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Effect of residual opening on the inflow performance of a hydraulic fracture

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ABSTRACT

The problem of steady state fluid production from a hydraulic fracture subject to remote compressive stresses is considered. The fracture is partially filled with proppant and the distribution of proppant is symmetric about the wellbore. The unpropped fracture segments can provide additional length to the fracture and highly conductive pathways for fluid flow. However, these fracture segments are susceptible to closure due to the confining stresses. The governing equations for fracture opening and fluid flow into the fracture are solved numerically using the Gauss–Chebyshev quadrature technique and a sensitivity study is conducted to investigate the effect of the residual opening of the unpropped fracture segments on the performance of a hydraulic fracture. The range of governing parameters is identified for which the residual opening of a fracture leads to production enhancement.

1. Introduction

Hydraulic fracturing is a widely applied technique in oil and gas industries for enhancing the productivity of wells drilled in low-permeability reservoirs (Valkò & Economides, 1995). Among many parameters, the increase in well productivity due to the fracturing treatment also depends upon the residual opening of the fracture which incorporates the length, width and shape of the fracture during the production stage. Typically, a fracture is only partially filled with proppant due to the plugging of proppant particles between the asperous fracture walls or their sedimentation during the proppant injection stage. Partial filling of a hydraulic fracture can lead to a complex residual opening profile during the production stage (Bortolan Neto & Kotousov, 2012b; Bortolan Neto & Kotousov, 2013) and complete closure of the unpropped fracture segments. Such effects have not been incorporated in the existing analytical solutions for fluid production from hydraulic fractures (Diyashev & Economides, 2006; Entov & Murzenko, 1994; Kanevskaya & Kats, 1996; Valkò & Economides, 1995). The presence of unpropped fracture segments with much higher conductivity than the sand-filled or propped fracture may significantly alter the inflow performance of the fracture and subsequently the production rate. It is of practical importance to investigate the effect of residual opening of a partially filled fracture on the well productivity. In particular, the range of governing parameters for which fracture residual opening has a significant impact on production must be identified (McLennan et al., 2008; Mukherjee et al., 1995).

In this paper, a hydraulic fracture which is partially filled with proppant is modelled as a straight crack opened by a rigid inclusion and subject to remote compressive stresses as illustrated in Fig. 1. The solution to the mechanical problem is obtained by using the distributed dislocation technique (Bilby and Eshelby, 1968, chap. 2). This solution for the residual opening profile is substituted into the governing equations for fluid production to evaluate the effect of residual fracture

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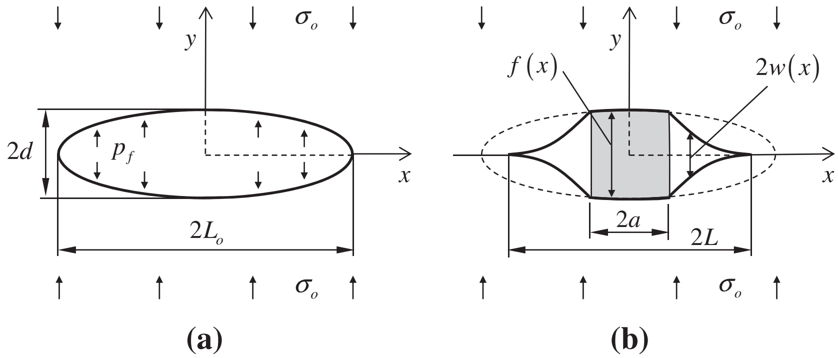

Fig. 1. Schematic representation of a partially filled hydraulic fracture as a 2D crack opened by a rigid inclusion and subject to remote compressive stresses (a) The initial crack geometry prior to the injection of proppant and (b) The residual opening profile of the crack upon the removal of the fracturing fluid pressure.

opening on the inflow performance of a hydraulic fracture. The main objective of the simplified modelling is to evaluate the effect of the residual opening on the production rate and to investigate general tendencies of the numerical solution by conducting a case study.

2. Mathematical model

Consider a fracture of initial length $2L_o$ and maximum opening $2d$ as shown in Fig. 1(a). The fracture is partially supported by a proppant pack and subject to remote confining stresses. Due to the confining stresses, closure of the un-propped segments of the fracture occurs and the equilibrium crack length $2L$ needs to be determined (Fig. 1(b)). The coordinate x is aligned with the length of the fracture and the problem is symmetric about $x = 0$. The symmetry of the problem is utilized in the mathematical model and the governing equations are written over the interval $-L \le x \le 0$.

2.1. Residual opening profile

The opening profile of a crack subject to uniform internal pressure is given by:

$$f(x) = 2d\sqrt{(1 - (x/L_o)^2} \tag{1}$$

The elliptical opening profile defined in Eq. (1) is commonly used to model the opening of hydraulic fractures and is referred as the KGD fracture geometry (Valkò & Economides, 1995). It is used to represent the initial opening profile of the fracture as shown in Fig. 1.

The residual opening profile of a crack opened by a rigid inclusion over $|x| \leqslant a$ can be calculated by considering the following boundary value problem:

$$2w(x) = f(x), \quad |x| \leqslant a, \tag{2a}$$

$$w(x) = 0, \quad |x| \geqslant L, \tag{2b}$$

$$\sigma_{yy}(x, 0) = -\sigma_o, \quad a < |x| < L, \tag{2c}$$

$$\sigma_{xy}(x, 0) = 0, \quad |x| < \infty, \tag{2d}$$

where $2w(x)$ is the residual opening profile and σ_o is the remote confining stress. The sign convention for stress is positive under tension. The unknown equilibrium crack length L is determined using the condition of no stress singularity at the crack tips i.e. $x = \pm L$.

The boundary value problem (2) can be formulated in terms of the function $b(x)$ associated with the edge dislocation density (Hills et al., 1996). The edge dislocation density function $b(x)$ is related to the crack opening as follows:

$$b(x) = -2\frac{dw(x)}{dx}, \quad w(x) = -\frac{1}{2}\int_{-\infty}^{x} b(t)dt. \tag{3}$$

For the coordinate system shown in Fig. 1, the edge dislocation density is an odd function of x i.e. $b(x) = -b(-x)$. Utilising the symmetry of the problem, the following Föppl integral equation can be written for the edge dislocation density function (Kotousov et al., 2013):