Journal of Petroleum Science and Engineering 164 (2018) 164–173

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

journal homepage: www.elsevier.com/locate/petrol

In-situ stresses controlling hydraulic fracture propagation and fracture breakdown pressure

Yushuai Zhang[a], Jincai Zhang[b,*,1], Bin Yuan[c,**], Shangxian Yin[b]

[a] Henan Polytechnic University, Jiaozhuo, Henan, China
[b] North China Institute of Science and Technology, Beijing, Yanjiao, China
[c] University of Calgary, Calgary, Alberta, Canada

ARTICLE INFO

Keywords:
Hydraulic fracture
In-situ stresses
Horizontal stress
Breakdown pressure
Depletion
Fracture curving

ABSTRACT

In-situ stress impact on hydraulic fracturing is investigated to enhance hydraulic fracturing performance. Lithology-controlled lower and upper bounds of the horizontal stresses are proposed, and an improved stress polygon method is presented. This improved method can narrow the area of the conventional stress polygon, particularly in shales; therefore, constrain the in-situ stress estimate. The lithology-controlled stresses indicate that a shale has a higher minimum horizontal stress and can be used as a barrier of the hydraulic fracture propagation when hydraulic fracturing is performed in adjacent sandstones. However, when hydraulic fracturing is performed in a shale oil or gas formation, a stress-barrier formation may not exist on the top or the bottom of the shale reservoir, and this will cause the hydraulic fractures to propagate out of the reservoir zone. We also examine the effects of the maximum and minimum horizontal stresses, shear stresses and depletion on the fracture initiation, breakdown, propagation and containment. Shear stresses cause hydraulic fractures kinking; from this evidence, we find that a horizontal well can be drilled with a certain angle to the minimum stress direction because in most cases the hydraulic fractures eventually curve to the maximum stress direction. In addition, we propose a new method to calculate the fracture breakdown pressure based on fracture mechanics. The proposed method predicts a higher breakdown pressure than the conventional one, which may better estimate the breakdown pressure.

1. Introduction

Hydraulic fracturing is a very important stimulation technology and has been used for about 70 years to enable the operators to produce from the tight and extremely low-permeable reservoirs. In the 1940s, Floyd Farris of Stanolind Oil proposed that fracturing a rock formation through hydraulic pressure might increase well productivity. This was followed in 1947 by the first application of the 'Hydrafrac' process at the No.1 Klepper well in the Hugoton Field, Kansas (Morton, 2013). Hubbert and Willis (1957) found that in-situ stresses control hydraulic fracture initiation and propagation: the minimum stress depends primarily on where the fracture is initiated, and the maximum stress dominates which direction the fracture propagates to. Perkins and Kern (1961) applied Sneddon and Elliott's solid mechanics solution (Sneddon and Elliott, 1946) to the oil and gas industry for hydraulic fracturing applications (PKN model). They treated the borehole as a circular fracture with an internal pressure inside the borehole and an isotropic far-field principal stress exerted to the fracture. This assumption neglects the effect of the anisotropy of the minimum and maximum horizontal stresses. Geertsma and de Klerk (1969) presented another 2-D analytical solution (KGD model) for a linearly propagating fracture by assuming that the fracture height is much greater than its length. Again, the KGD model neglects the effect of the difference of the in-situ stresses (the vertical, minimum and maximum horizontal stresses). In-situ tests of hydraulic fracturing and then the fractures mined back indicate that the in-situ stresses control hydraulic fracture containment (Warpinski et al., 1982). These tests also demonstrate that the in-situ stress contrast between the reservoir and a bounding layer is one of the most important factors controlling the fracture height. The advancements in multi-stage fracturing and long horizontal drilling techniques have made the hydrocarbon production from shale plays successful (King, 2010). Various simulation models have also been developed for evaluation of hydraulic fracturing performance

* Corresponding author.
** Corresponding author.
E-mail addresses: zhangjincai@yahoo.com (J. Zhang), bin.yuan@ucalgary.ca (B. Yuan).
[1] Now with Sinopec Tech Houston, Houston, TX, USA.

https://doi.org/10.1016/j.petrol.2018.01.050
Received 19 October 2017; Received in revised form 23 January 2018; Accepted 24 January 2018

0920-4105/© 2018 Elsevier B.V. All rights reserved.

(e.g., Yuan et al., 2015; Yuan et al., 2017, 2018, Yuan and Moghanloo, 2017; Clarkson, 2013; Wang et al., 2017; Zheng et al., 2018).

Microseismic measurements during hydraulic fracture operations also show the importance of in-situ stresses and find that shear stresses and the depletion effect on the in-situ stresses play very important roles on hydraulic fracture propagation (Dohmen et al., 2013, 2014). Recent numerical modeling also shows that in-situ stresses have an important effect on hydraulic fracture propagation (e.g., Zhang et al., 2017). Therefore, in-situ stress impact on hydraulic fracture propagation and operations performance should be more emphasized, not only in research, but also in the planning and operations stages. This paper will investigate some aspects of the in-situ stress effects on hydraulic fracturing.

The fracture breakdown pressure, closely related to in-situ stresses, is a very important parameter for hydraulic fracturing planning and operations. However, the industry still does not have a good method to predict it. In this paper, we will examine the effects of in-situ stresses (particularly the maximum and minimum horizontal stresses and shear stresses) on the fracture initiation, breakdown, kinking, propagation and containment. We will also study the fracture breakdown pressure to find a new solution.

2. In-situ stress controlling hydraulic fracture propagation

2.1. In-situ stress regimes and hydraulic fracture propagation

It is commonly assumed that the in-situ stresses include three mutually orthogonal principal stresses in the subsurface; typically, they are the vertical (overburden) stress, the maximum and minimum horizontal stresses (σ_V, σ_H, σ_h). Based on Anderson's faulting theory, three stress regimes can be used to describe in-situ stress states (e.g., Zoback et al., 2003), i.e.:

(1) Normal faulting stress regime (NF). In this case, the vertical stress drives normal faulting, and fault slip occurs when the minimum stress reaches a sufficiently low value. In this stress state, the vertical stress is the greatest principal stress, i.e. $\sigma_V \geq \sigma_H \geq \sigma_h$.
(2) Strike-slip faulting stress regime (SS). In this case, the vertical stress is the intermediate principal stress, i.e. $\sigma_H \geq \sigma_V \geq \sigma_h$.
(3) Reverse (or thrust) faulting stress regime (RF). In this case, the vertical stress is the least principal stress, i.e. $\sigma_H \geq \sigma_h \geq \sigma_V$.

Hydraulic fracture propagation is highly dependent on the in-situ stress state. Hydraulically induced fractures should be formed approximately perpendicular to the least principal stress (Hubbert and Willis, 1957). Therefore, in tectonically relaxed areas (normal faulting and strike-slip stress regimes), the hydraulic fractures should be vertical, whereas, in tectonically compressed areas (reverse faulting stress regime), they should be horizontal (Hubbert and Willis, 1957). Hydraulic fracture propagation is also dependent on the direction of the minimum horizontal stress and the horizontal well orientation (Abass et al., 1992). Fig. 1 shows the hydraulic fracture propagation directions versus drilling directions in normal and strike-slip stress faulting regimes. If a horizontal well is drilled in the minimum horizontal stress direction, hydraulic fractures may be optimal for contacting more reservoir rocks. If a horizontal well is not drilled in one of the principal stress directions, then shear stresses will be generated in the wellbore and perforation tunnels, causing hydraulic fractures kinking. Therefore, fully understanding in-situ stresses and stress regimes can help to optimize horizontal well drilling and completion.

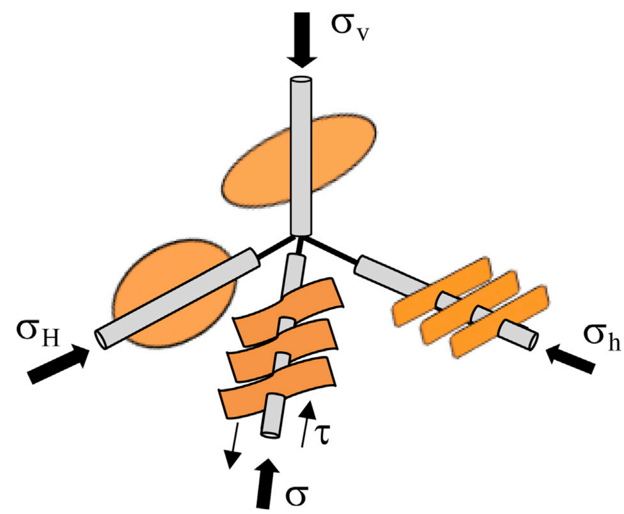

Fig. 1. Propagation directions of hydraulic fractures versus drilling directions in normal and strike-slip faulting stress regimes.

2.2. Lithology-dependent in-situ stress polygon

To constrain in-situ stresses, the stress polygon based on stress regimes has been used for decades (e.g., Zoback et al., 2003; Sibson, 1974); however, it needs the input of the coefficient of friction of the fault which is not easily obtained. Conventionally, it is assumed that the coefficient of friction of the fault is a constant (e.g., $\mu_f = 0.6$–0.7) based on Byerlee's law (Byerlee, 1978). This assumption may cause a large uncertainty in in-situ stress estimation in shale formations (as illustrated in Fig. 2) because of the coefficient of friction in the fault of shales has a much lower μ_f, e.g., $\mu_f = 0.15$–0.32 in smectitic shales (Saffer and Marone, 2003). The shales and other ductile rocks (such as shale plays) may have much lower μ_f values than those in the sandstones; therefore, the minimum horizontal stress is larger in shales (Zhang and Zhang, 2017) and a new stress polygon method needs to be used to constrain in-situ stresses in shales.

Zhang and Zhang (2017) verified that the horizontal stress calculated from the uniaxial strain method is the minimum value or the lower bound of the minimum stress. Therefore, this stress can be used as the lower bound horizontal stress to draw the stress polygon. This lower bound of the minimum horizontal stress (σ_h^{LB}) can be expressed in the following equation:

$$\sigma_h^{LB} = \frac{\nu}{1-\nu}\left(\sigma_V - \alpha p_p\right) + \alpha p_p \quad (1)$$

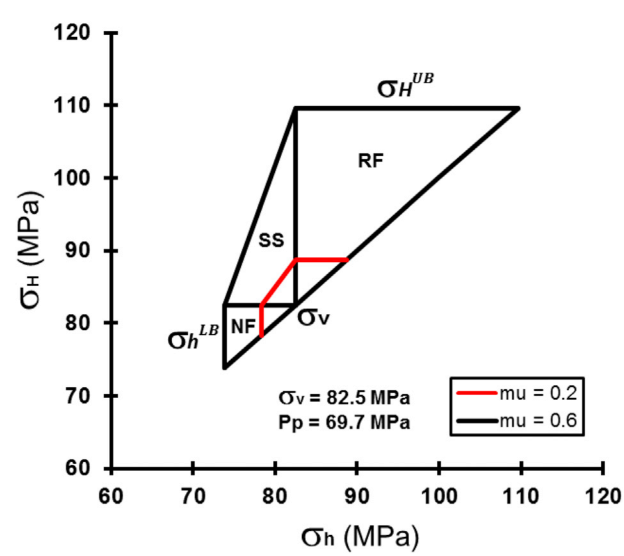

Fig. 2. Stress polygon plots for two coefficients of frictions of the fault (mu) $\mu_f = 0.6$ (in a sandstone) and $\mu_f = 0.2$ (in a shale) showing the in-situ stress uncertainty (Zhang and Zhang, 2017).

Download English Version:

https://daneshyari.com/en/article/8125296

Download Persian Version:

https://daneshyari.com/article/8125296

Daneshyari.com