Effective medium approach for analysis of natural fracture activation trends during hydraulic fracturing

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The paper presents an approach for estimating positions and spatial orientations of natural fractures, which become active during the operation of hydraulic fracturing a formation, which is characterized by the existence of natural fractures. Alongside with methodology of the approach, we present a simplified numerical model of hydraulic fracture in a naturally fractured rock mass.

Although hydraulic fracturing is one of the most useful methods of enhancing oil recovery, there are still some problems with predicting its efficiency using numerical or theoretical models. In the current study, we focus on the problem of hydraulic fractures in naturally fractured rock masses. Despite the fact that there are many developed methods of modeling the interaction between hydraulic fracture itself and natural fractures surrounding it, there is a problem with input data regarding natural fractures. To use the full potential of such models, one has to know the positions and geometrical properties of each natural fracture, which may seem to be impossible in some cases. To solve this problem, we try to implement an effective medium approach to study the interaction between hydraulic fracture and the rock mass characterized by effective properties of natural fractures instead of using discrete fracture networks.

To construct such an effective model, we implement a special approach. First of all, we consider natural fractures in the rock mass as realizations of inelastic strain accumulated during the whole stress state history. Usage of non-associated plastic flow law with friction hardening to describe the mechanical behavior of a naturally fractured rock makes it possible to determine spatial orientations and positions of natural fractures emerging and developing in the rock mass during the history of its stress state. At the same time, the current stress state of the rock mass determines which fractures will be activated during external impact, e.g., hydraulic fracturing of the considered rock. To be precise, natural fractures' mechanical behavior is mostly governed by normal and shear stresses acting on their planes and friction. In the current study we used a recently developed analytical solution for predicting spatial orientations of all natural fractures which are critically stressed in an arbitrary stress state.

A numerical study of hydraulic fracture propagation in a naturally fractured rock mass was performed using the extended finite-element method. Natural fractures were related to accumulated inelastic strain instead of being introduced as discrete fractures. Non-associated plastic flow law was developed based on laboratory experiments carried out for rock samples from a particular oil field characterized by the existence of natural fractures. Although such an approach makes it impossible to precisely predict geometry of hydraulic fracture, it allows estimating some general trends in positions and spatial orientations of natural fractures, which get activated due to stresses induced by hydraulic fracture propagation or fluid filtration. Stereonets with spatial orientations of critically stressed fractures were constructed for different stages of hydraulic fracture propagation and different domains of rock mass surrounding it. It was shown that there is a well-established relationship between the obtained trends in natural fractures activation and the approaches developed for microseismic monitoring. The proposed approach may be used for the optimization of hydraulic fracturing, e.g., for enhancing hydraulic connectivity of natural fractures in the vicinity of the main hydraulic fracture.

It should be noted that the aforementioned analytical solution for critically stressed fractures' spatial orientations is not limited to hydraulic fracturing. One is capable of implementing it to different problems of hydrocarbon reservoirs development, including prediction of induced seismicity caused by changes in fields of effective stresses.

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