Journal of Unconventional Oil and Gas Resources 9 (2015) 54–64

Contents lists available at ScienceDirect

Journal of Unconventional Oil and Gas Resources

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

Investigation of the influence of stress shadows on horizontal hydraulic fractures from adjacent lateral wells

N. Zangeneh *, E. Eberhardt, R.M. Bustin

Earth, Ocean and Atmospheric Sciences, University of British Columbia, Vancouver, British Columbia, Canada

ARTICLE INFO

Article history:
Received 14 June 2013
Revised 31 July 2014
Accepted 4 November 2014
Available online 15 November 2014

Keywords:
Unconventional hydraulic fracturing
Stress shadow
Adjacent lateral wells
Simulfrac and zipperfrac
Numerical modeling
Discontinuum model

ABSTRACT

Production efficiency from low permeability shale gas reservoirs requires techniques to optimize hydraulic fracture (HF) completions. This may be complicated by the presence of high horizontal in-situ stresses that result in horizontal HF, for example in parts of the Western Canadian Sedimentary Basin in northeastern British Columbia. One strategy involves the simultaneous or near simultaneous hydraulic fracturing of adjacent lateral wells to maximize the fracture network area and stimulated reservoir volume. However, changes to the in-situ stress field caused by an earlier HF on subsequent HF are not accounted for in traditional hydraulic fracturing design calculations. Presented here are the results from a set of transient, coupled hydro-mechanical simulations of a naturally fractured rock mass containing two wellbores using the discontinuum-based distinct-element method. The results demonstrate the influence of stress shadows generated by a HF on the development of subsequent HF from an adjacent well. It is shown here that these interactions have the potential to change the size and effectiveness of the HF stimulation by changing the extent of the induced fracture around the secondary well. Also, the influences of in-situ stress and operational factors on the stress shadow effect are investigated and their effects on different operational techniques are studied.

Introduction

Unconventional shale gas reservoirs require technology-based solutions for optimum development. The successful exploitation of these reservoirs has relied on technological advances in lateral drilling, multiple stage completions, innovative fracturing, and fracture mapping to engineer economic completions. Towards this purpose, hydraulic fracturing (HF) serves as the primary means for improving well productivity. In northeastern British Columbia along the western margin of the Western Canadian Basin, world-class shale gas plays such as the Montney and Horn River are estimated to hold over 1200 trillion cubic feet of natural gas (B.C. Ministry of Energy and Mines, 2012). Recoverable resource numbers are dependent on advances associated with lateral drilling techniques and hydraulic fracturing procedures, especially given the high horizontal stress ratios in this part of the basin, almost all of which involve strike-slip or thrust fault stress regimes (Wikel, 2011).

Simulations demonstrate that shale with ultra-low permeability requires an interconnected fracture network, which comprises both natural and induced fractures, to obtain a reasonable recovery factor (Warpinski et al., 2008). Hence, multiple HF from one or more lateral wellbores provide an effective means to maximize the fracture network surface area. Recent studies have suggested that simultaneous hydraulic fracturing of adjacent wells results in better well performance than fracturing adjacent wells sequentially. This has evolved into the drilling of multiple lateral wells from adjacent pads on leases in the Montney and Horn River in an attempt to maximize the stimulated volume of reservoir rock through HF. However, changes to the in-situ stress field caused by an earlier HF on subsequent HF, referred to here as "stress shadows", are not accounted for in conventional HF design calculations.

Stress shadow effects are potentially critical to the design of multiple lateral well HF treatments, and thus multi-stage single wells or adjacent lateral wells should not be designed identical to a single lateral well treatment. This study describes a series of numerical experiments investigating the influence of stress shadow on HF treatments between adjacent lateral wells. The analysis is carried out for different completion scenarios to investigate their effect on the propagation of horizontal hydraulic fractures. The changes in fluid pressure and corresponding effective stress changes around each wellbore during different completion techniques are examined. The effects of adjacent lateral well hydraulic fracturing on stress shadowing are also studied as a function of the

* Corresponding author at: Schlumberger, 1325 South Dairy Ashford, Houston, TX 77077, United States. Tel.: +1 7132135574.
E-mail addresses: neda@eos.ubc.ca, NZangeneh@slb.com (N. Zangeneh).

http://dx.doi.org/10.1016/j.juogr.2014.11.001
2213-3976/

reservoir depth, in-situ stress ratio, wellbore spacing, and injection rate.

Influence of stress shadows arising from neighboring hydraulic fractures

Altered-stress fracturing is a concept whereby a HF in one well is affected by another in a nearby adjacent well. One of the earliest studies was done by Warpinski and Branagan (1989), where they presented field tests and finite element calculations examining the modified stress field around a wellbore. Termed "stress shadows", the disturbance of the stress field is especially important when considering a multiple stage HF design. When sequential HF stages are initiated in lateral wells that are close to one another, the stress perturbation caused by one may affect subsequent hydraulic fractures.

Different authors have examined stress perturbation in multi-stage fracturing from lateral wellbores to optimize lateral completion techniques. For example, Fisher et al. (2004) presented results investigating the influence of multi-stage HF with a wellbore separated into equal sections in Barnett shale using microseismic data. They showed that stress diversion is present when the reservoir has been supercharged by a previous fracture treatment stage. They also showed that stress in this region is increased due to locally higher fluid pressures, which influence subsequent stages. Morrill and Miskimins (2012) performed a series of numerical simulations of stresses around a fracture tip in a multiple hydraulically fractured lateral well in order to determine the optimal fracture spacing to avoid stress field interactions and allow for predictable fracture geometries and conductivities in shale gas. Daneshy et al. (2012) reported the results of pressure measurements carried out in four lateral wells where two of the wellbores served as observation wells throughout the project while the other two were actively being fractured. The motivation for these measurements was the detection of HF shadowing created through their extension. They showed that field measurements can be incorporated into the development plan and concluded that real-time monitoring gives the operator time to optimize the treatment and modify future designs accordingly.

A recent consideration regarding stress shadow effects is when closely spaced multiple lateral wells are used. Vermylen and Zoback (2011) studied stress shadow effects in multiple lateral wells in the upper Barnett shale for different completion procedures (simulfrac and zipperfrac) to test the effectiveness of different fracture methods. Simulfracs involve pressurization of two adjacent lateral wellbores at the same time; zipperfracs involve first injecting from one wellbore while the neighboring wellbore is not active and then injecting from the neighboring wellbore after injection into the first wellbore was completed. Vermylen and Zoback (2011) compared the activity level of a fracture stage for the different completion techniques using microseismic events. They found significant differences in stimulation outcome for the different HF procedures owing to stress shadow effects. Nagel and Sanchez-Nagel (2011) performed a numerical evaluation of the effect of multiple HF on stress shadowing as a function of in-situ stress and operational factors. Roussel and Mukul (2011) also performed a series of numerical simulations of stress interference resulting from multiple HF in lateral wells. They analyzed the results for the HF impact on simultaneous and sequential fracturing from lateral wells and concluded that stress interference or reorientation increases with the number of fractures created and depends on the sequence of fracturing in different HF techniques. They also suggested that advantages can be gained through different HF sequences over conventional fracturing to improve the performance of stimulation treatments in lateral wells. Nagel et al. (2013) presented the results of a numerical study to evaluate the effectiveness of multiple lateral wells including modified zipperfracs which involve sequential pressurization of offsetting stages of two adjacent lateral wellbores. They suggested there is a potential for only modest stimulation improvement from the modified zipperfrac. Wu et al. (2012) presented results of their study on stress shadow effects of multi stage HF from a lateral well, showing that fractures can either enhance or suppress each other depending on their initial relative positions. They concluded that accounting for these factors and their effects provides a means to optimize shale completions.

These previous studies have primarily focused on the influence of stress-shadows on subsequent HF, whether off a multi-stage single well or adjacent lateral wells. Further study is required to investigate the role of stress perturbation in multi-stage fracturing from multiple lateral wellbores towards optimization of lateral completion techniques by comparing the stimulated volume for different completion procedures. Also, investigation of the influence of other factors, including the local in-situ stress and operational factors, on HF effectiveness is still required when the reservoir has been supercharged by a previous fracture treatment stage.

Numerical modeling methodology

The Distinct Element Method (DEM) is a Lagrangian numerical technique in which the problem domain is divided through by discontinuities of variable orientation, spacing and persistence (Cundall and Hart, 1993). Fig. 1 provides an idealization of a DEM discretization of a problem domain and representation of the hydromechanical interactions between neighboring blocks. One fundamental advantage of the DEM is that pre-existing joints in the rock mass can be directly incorporated, providing the freedom for the problem domain to undergo large deformations through shear or opening along the discontinuities. This allows the geology to be treated in a more realistic way compared to continuum-based hydraulic fracture codes. The 2-D commercial code UDEC (Universal Distinct Element Code; Itasca Consulting Group, 1999) is used here to simulate the response of a jointed rock mass subjected to static loading and hydraulic injection.

UDEC is capable of modeling the progressive failure associated with crack propagation through the breaking of contacts between the pre-defined joint bounded blocks. The blocks are deformable but remain intact. Key for simulating hydraulic fracturing, UDEC has the capability to model fluid flow through the defined fracture network. A fully coupled hydro-mechanical analysis can be performed in which the mechanical deformation of joint apertures changes conductivity and, conversely, the connectivity changes the joint water pressure, which affects the mechanical computations of joint aperture. The blocks in this assemblage are treated as being impermeable, and fracture flow is calculated using a cubic law relationship for joint aperture:

$$q = ka^3 \frac{\Delta P}{l} \tag{3.1}$$

where, k is a joint conductivity factor (dependent on the fluid dynamic viscosity), a is the contact hydraulic aperture, ΔP is the pressure difference between the two adjacent domains, and l is the length assigned to the contact between the domains. Since the UDEC formulation is restricted to the modeling of fracture flow, leak-off along the fractures diffusing into the intact rock matrix is assumed to be zero (only leak-off into other incipient fractures is considered). Furthermore, the cubic law flow assumption disregards tortuosity. When an incipient fracture contact is broken, the fluid flows into the new fracture.