Journal of Petroleum Science and Engineering 166 (2018) 592–601

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

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

Experimental study of directional propagation of hydraulic fracture guided by multi-radial slim holes

Tiankui Guo[a], Zhenhua Rui[b,c,*], Zhanqing Qu[a], Ning Qi[a]

[a] College of Petroleum Engineering, China University of Petroleum, Huadong, 266580, China
[b] College of Petroleum Engineering, Southwest Petroleum University, China
[c] Massachusetts Institute of Technology, USA

ARTICLE INFO

Keywords:
Radial slim hole
Hydraulic fracturing
Fracture propagation
Horizontal stress difference
Azimuth

ABSTRACT

The conventional hydraulic fracturing fails in the target oil/gas zone (remaining oil, closed reservoir, etc.) which is not located in the azimuth of maximum horizontal stress of available wellbores. The technology of directional propagation of hydraulic fracture guided by vertical multi-radial slim holes is innovatively developed. In order to verify this technology, lots of true triaxial hydraulic fracturing simulation experiments were carried out with artificial cores, aiming at investigating the influence of in-situ stress, fracturing fluid displacement, and azimuth, diameter, number, and spacing of radial slim holes on fracture propagation. The results show that directional propagation of hydraulic fractures guided by vertical multi-radial slim holes is feasible. Regardless of varied radial slim hole and in-situ stress parameters, hydraulic fracture always initiates in the heel of radial slim hole. For hydraulic fracturing assisted by single radial slim hole, smaller horizontal stress difference (3 MPa, $\sigma_H/\sigma_h = 1.25$) and smaller radial slim hole azimuth (15°) may guide propagation of hydraulic fractures along radial slim hole, and larger horizontal stress difference (6 MPa, $\sigma_H/\sigma_h = 1.67$) can sharply reduce guidance of radial slim hole. Affected by mutual interference from guidance of radial slim holes and controlling of horizontal in-situ stress, fractures tend to distort along fracture length and fracture height. For hydraulic fracturing assisted by vertical multi-radial slim holes, horizontal stress difference is one of key factors influencing the directional propagation effect of hydraulic fracture. Larger horizontal in-situ stress difference (> 6 MPa, $\sigma_H/\sigma_h > 1.67$) hardly results in directional propagation of hydraulic fracture along radial slim hole row, and creates bigger diversion angle of fracture, and larger azimuth (> 45°) of radial slim hole row reduces the guidance strength, resulting small fracture diversion radius. In conditions of larger angle between target zone and maximum horizontal stress, and requirement of large azimuth of radial slim hole row, the effective hydraulic fracture propagation along radial slim holes and ideal fracture height will be achieved through human intervention, e.g. increment of the number and diameter of radial slim holes, reduction of radial slim holes spacing, increment of fracturing fluid displacement, etc. The simulation results provide methods for designing directional propagation of hydraulic fractures guided by vertical multi-radial slim holes.

1. Instruction

The conventional hydraulic fracturing will fail in the target oil/gas development zone (remaining oil, closed reservoir, etc.) which is not located in the azimuth of maximum horizontal stress of available wellbores. How to realize directional propagation of hydraulic fracture is a hot issue of research. The radial slim hole (also known as the radial well) refers to a horizontal borehole with curvature radius far less than that of conventional drilling, and its borehole is formed much by hydraulic jet or drilling, with length between 10 m and 100 m and borehole diameter between 25 mm and 50 mm (Li et al., 2000; Gong et al., 2016). Combination of radial slim hole and hydraulic fracturing is an innovative technology to effectively develop the low-permeability reservoir (Wang et al., 2017), thin-layer reservoir (Guo et al., 2017a), fractured reservoir (Sun et al., 2016), water-flood “dead oil area” and lithologic closed reservoir (Rui et al., 2017a).

The main role of radial slim hole is to guide the direction of hydraulic fracture and enhance deep penetration. But when the single radial slim hole deviates significantly from the direction of maximum horizontal stress and/or there is a large horizontal stress difference and severe reservoir anisotropy (Liu and Ehlig-Economides, 2015; Guo et al., 2017b, 2017c), it is possible that the hydraulic fracture does not

* Corresponding author. College of Petroleum Engineering, Southwest Petroleum University, China.
E-mail address: zhenhuarui@gmail.com (Z. Rui).

https://doi.org/10.1016/j.petrol.2018.03.102
Received 16 November 2017; Received in revised form 26 March 2018; Accepted 28 March 2018
Available online 29 March 2018

propagate along the orientation of radial slim hole to target zone, and it's also possible that the fracture orientation transfers, or transverse fracture forms, which creates unsatisfactory stimulation result and limits the application of this technology. How is the directional propagation of hydraulic fracture realized when single radial slim hole could not effectively guide fracture propagation (Guo et al., 2017d; Rui et al., 2018c)? Some related researches in other fields provide us with inspiration and ideas. Many researchers have studied the spatial stress theory related with guidance of multi-holes to control fracture propagation (Bashkirov and Vityazev, 1996; Rui et al., 2017b), which show that the axis plane of hole is main stress plane, and superposition of tensile stress in axis plane of borehole creates maximum tensile stress in borehole wall of axis plane and it reaches the tensile strength of formation firstly. Thus, the radial crack is initiated firstly in hole wall of hole axis plane, and it grows as expansion stress increases. Liu and Liu (2013) published an article about adding multi-directional perforation to wellbore and creating slot in coal bed through high-pressure hydraulic jet, which initiates cracks in shear failure zone around crack tip. Then, another direction of fracture is created in next fracturing operation. Yuan et al. (2017) developed a novel analytical methodology first which integrates the characterization of the properties of both reservoir and fractures, and optimization of fracture design, and well performance predication together. Xia et al. (2013) suggested placing the reasonable directional drilling around fracturing borehole to realize the guidance of hydraulic fracture, which could prevent hydraulic fracture from deflecting or propagating towards adjacent reservoir, and guarantee fracture to propagate along plastic coal formation, namely that hydraulic jet slotting creates continuous plastic zone in coal bed and communicates the plastic zone resulted from slotting fracture.

Based on the above theory, a method is presented that radial slim hole rows are vertically displaced along wellbore with certain spacing, and all radial slim hole rows extend toward target development zone (shown in Fig. 1). To realize the artificial control of directional propagation of hydraulic fractures along radial slim holes row orientation, increase drainage area and effectively communicate the target zone, the interference between radial holes should be used to overcome the control of in-situ stress (Zhang and Zhang, 2017) and formation anisotropy (Guo et al., 2015a). What's the special of the propagation guided by vertical multi-radial slim holes? Due to the larger controllable range of the diameter (25 mm–50 mm) and length (10 m–100 m) of the radial slim holes, and the relatively easy adjustment of net pressure in the hydraulic fracturing construction, the directional propagation effect of the hydraulic fracture guided by the radial slim holes may be better than the other treatments.

At present, the related experimental study on the directional propagation of hydraulic fracture guided by vertical multi-radial slim holes has not yet been reported. The similar study is limited to the initiation of hydraulic fracture guided by directional perforation (Abass et al., 1994; Alekseenko et al., 2012). Behrmann and Nolte (1999) conducted an experimental study on a perforated wellbore and found that when the perforation gun orientation is not properly selected and/or when the directions of the in situ stresses are not accurately known, the width of the fracture near the wellbore would be mostly less than that of the main body of the fracture. This is because the magnitudes of induced stresses are larger near the wellbore compared to in situ stresses. Through large scale hydraulic fracturing simulation experiments, Chen et al. (2010) found that the change of directional perforation angle and horizontal stress differences influences propagation of hydraulic fracture. Hong et al. (2014) studied the guidance of perforation number to hydraulic fracture, and it is thought that sufficient guidance holes create effective crack, which promotes initiation and guidance of hydraulic fracture. Lei et al. (2015) studied the influence of perforation spacing and horizontal stress differences on propagation of hydraulic fracture for small-size cores, and the results show that more perforations and smaller in-situ stress difference benefit fracture propagation along perforation direction. The experiment of hydraulic fracturing in tight sandstone was conducted by Fallahzadeh et al. (2015) who found that both borehole and perforation affect initiation mechanism of tight reservoir, and it is thought that perforation affects the geometrical morphology of hydraulic fracture in immediate vicinity of wellbore.

The results of the previous studies show that perforation number and azimuth, wellbore trajectory, casing and cement sheath properties, and the state of the in situ stresses are the basic governing parameters in fracture initiation from a cased hole. However, the effect of fracturing fluid displacement, holes diameter and spacing on guidance strength of hydraulic fracture are not yet well studied, and because of large differences between radial slim hole and perforation in hole forming method, length, diameter and holes spacing, the two techniques are certainly not same in the their guidance strength to hydraulic fracture (Zhu et al., 2015). At the same time, in the above-mentioned simulation experiments, the simulation method of perforations is too simple, and often to realize by slitting or implanting a very short metal tube (Zhang et al., 2008; Zhang and Chen, 2009). It can't effectively simulate the physical characteristics of large-size radial drilling, and achieve specimens production of vertical multi-radial slim holes.

In this paper, lots of true tri-axial hydraulic fracturing simulation experiments were carried out for the large-size artificial cores (Ma et al., 2017a, 2017b) through a novel simulation method. It reveals influences of horizontal stress difference, fracturing fluid displacement, and azimuth, diameter, spacing and number of radial slim holes on guidance strength of radial slim hole row, and provides scientific basis for effective operation of the directional propagation of hydraulic fracture guided by the radial slim holes (Rui et al., 2017d, 2018a, 2018b). Thus, by solving the problems that the hydraulic fracture only extends along the direction of maximum horizontal stress, which causes available wellbores fail to develop remaining oil and closed reservoir, and that complex multi-fractures tend to generate in immediate vicinity of wellbore, which makes it hard to realize deep penetration of fracture, it improves the effect of fracturing operation and recovery efficiency of oil/gas field. Furthermore, the study has important reference value for other unconventional reservoirs where the multiple fractures are produced by the guidance of multi-radial slim holes to increase stimulate reservoir volume or enhance control of fracture shape in geothermal systems (Hofmann et al., 2014; Cui et al., 2017).

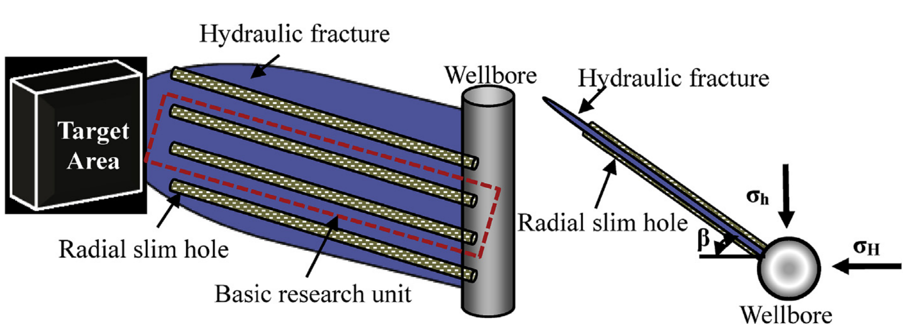

Fig. 1. Schematic diagram of hydraulic fracture directed propagation guided by radial wells.