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Hydraulic Fracture Propagation under Varying In-Situ Stress Conditions of Reservoirs

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Abstract

In-situ stress state in deep reservoirs is highly variable due to many factors and it markedly influence the propagation behavior of hydraulic fractures. The direction and extent of hydraulic fracture propagation are predominantly controlled by the in-situ stress state of reservoirs. We conducted distinct element method-based numerical simulations to explore the behavior of hydraulic fracture propagation and containment under varying in-situ stress conditions and fluid injection rates. The results revealed that even a small contrast of minor principal stress between pay-zone and adjacent bounding zones can cause a significant hydraulic fracture containment. Simulations performed under different injection rates showed that the hydraulic fracture containment is also influenced by the injection rate and higher injection rates tend to increase the hydraulic fracture penetration into the adjacent bounding zones. Overall, the results of the present study generally suggest that the fracture propagation during hydraulic fracturing is not an unconstrained event as one would imagine and natural barriers such as varying in-situ stresses, which are common in deep reservoirs, often limit fracture propagation to a certain finite extent. In addition, operational conditions such as fluid injection rate can be selected appropriately to control the hydraulic fracture propagation into unproductive bounding strata.

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Keywords: hydraulic fracturing; in-situ stress; numerical modelling

1. Introduction

Hydraulic fracturing is used to enhance oil and gas recovery from unconventional reservoirs since few decades ago. The same technique is also used in applications such as geothermal energy extraction, CO2 geo-sequestration

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and management of high stresses encountered with deep mining [1]. The direction and extent of hydraulic fracture propagation play important roles in the economics of oil and gas production projects. Therefore, a thorough understanding of the geometrical nature of hydraulic fracture propagation under reservoir conditions is imperative for successful hydraulic stimulation designs.

In-situ stress field in deep reservoirs is highly variable in nature. This cannot be explained by the effects of gravity and topography alone, for which the role of tectonic stresses is undeniable [2]. The state of the in-situ stress is one of the primary factors to be considered in design and implementation of hydraulic fracturing treatments [3, 4, 5]. Two fracture propagation models have been widely used for hydraulic stimulation designs of oil and gas reservoirs – (1) KGD model [6, 7] and (2) PKN model [8, 9]. Each model was developed based on different simplified assumptions and with certain limitations meaning that the user should carefully apply them with a sound understanding of these stipulated conditions. PKN model assumes an elliptical fracture cross section in the vertical plane and the formation stiffness is concentrated in the vertical planes perpendicular to the direction of fracture propagation while KGD model assumes a rectangular cross section in the vertical plane and the stiffness of the formation is concentrated in the horizontal plane [10]. The numerical simulation program of this study is compatible with the assumptions of the KGD model and thus further discussions are only limited to the KGD model. As Meyer [11] states, for a hydraulic fracture with unit height, the fracture length (l_t) and aperture width at the wellbore (w_t) can be expressed as shown in Equations 1 and 2, respectively, assuming zero leak-off into the formation (see Figure 1).

$$l_t = a\left[\frac{Q^3 G}{(1-\upsilon)\mu}\right]^{\frac{1}{6}} t^{\frac{2}{3}} \tag{1}$$

$$w_t = b\left[\frac{Q^3(1-\upsilon)\mu}{G}\right]^{\frac{1}{6}} t^{\frac{1}{3}} \tag{2}$$

where, Q is the constant injection rate, G is the shear modulus, υ is the Poisson’s ratio, μ is the viscosity of the fluid, t is the time and a, b are constants.

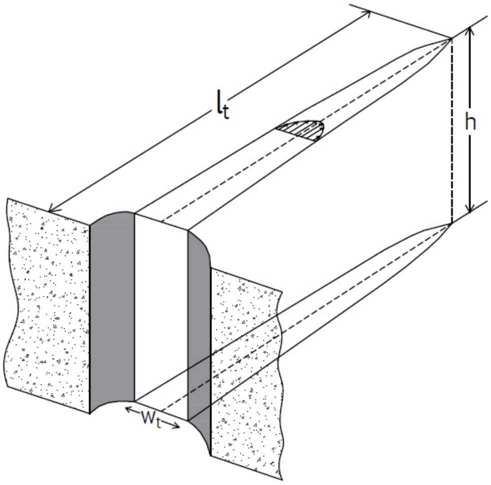

Fig. 1. KGD constant height fracture model (modified after [12]).

According to Meyer [11] and Geertsma and Haafkens [13], for a hydraulic fracture that propagates along both directions from a wellbore a is 0.48 and b is 1.32, and for a hydraulic fracture that propagates only along one