Geophysical Research Abstracts
Vol. 20, EGU2018-1844, 2018
EGU General Assembly 2018

Hydraulic anisotropy in simulated sheared fractures: a statistical analysis with comparison of aperture determination methods

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Developing and operating deep geothermal reservoirs require a comprehensive understanding of the hydraulic properties of rocks. Rock features such as fractures have a crucial impact on hydraulic conductivity and then on the geothermal reservoir sustainability. Thus, the detailed understanding and appropriate quantification of single fracture flow is a major step forward in modelling flow in fractured reservoirs.

Therefore, simulations are needed to perform statistical analysis on the identified hydraulic conductivity patterns. Indeed, statistical methods are essential to ensure that the simulated data are correctly interpreted and that the identified patterns are meaningful and do not simply occur arbitrarily. In order to investigate these fluid patterns, we outline here a numerical multi-tool protocol to generate a database of 100 2D-fractures for which the fluid flow is simulated. Flow is calculated using two definitions of the cubic law based either on the vertical (AV) or the effective aperture determination method (AE). Moreover, to study the effect of shearing, 10 different shear displacements (offsets) were applied to each fracture. Thus, our results are based on the simulation of 1000 different fracture configurations.

We apply this workflow to study the impact of aperture determination methods on the flow anisotropy which refers to the dependence of the mean flow on the orientation of the pressure gradient. Similarly, we examine the link between shear displacement and flow anisotropy. Here we find higher fluid flow perpendicular to the offset direction (FPe) than parallel (FPa) to it. This result is in good agreement with literature. In addition, we observe an increase of the anisotropy ratio (FPa over FPe noted K) by using AE instead of AV. This difference of the ratios increases with shearing and is more than tripled for an offset of five discretization elements. Indeed, the impact of geometrical features from the surface is differently weighed according to the aperture determination method. This leads to variations of the K values for a same shear displacement using AV or AE. Furthermore, we note that K decreases steadily for AV as the offset increases whereas this ratio decreases less or even remains constant with an increasing offset for AE. These heterogeneous trends show that increasing shearing is not directly linked to an increase of the fluid flow anisotropy according to the aperture definition. This new observation is contrary to previous observations in the literature.

Finally, with a simplified fluid flow model modified to insert the surface roughness parameters with AE and a statistical analysis of the obtained results, we demonstrate that the relationship between flow anisotropy and shearing is affected by the aperture determination. This shows that the studied relationship is biased by the method to determine spatial features and therefore both results from AE and AV should be considered to interpret the fluid flow behavior.