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A novel approach for calculation of proppant embedment-compaction and stress-dependent permeability of hydraulic fractures in shales

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The shale gas reservoirs have become the hotspot of development in petroleum industry due to its abundant fossil energy. However, the extreme low in-situ permeability makes it difficult to extract this unconventional resource. As the result, in shale reservoir development, the hydraulic fracturing technology is widely used to create fracture network in shale formation and facilitate the transport of hydrocarbons to wells. Nevertheless, fracture permeability decreases sharply and continuously due to reduction of effective stress. Especially for some clay rich reservoirs with low hardness, it is a challenging problem to maintain fracture permeability. Therefore, it's of great significance to predict the behavior of proppant embedment and compaction within hydraulic fractures. The objective of this work is to establish a reasonable model to determine the essential controls on permeability of hydraulic fractures in shale formation under stress condition. The theoretical model is derived from Hertz contact deformation principle, considering proppant packs embedment as well as the arrangement and deformation of proppant packs within fractures. Each parameter in the model has a specific physical meaning without the need to introduce any empirical constant. The predictions from the proposed model agree well with the available experimental data presented in the literature. The results show that fracture permeability during pressure loading process is a function of effective stress, rock lithology parameters, proppant packs size, and proppant packs lithology parameters, etc. During the early pressure-loading period, proppant packs embedment, structural deformation and primary deformation work together, and permeability decreases dramatically with increase in effective stress. When the effective stress increases up to a certain value, the structural deformation is stable whereas proppant packs embedment and the primary deformation continues to grow, and the permeability variation tends to be smooth and steady. This work presents an accurate and efficient analytical model to quantify the permeability of hydraulic fracture in shale formation under stress condition. The proposed model reveals more details of the mechanisms that affect the deformation behavior in hydraulic fractures and offer some insights for the parameter design and optimization during the execution of hydraulic fracturing.