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Posteriori assessment of fracture propagation in refractured vertical oil wells by pressure transient analysis

Liqun Shan[a], Boyun Guo[b,*], Dingwei Weng[c], Zhe Liu[c], Henry Chu[b]

[a] Northeast Petroleum University, China
[b] University of Louisiana at Lafayette, United States
[c] PetroChina, China

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ABSTRACT

Oil companies have realized that refracturing old wells is the more budget-friendly way to achieve cash flow than drilling and completing new wells in the down turn of the energy industry. But it has been seen that the refracturing technology does not always work equally well in all reservoir conditions. It is desirable to have a quantitative method for assessment of well refracturing design and operations. An analytical transient flow model was derived in this study to estimate the orthogonality between the old and new hydraulic fractures after refracturing. Pressure transient data from seven wells refractured in an oilfield in the southwestern China was analyzed with the model. The model implies that orthogonal fractures created in well refracturing treatments induce orthogonal reservoir linear flow in the stimulated reservoir volume. This fracture configuration can be identified by the unit slope of pressure derivative in the log-log diagnosis plot. The angle between fractures initiated from wellbore can be estimated using pressure transient data analysis technique with a log-log diagnostic plot, with extreme situations that merged or parallel fractures will show a half slope and orthogonal fractures will show a unit slope. Case studies of data from 7 wells show that orthogonal fractures were created in 3 wells, merging or parallel fractures were created in 1 well, and fractures with non-right angles were created in 3 wells. The actual well productivity data for the 7 wells are basically consistent with the expected trend implied by the estimated fracture configurations with an exception of one well. The reason is not clear and needs further investigations. More production data from refractured wells are required to further validate the technique.

1. Introduction

Low oil and gas prices have aroused an interest in lower-cost methods of enhancing oil and gas production. Refracturing wells has been considered as an opportunity for oil and gas operators to increase energy production with the more budget-friendly way than drilling and completing new wells (Khusainov et al., 2014; Roussel and Sharma, 2013; Strother et al., 2013; Urban et al., 2016; Zhang and Mack, 2017). While some people are certain that the refracturing works quite well, others are still unsure of the success rate of refracturing owing to variation of reservoir conditions (Shah et al., 2017; Vincent, 2010). It is desirable to have a quantitative method for assessment of well refracturing design and operations to maximize the success rate of well refracturing.

In refracturing, the initial fracture can have a significant influence on the propagation of second hydraulic fracture. The new fracture does not route at the same path of the initial fracture owing to the change in stress anisotropy (Rongved et al., 2017; Siebrits et al., 2000; Zhai and Sharma, 2007; Waters et al., 2009). Mechanisms responsible for the change in the stress anisotropy are 1) the increase in stress owing to presence of propped fractures, and 2) the poroelastic effect in which stress decreases owing to the reduction in pore pressure after a long production period. The combination of these effects would dictate fracture propagation direction during refracturing operations (Yi and Sharma, 2016). In the past, a wide range of experiments has been conducted to investigate the intersection of the second hydraulic fracture to the first hydraulic fracture initiated from wellbore fractures (Siebrits et al., 2000; Morales et al., 2016; Pankaj et al., 2016). Elbel and Mack (1993) proposed a two-dimensional coupling model, and concluded that the stress difference between the horizontal maximum and minimum stresses at various locations changed with time, and the original stress difference is the most important factor to refracture. Weng and Siebrits (2007) explained the implication of production induced stress field surrounding the earlier fracture on refracture propagation and refracture reorientation. The surface tiltmeter measurements on several initial hydrofracturing and refracturing treatments

* Corresponding author.
E-mail address: boyun.guo@louisiana.edu (B. Guo).

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were used to determine fracture orientation in the Codell formation of the Wattenberg field, Colorado (Wang et al., 2007; Wolhart et al., 2007). Zhang and Chen (2010) proposed a model for simulating the dynamic path of fracture propagation during refracturing, based on fracture mechanics and hydraulic fracturing theory, and showed that stress difference and initiation angle contribute to the change in fracture propagation path.

For maximizing well productivity of refractured wells, it is possible to create a secondary fracture that would propagate orthogonally to the initial fracture, although extending the initial fracture can also improve well productivity. Siebrits et al. (1998) studied the parameters affecting the azimuth and length of a secondary fracture in tight gas reservoirs, and concluded that a refracture can orient at 90° to an old hydraulic fracture under specific conditions. The second orthogonal fracture can be created within a certain time window that, in turn, depends on the reservoir properties (Roussel and Sharma, 2010). Roussel and Sharma (2013) presented a systematic methodology for selecting candidate wells for refracturing using production data. It considers the stress reorientation occurring around a fractured well, causing the refracture to propagate orthogonally to the initial fracture in the depleted sections of reservoir. Wright et al. (1995) studied field evidence of fracture reorientation. Tiltmeter measurement performed on refracturing operations has shown that the propagation of refracture treatments at an angle of 30° - 60° to the old fracture, while an infill hydraulic fracture in a secondary recovery project was shown to be affected by the fluid pressure gradients. Yao et al. (2007) used the tiltmeter measurement to monitor fracture propagation, considering how the initial hydraulic fractures and the oil and gas wells production/injection impact on the initial stress field after refracturing. They showed that the reorientation is consistent with the production history of the wells. Liu et al. (2008) investigated fracture reorientation in laboratory tests conducted on refracure treatments and tiltmeter mapping, showing a change in the direction of the new fracture growth after producing from the initial fracture.

Asalkhuzina et al. (2017) performed a numerical method to build a model of well production rate and pressure performance before and after refracturing. They estimated the contributions of the old fracture and new refracture, and checked the occurrence of fracture reorientation in all considered examples in their geomechanical model. Fu et al. (2017) conducted mechanics analysis and numerical simulation based on boundary element method. Their study shows that the initial and reversal stresses, rock tensile strength, Young Modulus, fracture toughness and pumping parameters all determine the result of refracturing. A new fracture would initiate at some angles even orthogonal to the azimuth of the initial fracture which is closed. The initial fracture would reopen firstly and a new fracture would initiate at some angles subsequently. Instead of new fracture initiation, the initial fracture would reopen and reorient along the direction of maximum stress.

In practical refracturing treatments, reorientation of new fractures will take place. However, the realistic path of refractures is not clear, which is critical to hydraulic fracturing operations and well production. This paper presents a method to assess the orientation of the second fracture relative to the first fracture, i.e., the orthogonality between the fractures. This work helps fill the gap between the performance of a refractured well and the optimization of the next well to be refractured.

2. Mathematic models

Pressure transient analysis has been widely used for extracting reservoir properties and heterogeneities such as permeability, skin factor, and sealing fault existence. The technique was employed in this work to extract the information about fracture orientations in refractured oil wells. Reservoir flow models and a diagnosis method using the models are described in the section that follows.

Reservoir Flow Models. While multiple fractures can initiate near a vertical wellbore, orthogonal fractures are obviously preferable to form in the refracturing processes for maximal well productivity. The second fracture may be overlapped on the first fracture. Fractures can be intersected with an angle. Two special scenarios are the parallel and perpendicular fractures.

Prior to refracturing, if the minimum stress is still in the direction that is perpendicular to the existing fracture, it is expected that the new fracture would propagate in the same direction as the existing fracture, or merge to the existing fracture. In this case, reservoir linear flow behavior should be identified from pressure transient data analysis. Mathematical models describing reservoir linear flow were presented by several investigators including Clark (1968), Millheim (1968), Gringarten et al. (1975), and Cinco et al. (1978). The well pressure behavior of linear flow for constant production rate is expressed as:

$$p_w = p_i - \frac{4.064\ QB}{h\ x_f}\sqrt{\frac{\mu}{\varphi c_t k}}\sqrt{t} \tag{1}$$

where p_w is wellbore pressure, p_i is the initial reservoir pressure, Q is fluid rate, h is pay zone thickness, x_f is fracture half length, μ is fluid viscosity, ϕ is rock porosity, c_t is reservoir total compressibility, k is rock permeability, and t is time. During the early time of production (flowback), it is expected that bilinear flow will occur in the fracture and in the formation matrix. Cinco and Samaniego (1981) introduced this flow regime to the well test literature. Bilinear flow occurs in hydraulically fractured wells when the conductivity of the fracture is finite. In this flow regime, two types of linear flow occur, one from the matrix to the fracture and one from the fracture to the wellbore. This is usually evident in long fractures or in natural fractures. The well pressure behavior of bilinear flow for constant production rate is expressed as:

$$p_w = p_i - \frac{44.13\ Q\mu B}{h\ \sqrt{k_f w}\ \sqrt[4]{\varphi \mu c_t}}\sqrt[4]{t} \tag{2}$$

where k_f is fracture permeability and w is fracture width.

Prior to refracturing, if the maximum stress is in the direction that is perpendicular to the existing fracture owing to stress shadow effect, it is expected that the new fracture would propagate in the direction perpendicular to the existing fracture. The stimulated reservoir volume is illustrated in Fig. 1.

Assuming simultaneous reservoir linear flow from rock matrix to the two fractures (orthogonal reservoir linear flow), the well pressure behavior under constant production rate condition can be approximately described by (see Appendix A for derivation):

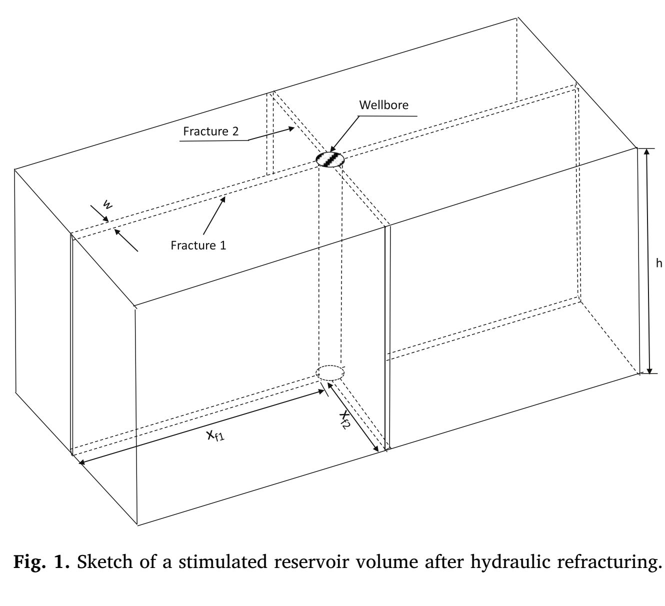

Fig. 1. Sketch of a stimulated reservoir volume after hydraulic refracturing.