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Numerical study on the geometry evolution prediction of fracturing tool used for unconventional oil and gas exploitation

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ABSTRACT

With the increasing requirement for energy, unconventional oil and gas resources such as shale gas, shale oil and coalbed methane play a vital role in energy supply. Therefore, the erosion phenomenon which causes serious tool damage during exploitation has attracted tremendous attention and research interest. The objective of this paper is to investigate the effect of flow characteristics on the geometry evolution process of the downhole fracturing tool. Computational fluid dynamics (CFD) simulation with standard k-ε turbulence model and Lagrangian particulate flow model is carried out to investigate the fracturing process. Effects of flow rate, fluid viscosity and proppant size on pressure drop and erosion rate are studied. It is found that erosion rates increase significantly with the increasing flow rate, while decrease with increase of fluid viscosity and proppant size. Furthermore, second and subsequent impacts occur during fracturing. The maximum erosion rate appears around the port of sliding sleeve. The geometry evolution of sliding sleeve can be predicted through the analysis of erosion information. Moreover, a general agreement between numerical results and field data is achieved. These numerical simulations can provide useful guidance for prolonging the erosion life of fracturing tool and improving exploitation efficiency.

1. Introduction

Severe erosion and corrosion of fracturing tools used for pumping proppant slurry is the most serious problem confronted by the oil and gas industry. Erosion phenomenon which represents a form of material wear and loss has been reported in many areas of oil and gas production [1–3]. Tool failures such as washout and perforation can cause enormous economic loss and extra production risk [4–5]. Fig. 1 shows the erosion status of tool after fracturing process. As can be seen in the figure, the surface surrounding the ports of tool suffered from severe erosion. The wear mechanism under particle impingement is a combination of micro-cutting, plastic deformation, fatigue and brittle fracture [6–7]. Material loss of tool and equipment is caused by particle impingement during the fracturing process. Studying the solid-liquid two phase flow is helpful to a better understanding of particle impact and the erosion phenomenon. Hydraulic fracturing technology has becomes an effective and economical stimulation treatment for unconventional oil and gas reservoirs such as shale gas, shale oil and coalbed methane which are trapped in the rock pores [8–11]. Fracturing fluid containing water, proppants and special chemicals is usually injected into formation to improve the permeability. Sliding sleeve is one of the key components to conduct the fracturing [12–13]. With further exploration and development of unconventional oil and gas reservoirs, requirements of fracturing tools such as pressure resistance, corrosion resistance and erosion resistance are proposed. In the erosion process, parameters such as particle velocity, particle trajectory and particle distribution are strongly affected by the flow characteristics of fracturing fluid. Thus, it is very urgent to study the erosion phenomenon and the geometry evolution process.

To overcome the tensile strength of the downhole rocks and thus make the formation fractured, the fracturing fluid containing proppants is pumped to prevent the cracks closure after the fracturing process [14]. In a typical fracturing process in Shengli Oilfield, a total volume of 50–75 m^3 of proppants is pumped downhole when fracturing treatment stimulation of 8–10 stages. The fracturing fluid is pumped through the sliding sleeve with the flow rate ranging from 1 m^3/min to 5 m^3/min.

Although lots of fracturing works has been done in oil and gas industry today, the research of erosion phenomenon is still limited. One reason for this can be attributed to the complex nature of downhole flow involved in the fracturing process. Experiment conditions same as the harsh downhole environment is difficult to establish on land. On the other hand, the fracturing fluids are generally non-Newtonian [15–16]. Moreover, the full-scale tests for fracturing tools are rather expensive. The rheological characteristics of the fracturing fluid increase the difficulty of the research.

Fortunately, computational fluid dynamics (CFD) technique can provide detailed information on the hydrodynamics of fluid, which is difficult to obtain through conventional physical experiments [17–18]. Chu et al. presented a numerical study of the gas-solid flow in a gas cyclone by use of the discrete element method (DEM) and computational fluid dynamics (CFD) model [19]. Their model successfully captures the key

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Fig. 1. Image showing severely eroded fracturing tool.

flow features in a gas cyclone, such as the strands flow pattern of particles, and the decrease of pressure drop and tangential velocity after loading solids. Tsai et al. shown advances in the numerical simulation of proppants transport in hydraulically stimulated fractures for oil and gas production [20]. In their study, the flow and proppants interaction were accounted using CFD code. Subhash et al. conducted a CFD simulation on the coiled tubing erosion phenomenon [21]. The obtained results indicated that the flow rate to be the most significant factor affecting erosion. Rosine et al. used computational fluid dynamics (CFD) software to provide greater insight into actual coiled tubing flow patterns, including flow velocity profiles, secondary flow regimes, and erosion phenomenon [22]. Their research presented that CFD has been proved to be an effective alternative to full-scale testing. As it is mentioned above, the CFD simulation methods are widely used in oil and gas industry.

Previously, the downhole erosion phenomenon has not been clearly understood and no work has been done to study the geometry evolution process of the fracturing tool. In the present study, based on the particle trajectory model which is focused on forces exerted on proppants by fluid, the CFD simulation approach tracks the motion status of proppants and will provide detailed information for further analysis of the erosion phenomenon and the geometry evolution process. By conducting a series of numerical simulations, fracturing parameters including flow rate, fluid viscosity of proppant size are changed and their effects on pressure drop and erosion rate are studied. Based on the numerical simulations, the influence of fracturing parameters on erosion rate can be obtained and the geometry evolution of sliding sleeve can be predicted. These obtained results will provide useful guidance for the fracturing process, the design process of fracturing tool and prolonging the erosion life.

The presentation of the work is organized as follows. In Section 2, the basic principle and theory employed are described in detail. In Section 3, the numerical simulation of flow domain is performed. In Section 4, the simulation results are presented and discussed. Finally, main conclusions are drawn in Section 5.

2. Basic principle and theory

2.1. Continuous phase model

In the fracturing process, proppants and fracturing fluid are incompressible flows. To calculate the interaction between the proppants and fracturing fluid, the system is modeled in two-phase. The proppants are treated as discrete phase and governed by the motion equation, while the fracturing fluid is treated as continuous phase and governed by the Navier-Stokes equations. During the calculation, the interaction between solid phase and liquid phase is calculated. When the calculation is finished, results such as velocity, pressure, streamline and proppant trajectory can be obtained. The governing equations for continuous phase which mainly include continuity equations, momentum equations and energy equations are given as follows:

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x_i}(\rho u_j)=0 \tag{1}$$

$$\rho\left(\frac{\partial u}{\partial t}+u_i\frac{\partial u_j}{\partial x_i}\right)=-\frac{\partial p}{\partial x_i}+\mu\frac{\partial^2 u_i}{\partial x_i x_j}+\left(\frac{1}{3}\mu+\mu_t\right)\frac{\partial}{\partial x_i}\left(\frac{\partial u_i}{\partial x_j}\right)+f_i \tag{2}$$

$$\rho\frac{\partial E}{\partial t}+\frac{\partial(\rho E+p)}{\partial x_i}=-\frac{\partial q}{\partial x_i}\left(\frac{\partial(\tau u_i)}{\partial x_j}\right) \tag{3}$$

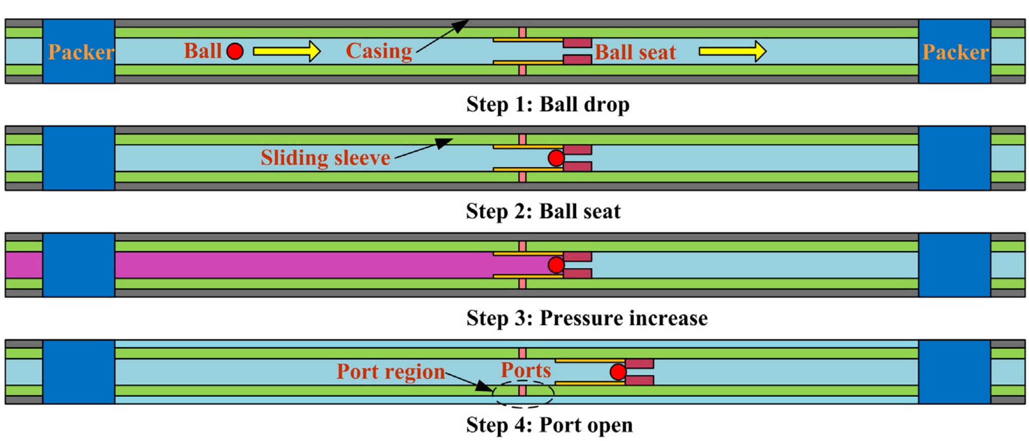

Fig. 2. Schematic of the fracturing process used in this study.