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Parameter simulation and optimization in channel fracturing

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ABSTRACT

Channel fracturing revolutionarily changes continuous sanding into discontinuous distribution by wrapping proppant particles with a degradable fiber and then injecting these packs or pillars into the formation. Channel fracturing creates open channels between pillars and substantially increases the fracture conductivity. The pulse time of injecting proppants can influence pillar spacing, thereby changing the opening of the fracture. Under different formation conditions, determining a proper pulse time to improve the wellbore productivity is the key problem in channel fracturing.

On the basis of Hertz contact theory, we assume that a proppant pillar is a standard cylindrical indenter. We also calculate the penetration depth beneath the original surface. In this manner, we obtain the residual fracture width under a certain confining stress. This residual fracture width serves as our optimization objective. Then, by combining the flow conservation equation, we find that a restriction relationship exists between the pillar spacing and pulse time. By controlling the variables, we adjust the parameters to find the maximum fracture width. The fracture width reaches its maximum when the horizontal spacing equals vertical spacing.

A set of simulations are completed and analyzed. The results show that the pulse time, pillar spacing, and formation parameters such as the closure pressure, elasticity modulus and initial crack width, can significantly affect the supporting effectiveness of the proppant pillar. Critical points exist when these parameters increase or decrease to a certain level. For the convenience of field operation, a reference plate is provided. A proper pulse time can be determined on the plate under certain formation conditions, thereby providing theoretical guidance for actual channel fracturing.

1. Introduction

Energy resources are being consumed at an alarming rate, and low-permeability oil fields have become the targets of exploration and development. The geological condition of unconventional resources is hostile to recovery, but these geological formations contain abundant oil reserves (Todd et al., 2015). Traditional hydraulic fracturing technology is often used as a good stimulation method to extract oil from these formations. The process involves a high-pressure injection of proppant-laden fracturing fluid into a wellbore to create fractures in the formations through which oil and gas flow (Adams and Rowe, 2013; Golshani and Tran-Cong, 2008). Proppants are distributed evenly within the fractures to guarantee that the fracture will maintain the flow channel under the closure pressure (Patel et al., 2014). People usually take various measures, such as improving the proppant strength, developing mild carrier fluids, or using efficient fracturing fluid breakers, to improve fracture conductivity (Saldungaray et al., 2013; Kayumov et al., 2012). However, we still lose part of the fracture conductivity even if these jobs are well done.

Gillard M. introduced the concept of channel fracturing in 2010 (Gillard et al., 2010). Channel fracturing generally refers to a type of novel hydraulic fracturing treatment that relies on the intermittent pumping of proppant-laden and proppant-free fluid to generate highly conductive channels within the formation (Johnson et al., 2011). The fracture conductivity within the proppant pack can increase up to several folds. The conglomeration of degradable fibrous material can prevent the dispersion of the proppant pulses during the operation (Qian et al., 2015).

Channel fracturing changes the relationship between the fluid and the proppants, and the concept of fracturing is redefined. Channel fracturing creates a complex but stable channel system

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within the fracture. The fracture conductivity does not rely on the ability to flow through a porous proppant pack, but relies on the free channel among proppant packs. Therefore, compared with the traditional fracturing technique, channel fracturing provides highly conductive paths for hydrocarbons to flow from a reservoir to a wellbore (Malhotra et al., 2013; Ejofodomi et al., 2014).

In recent years, channel fracturing technology has been applied in the United States, Russia, Middle East, and other productive fields around the world more than 3800 times, and good stimulation results are achieved (Qu et al., 2015). The channels in the fractures extend to the crack tip; thus, a long effective fracture half-length and high oil recovery rate are achieved (Barasia and Pankaj, 2014). The distribution of proppants is optimized; thus, several related problems, such as the flowback difficulty and formation damage, are effectively solved (Valiullin et al., 2015). Channel fracturing can also decrease the operation cost by minimizing water and proppant consumption (Yudin et al., 2015). We can expect that channel fracturing has an important meaning for low-permeability reservoirs.

If the flow rate remains constant, then the pulse time directly determines how many proppants are pumped into the formation and how these proppant packs are distributed in the fracture. A long pulse time has two meanings. First, a long time at the proppant-laden stage means that proppants are pumped into the fracture, and the proppant packs grow. A large proppant pack can support the fracture at certain locations; however, these fiber-wrapped low-permeability packs may add resistance to fluid flow. Second, a long pulse time at the proppant-free stage means that the proppant packs are distributed sparsely. A large pack spacing can create a free channel for fluid flow, but the hydraulic fracture may tend to collapse under a high confining stress. Thus, in some ways, the most important parameter in the channel fracturing operation is the pulse time. In this study, we establish an analytical model to calculate the fracture opening, and to perform a sensitivity analysis. Finally, we provide a novel reference plate in the final chapter to select the proper pulse time.

2. Model building

In channel fracturing, proppant-laden and proppant-free fluids are intermittently pumped into the formation; thus, proppant particles are separated by fracturing fluids slug, and a proppant pack is formed (Yudin et al., 2014). For the convenience of calculation, we assume that the spherical proppant pack changes into a proppant pillar under compaction after this pack enters the formation (Fig. 1). Free flow channels exist among the proppant pillars. In general, the fracture surface deforms under the confining stress, and the fracture surfaces in each side move close to each other. The fracture conductivity is seriously weakened when the spacing between the two sides becomes sufficiently small.

The problem of determining the fracture opening profile can be simplified as a contact problem. The proppant pillars are modeled as rigid cylinders, and the deformation of the fractures is assumed to be purely elastic. The elastic spaces are subjected to a remote closure pressure, as illustrated in Fig. 1. The pillars are arranged in a square array. The fracture opening decreases with the increase in the distance from the proppant because of elastic deformation, and the minimum opening occurs at the half-point of pillar spacing.

The contact problem is decomposed into the indentation of an elastic half-space via rigid cylinders and a uniform pressure applied on the surface of an elastic half space. The solutions to these problems are provided by many researchers. Hertz (Hertz, 1881, 1882) conducted many studies on the nature of the localized deformation between two elastic bodies placed in mutual contact in 1881. His Hertz contact theory can be used to calculate the normal displacement with a cylindrical punch indenter. A mathematical description of the indentation stress field associated with a particular indenter begins with the analysis of the condition of a point contact. This condition was investigated by Boussinesq in 1885 (Boussinesq, 1885). Boussinesq's solution can be used to determine the stress distribution and displacement within a contact area through the principle of superposition. In 1946, Sneddon (Sneddon, 1946; Harding and Sneddon, 1945) and other researchers analytically determined the stress field associated with a cylindrical punch indenter via a superposition of the Boussinesq stress field.

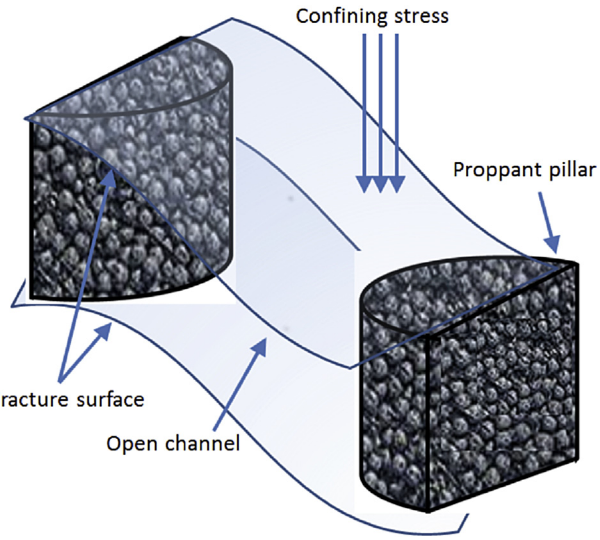

Fig. 1. Fracture deformation under closure pressure.

Beneath the proppant pillar, the vertical displacement (Johnson, 1985) of the fracture surface at a distance *r* from the point of contact is shown in Fig. 2.

$$u_{z1} = \frac{1-\upsilon^2}{E} p_m a \frac{\pi}{2} \quad r \le a \tag{1}$$

Outside the contact area, the displacement (Barquins and Maugis, 1982) of the unsupported fracture area is expressed as follows:

$$u_{z2} = \frac{1-\upsilon^2}{E} p_m a \left(\sin\left(\frac{a}{r}\right)\right)^{-1} \quad r > a \tag{2}$$

where υ is the Poisson ratio, E is the elasticity modulus, a is the radius of the proppant pillar, P_m is the closure pressure, and r is the distance between the calculation point and the pillar center. The maximum fracture displacement can be determined as follows:

$$u_z = \max u_{z1}, u_{z2} \tag{3}$$

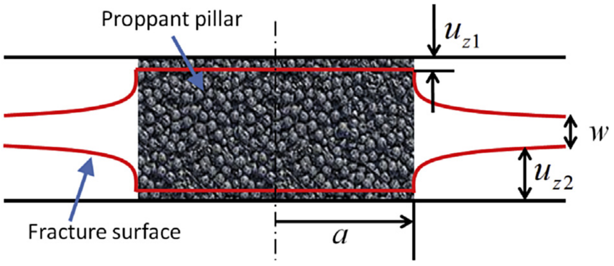

Fig. 2. Displacement of the fracture surface.