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Simulating the hydraulic stimulation of multiple fractures in an anisotropic stress field applying the discrete element method

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Key to a successful exploitation of deep geothermal reservoirs in a petrothermal environment is the hydraulic stimulation of the host rock to increase permeability. The presented research investigates the fracture propagation and interaction during hydraulic stimulation of multiple fractures in a highly anisotropic stress field. The presented work was conducted within the framework of the OPTIRISS project, which is a cooperation of industry partners and universities in Thuringia and Saxony (Federal States of Germany) and was funded by the European Fond for Regional Development. One objective was the design optimization of the subsurface geothermal heat exchanger (SGHE) by means of numerical simulations. The presented simulations were conducted applying 3DEC (Itasca™), a software tool based on the discrete element method.
The simulation results indicate that the main direction of fracture propagation is towards lower stresses and thus towards the biosphere. Therefore, barriers might be necessary to limit fracture propagation to the designated geological formation. Moreover, the hydraulic stimulation significantly alters the stresses in the vicinity of newly created fractures. Especially the change of the minimum stress component affects the hydraulic stimulation of subsequent fractures, which are deflected away from the previously stimulated fractures. This fracture deflection can render it impossible to connect all fractures with a second borehole for the later production. The results of continuative simulations indicate that a fracture deflection cannot be avoided completely. Therefore, the stage alignment was modified to minimize fracture deflection by varying (1) the pauses between stages, (2) the spacing's between adjacent stages, and (3) the angle between stimulation borehole and minimum stress component.
An optimum SGHE design, which implies that all stimulated fractures are connected to the production borehole, can be achieved by aligning the stimulation borehole at an angle of 45° to the minimum stress component. Furthermore, longer pauses between injection stages and higher spacing between stages promote more consistent fracture geometries.
The simulation results indicate that fractures tend to propagate in random directions away from the stress shadows of existing fractures, even for a stage spacing of 200 m. This fracture deflection may result in undesirable fracture propagation directions or produce shortcuts between fracture stages. A careful planning of the stage alignment seems the most promising procedure to counteract/control fracture deflection.