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# Investigation of the initiation pressure and fracture geometry of fractured deviated wells

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ABSTRACT

To investigate the effects of oriented perforations on the initiation pressures and morphologies of fractures from deviated wells, hollow cylinders that were made from synthetically manufactured cubic mortar samples and made with 300 mm perforations were forced to fail by pressurizing their internal cavities to simulate hydraulic fracturing. The borehole and perforations were preset in the sample for casting and finalized during curing. The cubic samples were subjected to independent triaxial stresses to reproduce field test conditions. In addition to the experimental investigations, an analytical elastic solution for the stresses at the walls of a perforation tunnel in an inclined borehole was presented considering both the casing and fluid penetration effects to derive the initiation pressure and preferred perforation orientation. The modeling results fit the experimental results well and revealed that well deviation and perforation orientation have profound effects on the in situ stress fields and consequently the initiation pressure and fracture geometry. Fluid penetration was found to aid in fracture initiation in the perforated boreholes, and an optimal perforation orientation was identified for various formation parameters. When the deviated well was drilled along the maximum principal stress, the preferred perforation orientation was at either 0° or 180° regardless of the deviation angle. As the wellbore rotated away from the maximum stress direction, the optimized perforation direction varied depending on the deviation of the wellbore from the azimuthal angle. An optimized perforation orientation procedure was presented to estimate the ideal fracture perforation orientation for inclined holes, assuming that several variables are known.

## 1. Introduction

The practice of drilling a deviated well is used to extend the reach of the well and obtain better production (Liu et al., 2016). This practice allows several wells to be drilled from a single surface location at less than ideal locations, decreasing expenditures considerably (Mansouri et al., 2015). Most deviated wells still require hydraulic fracturing to increase their production due to ultralow formation rock permeability (Li et al., 2016; Zhu et al., 2015). Hydraulic fractures usually propagate in the direction of least resistance, which is in a plane parallel to the direction of the maximum principal stress, e.g., the PFP (the preferred fracture plane) (Zeng and Guo, 2016). For a perforated deviated wellbore, fracture initiation and evolution are fully controlled by the complex stress state of the borehole, cement and perforations near the wellbore (Behrmann and Elbel, 1991; Yew and Li, 1988). When the fracture initiation plane is not located in the PFP direction, abnormally high initiation pressures occur and tend to create complex flow paths that cause fracture reorientation to the PFP plane (Yew and Li, 1988; Hossain et al., 2000). During the fracture extension process, several hazardous events may occur, including sand-outs, which often result in the abandonment of the borehole (Behrmann and Elbel, 1991; Morita and Mcleod, 1995; Pearson et al., 1992). To improve hydraulic fracturing efficiency, the perforation tunnel should lie along the PFP to reduce the near-wellbore tortuosity, requiring that the oriented perforation direction coincides with the minimum initiation pressure around the wellbore. The mechanism of presetting the perforation tunnels to lie along the PFP is called the oriented perforation technique (OPT) (Behrmann and Elbel, 1991; Pearson et al., 1992; King, 1989; Almaguer et al., 2002). Many authors have investigated oriented perforation of vertical wellbores (Hubbert and Willis, 1972; Haimson and Fairhurst, 1967, 1969; Ito, 2008). Since the vertical well axis was aligned with the three in situ principal stress directions, the oriented perforations were placed along

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the maximum horizontal principal stress direction at 180° (Fig. 1).

In contrast to vertical wellbores, an inclined wellbore axis deviates from the direction of the the in situ stress, and the medium surrounding the wellbore is thus subjected to the combined action of normal and shear stresses, resulting in a reorientation of the stress state around 3D stress state of the wellbore (Bradley, 1979; Alekseenko et al., 2012) (Fig. 2). When analyzing oriented perforation technology in inclined boreholes, the importance of the effects of shear stresses must be considered. Under most circumstances, the optimized perforation direction is no longer the maximum principal stress direction. However, there is an optimal perforation direction that produces the lowest initiation pressure and deviates from the PFP by only a few degrees (Yew and Li, 1988).

As mentioned above, hydraulic fracture initiation and propagation have become essential issues in hydraulic fracturing research. Many theoretical (Liu et al., 2016; Yew and Li, 1988; Pearson et al., 1992; Alekseenko et al., 2012; Soliman, 1990; Mastin, 1988) and experimental (Daneshy, 1973; Hallam and Last, 1991; Fallahzadeh et al., 2015) investigations of fracture initiation and extension have been conducted, but the effects of casing cementation and perforation have not been considered in these models. Several other investigators (Zhu et al., 2015; Hossain et al., 2000; Fallahzadeh et al., 2015; Li et al., 2015; Fallahzadeh et al., 2010) have conducted experimental and theoretical cased/perforated completion studies on fracture initiation and near-wellbore fracture geometry. These authors treated the perforated cemented wellbores separately by using both the wellbore and perforation cavities. Each segment can be represented using equations of the elasticity of a cylindrical cavity loaded with identical internal pressures. In addition, each segment has an explicit analytical solution if the segment is considered as an infinitely long cylinder. The total stress along the perforation tunnel can be obtained by summing the results of the sub problems (Zhu et al., 2015; Hossain et al., 2000; Li et al., 2015). Based on the experimental results, the investigators analyzed the influences of wellbore deviation, the angle of the perforation tunnel and the remote in situ stress ratio on the fracture initiation pressure (FIP).

Notably, most of the abovementioned researchers have not considered the effects of fluid infiltration on the hydraulic FIP in permeable rocks. These authors used an initiation formula that is correct only for impermeable rocks and assumed that the fluid pressure in the surrounding rock equals the initial pore pressure at the moment of fracture initiation. However, some interconnectivity among pores exists within rocks (Ito, 2008). The hydraulic fracturing fluid will penetrate into the formation through interconnected pores and increase the pore pressure during hydraulic fracturing (DetournayCheng, 1993). The excess fluid pressure in the formation superimposes a tension on the normal stresses but does not affect shear stress; thus, an increase in the fluid pressure in the formation would tend to rotate the principal stresses at the borehole wall into a new orientation (Aadnoy and Chenevert,

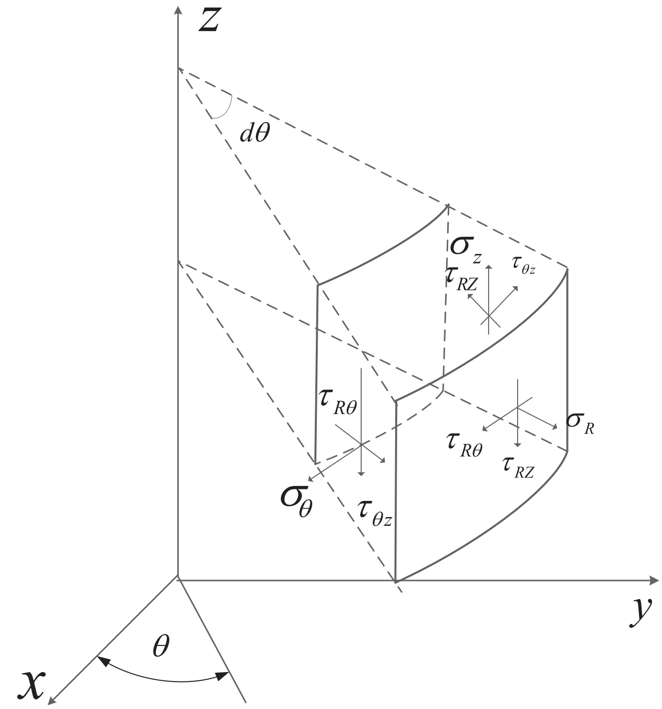


**Fig. 2.** Stress distribution surrounding the wellbore, plotted in polar coordinates.

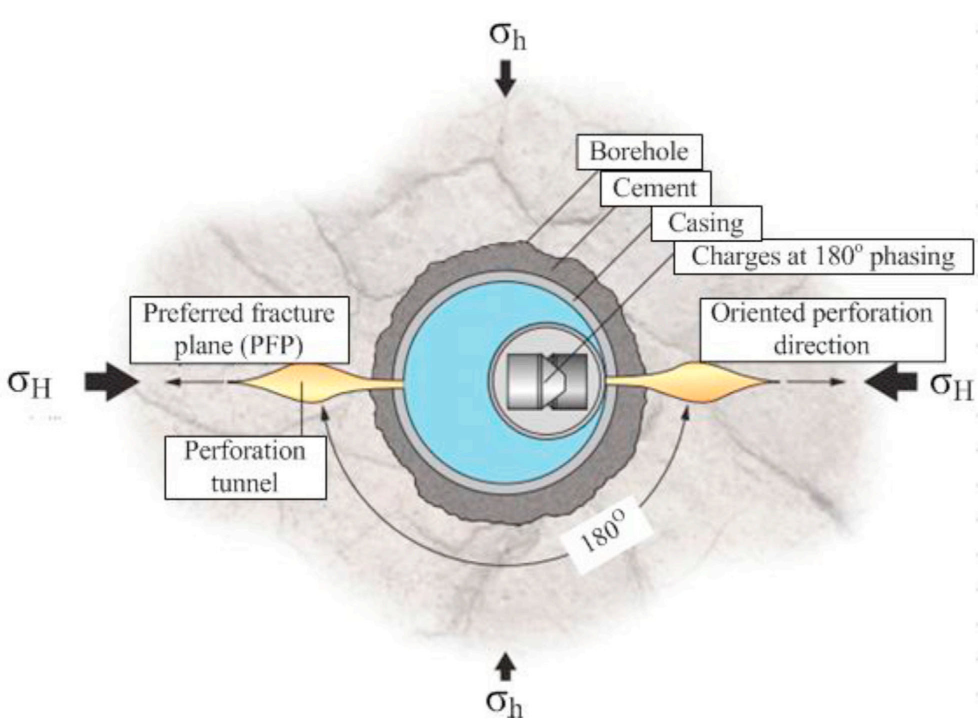


**Fig. 1.** The optimization of the use of the oriented perforation direction (Almaguer et al., 2002).