an extension of the ELP model with a fully coupled leak-off model, which can be used in both near impermeable rocks as well as in low permeable (sandstone, limestone, dolomites) rocks. Using Biot's theory of poro-elasticity, we model the mechanical behaviour of a fully saturated porous medium and obtain the solid deformation in the grains and the fluid pressure in the pores. We use an extended finite element approach to model cohesive fracture. Finally, we consider an additional degree of freedom to model the pressure inside the fracture due to the injection of fluid and its leak-off into the porous medium. As leak-off from the fracture into the porous medium becomes vital in low permeable rocks, an accurate leak-off model which is fully coupled with the fluid flow in the porous medium is proposed. This model is based on the analytical solution for 1-D Terzaghi consolidation equation. The effect of this improved leak-off model on single fracture propagation and a fracture network formation is studied with numerical examples.

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