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Evaluation of production losses from unconventional shale reservoirs

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ABSTRACT

The Promising production trends and predictions, as well as improvements in hydraulic fracturing and horizontal drilling technologies, have made unconventional reservoirs economically feasible. Although these reservoirs have high initial production rates, it is observed that their production performance declines fast. Therefore, it is necessary to identify the reasons behind the production performance reduction. With continuing production, pore pressure decreases and consequently the effective stress applying on fractures increases. This phenomenon causes the fracture closure. In this paper, both individual and combined effects of natural fracture and hydraulic fracture closures on well performance are investigated. We use available experimental data to represent hydraulic and natural fracture conductivity alterations with changing stress conditions. Simulation results show that the individual effects of hydraulic and natural fracture closure on production performance is in the range of 6%–13% and 7%–23%, respectively. Additionally, the combined effect of natural and hydraulic fracture closure is in the range of 10%–25%. It is observed that the coupled effect of natural and hydraulic fracture conductivity losses is less than the summation of the individual effects. Sensitivity analysis is also performed for certain reservoir parameters. This work can provide a better understanding of the main reasons of production losses from unconventional reservoir simulations.

1. Introduction

Recent studies show that unconventional reservoirs will be the major supplier of world's energy demand. It is important to predict well performance of unconventional reservoirs before designing a field development plan. Therefore, it is essential to understand the mechanisms which are affecting the production performance of unconventional reservoirs. Fracture closure might be one of the mechanisms to cause significant reductions in production performances. Hence, fracture closure effects on production performances are systematically studied and reported in this paper. Furthermore, sensitivity analysis is performed to understand the circumstances that the geomechanical effects cause a significant production loss. Underground shale formations are scattered all over the map despite conventional resources. A look at U.S. shale assets will be a demonstration of the importance of the evaluation of production loss due to fractures closure that is the main objective of this paper.

Reservoir properties such as matrix permeability (except the Klinkenberg effect considerations) and porosity are often assumed as constant with production time. However, this assumption may not be true for fracture properties, since they are more stress-sensitive than the matrix according to Tao et al. (2010). Once the production starts from the reservoir, pressure in the natural and hydraulic fractures decreases; eventually effective stress applying on them increases and results in fracture closure. It should be noted that fracture closure is also referred to as "geomechanics effect". This effect will cause the loss of fracture conductivity. Although hydraulic fractures are propped with high quality proppants to avoid fracture closure, experimental studies show that fracture aperture will be reduced with the increasing effective stress and consequently results in the loss of fracture conductivity (Fredd et al., 2001; Cho et al., 2013). Experimental studies investigated the fracture conductivity under changing stress conditions and found that the relationship between the effective stress and fracture conductivity is non-linear (Barton et al., 1985; Wilbur and Amadei, 1990; Kwon et al., 2004; Gutierrez et al., 2000). For unconventional shale rocks experimental works also indicate and show that shale permeability is strongly stress depended (Soeder, 1988; Dong et al. (2010); Luffel et al. (1993). In this study, the

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experimental results of Suarez-Rivera et al. (2013) were used to represent the loss of natural and hydraulic fracture conductivity with the increasing effective stress.

Unconventional reservoirs are hydraulically fractured prior to production. This process creates primary propped fractures (hydraulic fractures) with large amounts of proppants, and secondary fractures (natural fractures) with less or no proppants. Most researchers claim that with continuing production, these fractures may close and cause a reduction of production performance. In order to investigate geomechanics effects on production, it is necessary to couple this effect with reservoir flow. For this purpose, Cho et al. (2013) analytically coupled natural fracture closures effects on production. Our previous studies (Aybar et al., 2014a; Aybar, 2014; Eshkalak et al., 2013; Omidvar Eshkalak, 2013) improved on their approach with a semi-analytical solution with using an empirical model as proposed by Raghavan and Chin (2004). Cipolla et al. (2010) numerically investigated the natural fracture closure effects on production. More recently Chen et al. (2015) highlighted the impact of natural fracture permeability decrease with the changing effective stress applying on them. For this purpose, Chen et al. (2015) model is theoretically constructs a relationship between natural fracture permeability and decreasing reservoir pressure with production. They further verified their theoretical model experimentally with different shale samples. On the other hand, other researchers investigated the hydraulic fracture closure effects on well performance of unconventional reservoirs (Moinfar et al., 2013; Eshkalak et al., 2014a,b,c). However, the impacts of both hydraulic and natural fracture closures on unconventional reservoir production performance have not been studied systematically. Hence, it is critical to quantify both the individual and combined effects of hydraulic and natural fracture closures on unconventional reservoir production performance and understand under what circumstances the effect of geomechanics should be taken into account.

In this work, we built a numerical reservoir model with hydraulic and natural fractures using typical reservoir and fluid properties from an unconventional reservoir to couple geomechanical effects with reservoir flow. After that, we performed a series of sensitivity studies to quantify the impacts of reservoir properties such as initial natural and hydraulic fracture conductivity and matrix permeability. The objective of this paper is to provide a better understanding of the effects of both natural and hydraulic fracture closures on unconventional reservoir production performance.

2. Experimental data for propped and un-propped fracture conductivity

There are many reported experimental studies investigating fracture conductivity changes with changing stress conditions. However, most of these experiments consider either propped or un-propped fracture conductivity individually. Since the aim of this paper is to analyze both individual and combined effects on production performance, it is necessary to have a data set from the same experimental study for both propped and un-propped fractures. For this purpose, the experimental results reported by Suarez-Rivera et al. (2013) were employed in our simulations.

Propped fracture conductivities represent the hydraulic fractures, while the un-propped fracture conductivities represent the natural fractures. The magnitude of loss of un-propped fracture conductivity under increasing closure stress is larger than that of propped fracture conductivity, since proppants can prevent the closure of hydraulic fractures to some degree. The raw data given by Suarez-Rivera et al. (2013) were normalized for hydraulic and natural fracture conductivities that were measured at the closure stress of 500 psi, see in Fig. 1. These data were used here to examine the pressure dependent natural and hydraulic fracture conductivity effects on production performance. Once the fracture conductivity data are normalized based on a reference pressure (500 psi in this paper), they need to be converted to conductivity multiplier to be used in the reservoir simulator. Pressure-dependent conductivity multiplier used in the reservoir simulator is given in Fig. 2 to couple reservoir fluid flow with the geomechanics effect.

3. Mathematical formulation

Relationship between the fracture pressure and net stress applying on the fractures can be represented by the Terzaghi's (1923) fundamental equation given by Eq. (1).

$$\sigma = S - P_p \tag{1}$$

where σ is net stress applying on medium, S is total stress applying on medium, and P_P is pore pressure. As seen from Eq. (1), decreasing pore pressure increases the net stress applying on the medium, resulting in fracture closure and consequently fractures conductivity loss.

Fracture conductivity is an important property that represents the ability of fractures to transmit the hydrocarbon flow from reservoir to the wellbore, and depends on the fracture width and the fracture permeability. Hydraulic fracture conductivity is defined in Eq. (2).

$$FC = w_{fracture} \times k_{fracture} \tag{2}$$

where w is fracture width, k is fracture permeability, and FC is fracture conductivity. The conductivity loss reduces the reservoir system ability to transmit the reservoir fluid to the wellbore. In order to quantify this effect on production performance, it is necessary to couple reservoir flow with varying conductivity along the pressure.

4. Numerical simulation procedure

It is difficult to fix the natural fracture density and orientation in unconventional reservoirs. In order to represent them in our numerical simulation studies, we defined their parameters from the practical range and considered an arbitrary number of natural fractures. Natural fractures in our reservoir model is represented with some simplifying assumptions such as uniform initial natural fracture conductivity for all the natural fractures considered in our

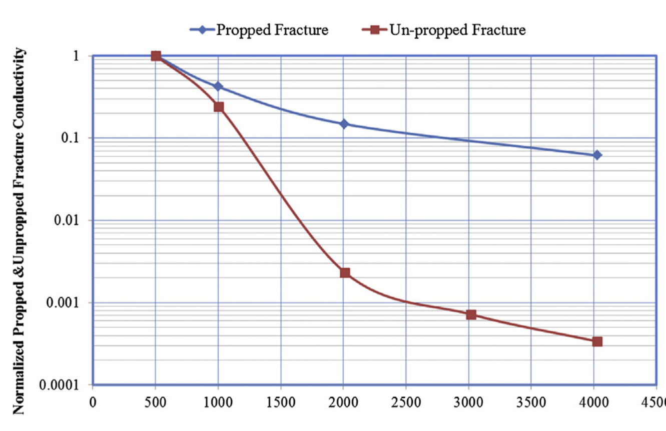

Fig. 1. Normalized propped and un-propped fracture conductivity.