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Dissolvable fracturing tool based on a controlled electrolytic method

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ABSTRACT

Fracturing tools such as sliding sleeves, fracturing balls, and ball seats are extensively used for downhole fluid and pressure control. The ball seat is one of the most important components in the multistage fracturing system. After the hydraulic fracturing treatment is complete, the traditional ball seat restricts the production flow and thus must be removed. Extra mechanical interventions are then required to mill out the ball seat after fracturing treatment. In this work, an innovative fracturing ball seat that can be dissolved was proposed and investigated using a controlled electrolytic method (CEM). The newly designed ball seat can be removed through a specific corrosion rate to facilitate an unrestricted flow path for oil and gas production. Comprehensive experiments on the CEM were conducted. The effects of various electrolytic parameters, such as electrolysis current, electrode distance, electrolytes, and tool thickness, on the material removal rate of the ball seat and sliding sleeve were investigated. Experimental results show that the electrolytic parameters significantly affected the electrolytic characteristics. Aluminum alloy is suitable for the manufacture of dissolvable fracturing tool because of its good strength and high electrolytic rate. The study on the newly proposed CEM could provide insights into the design of novel fracturing tools and intelligent well completion systems.

1. Introduction

With the continuous increase in energy demand and cost, unconventional reservoirs that are extremely difficult to extract have received considerable attention in the past decades (Becker et al., 2015; Aybar et al., 2016; Mahrer, 1999; Hejl et al., 2007). Unconventional oil and gas resources, including reservoirs such as oil shales, coalbed methane, and heavy oil, are becoming increasingly important (Ding et al., 2014; Wallace et al., 2016; Zhang et al., 2016; Ahn et al., 2014). The exploitation of these resources generally relies on artificial well stimulation methods, such as hydraulic fracturing, for economical production because of their extremely low permeability (Finkbeiner et al., 2011; Daneshy, 2011). Besides, many factors can affect the production of oil and gas well. The unconventional resources industry has taken tremendous effort to optimize the production. It has been proved that the production optimization not only relies on fracturing hardware, but also depends on detailed subsurface characterization, optimized completion design, and carefully designed reservoir management (Sun et al., 2015; Sebastian et al., 2015; Cadwallader et al., 2015).

Among the different types of fracturing treatments, ball-activated fracturing technology has been extensively used in the oil and gas industry (Wozniak, 2010; Shaw, 2011). In contrast to the conventional exploitation method, the horizontal ball-activated fracturing technology facilitates the separate fracturing of each formation and apparently improves the production efficiency. This completion technique also facilitates the placement of the fracturing tools at different target positions in the horizontal well. Therefore, operational efficiency can be enhanced by improving the stimulation operation efficiency through successive pumping of fracturing treatments (Miller et al., 2008; Hlidek and Rieb, 2011; Johnson and Courrege, 2010; Hill et al., 2010). Fracturing tools with excellent performance are required in this fracturing process.

A typical multistage hydraulic fracturing system consists of several internal components, such as packers, wellbore isolation valves, internal sleeves, shifting balls, and ball seats within the sleeve (Doane et al., 2012; Deng et al., 2013; Deshpande et al., 2012). The sleeves provide ports for fracturing fluids that are injected into each formation of the system. During fracturing, high-pressure fluids and high-strength proppants are injected into the reservoir, inducing hydraulic fractures to the horizontal wellbore, creating high-conductivity flow paths, and eventually producing oil and gas reservoirs (Haghshenas and Nasr-El-Din, 2014; Zoveidavianpoor and Gharibi, 2015).

The sliding sleeve can then be opened by dropping a shifting ball to the ball seat and then pressuring the ball onto the seat. However, the fracturing ball must be flowed back, and the ball seat must be mechanically removed to recover the original production pathway (Zheng et al., 2016; Griffin et al., 2013; Halvorsen and Arnskov,

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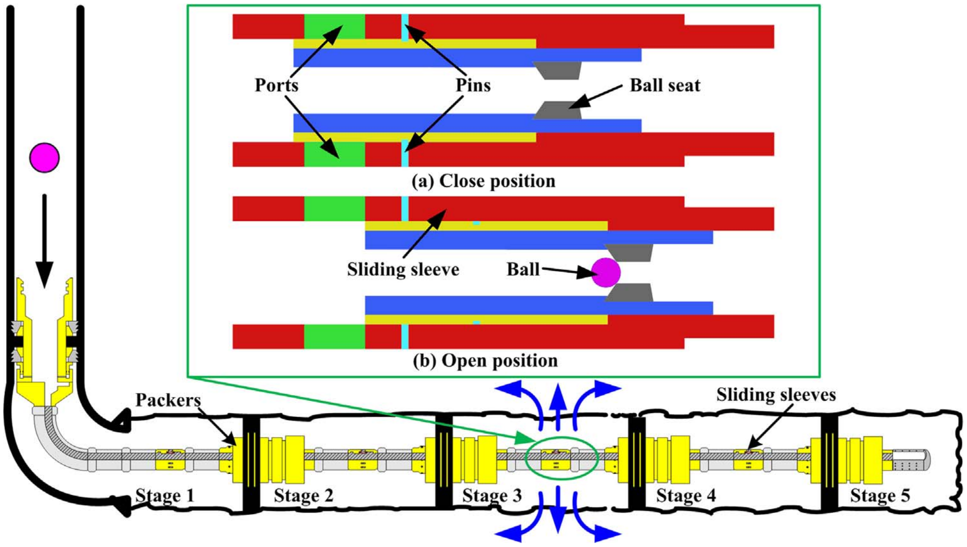

Fig. 1. Schematic of the horizontal multistage fracturing system.

2011). The mechanical operation is tedious and costly because of the torque and rotation, which cause the vibration of the fracturing strings. Given the excessive operations, the fracturing ball fixates in the flow channel in certain cases, causing a fracturing failure and thus increasing the production cost and risk during operation. Fracturing ball fixation in the pipeline and collision with pipeline accessories are some of the risks associated with downhole operation (Zhang et al., 2015; Gonzalez and Bernat, 2010). Despite the urgent need for an effective fracturing system, no system has satisfied the requirement for the downhole fracturing application. One of the approaches to address this problem is the dissolution of the ball and the ball seat for the current multistage fracturing systems. This approach can facilitate effective well stimulation and can improve productivity.

Previous investigations on fracturing systems were based on different methods (Zheng et al., 2015a, 2015b; Takahashi et al., 2015). Carrejo et al. developed a ball and ball seat by using a high-strength corrosive material for horizontal well hydraulic fracturing (Carrejo et al., 2013). Baihly et al. studied the material-mating performance of fracturing tools under various pressures (Baihly et al., 2012). However, little work has been devoted to the study of dissolvable fracturing tools using a controlled electrolytic method (CEM). As a light metal, aluminum alloys have been extensively used in various industrial fields, such as automotive, aerospace, and medicine. Aluminum alloys exhibit relatively higher efficiency in heat transfer, high pressure resistance, and high mechanical strength as compared with conventional metals. Thus, this work comprehensively examined a CEM for downhole fracturing tools. A dissolvable ball seat made of aluminum alloy was also systematically investigated. Furthermore, experiments with different parameters can validate the corrodibility of the fracturing tool. Therefore, the CEM can be an alternative to select the corrosion rate while maintaining the structural integrity of the fracturing tool under wellbore conditions. This novel ball seat has been developed using a metal alloy that reacts in a downhole environment.

The paper is structured as follows. The experiment details are described and presented in Section 2. Subsequently, results and discussions are presented in Section 3. Finally, main conclusions are presented in Section 4.

2. Experimental procedure

2.1. Basic principles of CEM method

The key process of electrolysis is the interchange of atoms and ions by the removal or addition of electrons from the external circuit (Tao et al., 2016; Suermann et al., 2016). During the electrolysis process, the Faraday's Laws presents the relationship between the amount of material liberated at the electrode and the amount of electric energy that is passed through the electrolyte. According to the Faraday's Laws, the substance liberated at an electrode during electrolysis is directly proportional to the quantity of electricity. When the current passed through the electrolyte, the weight deposited or liberated at the electrode can be obtained using the following equation:

$$W = kIt \tag{1}$$

where W is the weight of substance deposited or liberated at the electrode, k is the electrochemical equivalent, I is the electrolysis current, and t is the electrolysis time.

When aluminum and iron both exist in electrolyte, galvanic corrosion will occur. Galvanic corrosion which also called bimetallic corrosion is an electrochemical process in which one metal corrodes preferentially to another when both metals are in electrical contact, in the presence of an electrolyte (Håkansson et al., 2016; Srinivasan and Hihara, 2016). The aluminum will first electrolytic and iron is protected.

During the electrolysis process, it can be found that aluminum atoms are oxidized to aluminum ions at the anode:

$$Al+3H_2O-3e\rightarrow Al(\mathrm{OH})_3\downarrow+3H^+ \tag{2}$$

Meanwhile, hydrogen atoms are reduced to hydrogen at the cathode:

$$2H^++2e\rightarrow H_2\uparrow \tag{3}$$

2.2. Propose of dissolvable fracturing tool

Fig. 1 shows the schematic of the horizontal multistage fracturing string. The fracturing string consists of locking pins, fracturing balls, fracturing ball seats, and ball-activated sliding sleeves. In Fig. 1(a), the ball seat is locked and the fracturing ports are blocked by the ball seat. In Fig. 1(b), the fracturing ball moves along the horizontal pipe and finally reaches the target ball seat, and then the increased hydraulic pressure causes the lock pins to shear off, thereby opening the sliding sleeve (Zheng et al., 2015a, 2015b). When the sliding sleeve is open, the fracturing ports provide a flow path for the fracturing fluid, which contains high-strength sands, such as proppants. Concurrently, the formation can be fractured successively by dropping large shifting balls.