Engineering Failure Analysis 60 (2016) 188–198

Contents lists available at ScienceDirect

Engineering Failure Analysis

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

Numerical study on improving the erosion life of ball seat for oil and gas reservoir fracturing

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A R T I C L E I N F O

Article history:
Received 19 December 2014
Accepted 17 November 2015
Available online 18 November 2015

Keywords:
Numerical simulation
Downhole
Erosion
Failure
Structure optimization

A B S T R A C T

A method using Computational Fluid Dynamics (CFD) for structure optimization of ball seat is presented in this paper. The study aims to explore the erosion failure phenomenon and decrease the erosion rate of ball seat during hydraulic fracturing. To investigate the downhole erosion phenomenon, three dimensional CFD models are performed to analyze flow characteristics such as velocity, pressure, sand concentration and erosion distribution. And, the influences of parameters such as cone angle, structure style of ball seat on the flow characteristics are investigated. Based on simulation results, the maximum erosion area of the ball seat is found and the structure of ball seat is optimized. Furthermore, the validity of the simulation results is confirmed by performing an on-site experiment in a horizontal well, which shows that ball seat after structure optimization results in better erosion resistance and longer erosion life during oil and gas fracturing process.

1. Introduction

The fracturing technology has played an important role in oil and gas production. For example, multistage fracturing treatment in horizontal well can increase the production of reservoir and reduce production cost [1]. In the procedure of fracturing, fracturing tools such as sliding sleeve which is installed with ball seat are essential. Ball is dropped down and caught by downhole ball seat, resulting in sliding sleeve activated and opened [2]. Fracturing fluid with high sand ratio, high viscosity and high pressure flows across the ball seat. Factors such as friction, impingement and cutting cause the erosion behavior of ball seat. Fracturing tool erosion phenomenon has become a growing concern during fracturing process. The erosion of ball seat and has a significant impact on the sealing performance, leading to pressure leakage. Moreover, severe erosion will cause tool failure and the failure of fracturing operation [3–4]. Thus, the study of erosion phenomenon caused by solid–liquid two phase fracturing flow is urgent in fracturing process.

Erosion phenomenon can be attributed to the impingement between sand particles and surface of fracturing tool. Sand erosion phenomenon is very complicated and has not been explained clearly. Factors such as flow rate, sand ratio, properties of sand particles, wall material and characteristics of geometry can contribute to the erosion phenomenon [5–7]. In the industrial production, these parameters have been proven to have a significant impact on the erosion rate. It is necessary to analyze how these parameters impact on erosion problem and optimize the structure of ball seat for improving flow field during fracturing process [8–10]. It is difficult to simulate the harsh and complicated downhole working conditions on land test. However, CFD software can provide an effective method to analyze downhole flow characteristics, predict the erosion rate of fracturing tool and shorten development phase [11–13].

Previously, efforts have been taken to study erosion phenomenon in oil and gas production. For example, Zhu et al. [14] made an experimental and numerical study of drill pipe erosion wear in gas drilling. Their research showed that CFD simulation

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http://dx.doi.org/10.1016/j.engfailanal.2015.11.050
1350-6307/

technique helped to analyze the drill pipe erosion. Arefi et al. [15] developed a code written by C++ for transient simulation of the erosion of drilling tool geometry. Their results offered some advices for minimize the erosion of drilling tool. Forder et al. [16] calculated the erosion in oilfield control valves by using flow simulation and particle tracking method. More recently, Zhu et al. [17] presented numerical analysis of flow erosion on drill pipe in gas drilling. Based on their study, a structure optimized scheme by reducing the slope of drill pipe connector is put forward to reduce the erosion. All these research results show that CFD approach can be an effective method to study downhole erosion problem.

However, most of the previous investigations are focused on the manufacturing and little attention has been paid on the structural optimization. In this paper, CFD simulation method is performed to explore the erosion failure of ball seat during fracturing process. Here we investigate the effect of structure on characteristics of flow flied, movement of sand particles and erosion resistance of ball seat. Based on simulation results, the structure of ball seat is optimized. The validity of the CFD study results is confirmed by performing an on-site experiment.

2. Theory basis

2.1. Fracturing principle

During the application of fracturing treatment, ball drop system is designed to isolate and fracture different reservoir zones. The ball drop system consists of sires of sliding sleeves, ball seats and other downhole accessories. These sliding sleeves and ball seats are installed in a close position locked by pins [18]. Fig. 1 shows the schematic diagram of ball drop system. Before ball is pumped down, fracturing fluid flows across the ball seat as show in Fig. 1 (a) and (d). When ball is pumped down from land, it is carried by fracturing fluid and finally caught by ball seat. When ball reaches ball seat, pins are sheared and sliding sleeve shifts to open position as shown in Fig. 1 (b) and (c). After ball is caught by ball seat, it seals and isolates all the things below ball seat. Then, fracturing fluid containing sand particles as proppant flows into reservoir formation through ports on sliding sleeves. Fig. 1 (d) shows the structure of ball seat, with θ is the cone angle. It is seen that fracturing fluid flows across ball seat. Moreover, cone surface is the location where ball seals with ball seat.

In this study, diameters of ball and ball seat are 32 mm and 30 mm, respectively. The ball is manufactured by composite material which has a range of good characteristics such as low density, low shrinkage, high tensile strength, high elastic modulus and high flexural strength. The material for manufacturing ball seat is cast iron which is easy to mill out when fracturing operation is completed.

2.2. Turbulence model

In order to simulate the motion of solid–liquid two phase flow, proper turbulence model should be selected to describe the internal flow status. As it is know that, the downhole working conditions are rather harsh and complicated. Due to high Reynolds number and high velocity of sand-carrying fracturing fluid, the standard k-ε equation is selected to govern the flow status. The control equation of turbulence model is expressed as follows.

$$\rho u_j \frac{\partial k}{\partial x_j} = \frac{\partial}{\partial x_i}\left[\left(\eta + \frac{\eta_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + \eta_t \frac{\partial u_i}{\partial x_j}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) - \rho\varepsilon \tag{1}$$

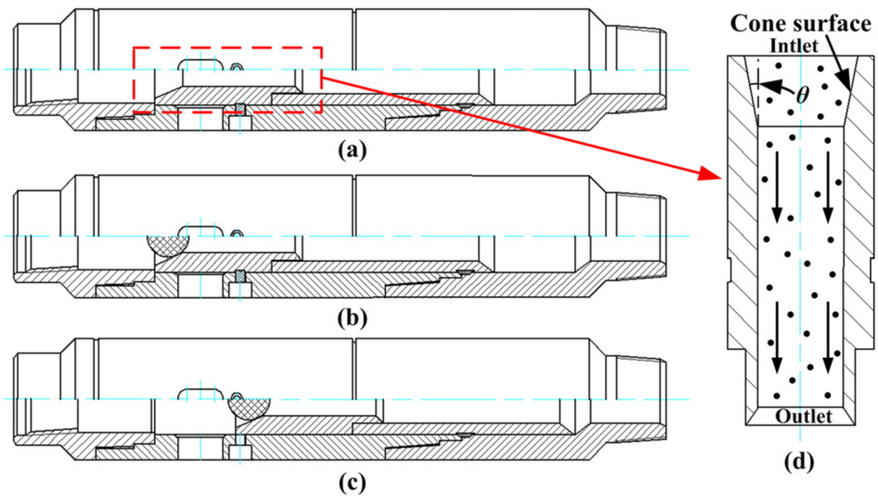

Fig. 1. Schematic diagram for sliding sleeve and ball seat: (a) Before ball drop, (b) and (c) After ball drop and (d) schematic diagram of ball seat.