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Performance study of erosion resistance on throttle valve of managed pressure drilling

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ABSTRACT

The throttle valve designed for managed pressure drilling (MPD) is a core equipment of MPD technology. Due to the direct contact with drilling fluid at well site, the throttle valve's internal flow passage will be eroded and worn by the drilling fluid with high mobility, which would negatively affect the working performance and service life of the throttle valve. Therefore, based on the working principle and geometric structure of throttle valve, the computational fluid dynamics (CFD) technique is used to establish the three-dimensional fluid numerical model, and the renormalization group k-epsilon (RNG k-ε) model is selected for the turbulence model of liquid-solid two-phase flow in throttle valve of MPD. At the same time, the fluid flow in the wall region is solved by wall function which allows the physical quantity near the wall surface to connect with it in the core turbulence region. In addition, the discrete phase model (DPM) model is selected for the discrete phase model, and the Ahlert erosion model is selected for the erosion model. The finite volume method is used in discrete calculation, and the SIMPLE algorithm is applied in continuity equation, momentum equation, energy equation and turbulent kinetic energy equation when solving the control. The influences of drilling parameters (such as throttle valve opening, drilling fluid flow rate, drilling fluid density, mass flow rate of solid particle) on the erosion characteristics of throttle valve of managed pressure drilling are studied by CFD. The results show that the erosion of the solid particles on the wall of MPD throttle valve mainly occurs at the end of the valve spool. Meanwhile, the drilling fluid flow rate has the greatest impact on the erosion rate of solid particles, which is followed by the solid mass flow. Compared with the above two, the erosion rate of solid particles is less influenced by the throttle pressure difference between inlet and outlet which is caused by the change of throttle opening and drilling fluid density. In addition, the simulation result reaches a good agreement with the laboratory data of throttle valve erosion experiment. This study could give several advices for relevant throttle valve investigation work and operators who attempts to decrease the erosion in valves.

1. Introduction

By precisely controlling the borehole annulus pressure, managed pressure drilling (MPD) is able to determine the downhole pressure window and then control the wellhead back pressure (Hannegan et al., 2004). This technique could keep the variation of bottom hole pressure within a limited range (less than 0.35 MPa), so that effectively solving the complicated drilling problems, such as well kick, lost circulation, noxious gas leakage, which are triggered by pressure loss, narrow density window, high temperature, high pressure, and high permeability fractured reservoirs. (Babadagli, 2005; Kadaster et al., 2005; Vajargah and van Oort, 2015). MPD technology can reduce 20%–40% non-production time, and the average cost per footage per well is also reduced by $39-$1915, which would significantly improve the drilling speed, shorten the drilling cycle, and make drilling operations more secure (Antonio Jose et al., 2006; Saponja et al., 2006). MPD technology relies on an integrated real-time pressure monitoring system, advanced technology and equipment such as ground pressure control devices, continuous cycle drilling equipment, and complete technical support (Matthew Daniel, 2006). Among them, the MPD throttle valve, as shown in Fig. 1, is the main

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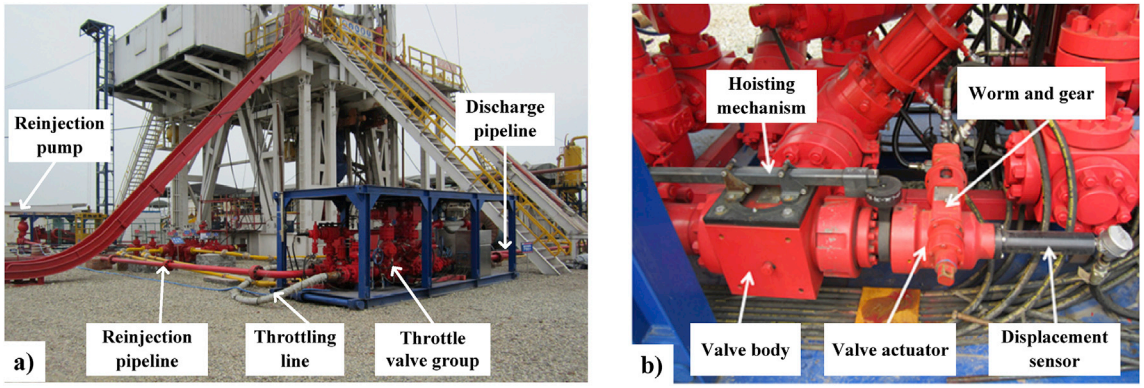

Fig. 1. MPD system in drilling field: (a) MPD system; (b) throttle valve group.

equipment to control the ground back pressure and also the key of pressure control drilling technology.

The basic principle of MPD throttle valve is to control the drilling fluid flowing back to wellhead by changing the throttle opening to maintain the controllability of wellhead casing pressure (Fu et al., 2013; Wang et al., 2015a). Since the throttle valve works for a long time under high pressure, its operating characteristics and reliability directly affect the success rate of MPD implementation (Hannegan and Kevin, 2005; Reitsma and van Riet, 2005). During MPD, due to the high flow rate of the drilling fluid, the ground pressure control device, in particular the internal flow path of MPD throttle valve in a choke manifold, is likely to be eroded. It will severely affect the service life of the MPD throttle valve (Wang et al., 2015b), even trigger a risk on wellhead safety, which then leads to well kick, lost circulation and other complex accidents. Therefore, in order to improve the performance reliability and service life of MPD throttle valve, it is necessary to study the erosion mechanism of two-phase flow of fluid and solid for MPD throttle valve.

In terms of the theoretical model of erosion, Finnie (Finnie, 1960, 1958) first proposed micro cutting theory of material erosion, and gave a relatively comprehensive quantitative relationship between impact angle of attack and impact velocity (volume). Later, he updated the micro cutting model and applied it to the plastic material's erosion with high impact angle of attack. Bitter (Bitter, 1963) put forward the deformation wear theory of erosion which better explained the erosion of plastic materials. Based on the theory of micro cutting,Tilly (1973) performed the secondary erosion theory of particles, which interpreted the problem of material erosion with high impact angle. Grounded on the research of brittle materials erosion by spherical particles, Sheldon et al. (Sheldon and Finnie, 1966) constructed the erosion wear model of brittle materials. Meng et al. (Meng and Ludema, 1995) found that only 28 out of the numerous erosion models conformed to the physical laws and could be experimentally verified. In the experimental study of solid particle erosion, scholars have identified the main factors that affect the erosion results, and put forward a series of semi-empirical formulas (Huang et al., 2008; Ahlert, 1994). In view of needle throttle valve, Haugen et al. (1995) simulated the erosion wear of solid particles on 28 different materials by experiments, including steel, tungsten carbide and ceramic coatings, then put forward the empirical equation of erosion wear of solid particles. Nøkleberg et al. (Nøkleberg and Søntvedt, 1995) experimentally simulated the erosion depth of WC and PCD valve spool wall at low impact angle, and optimized throttle valve. But in the experiment, high-speed camera (Habib et al., 2006) and fiber probe (Lyczkowski and Bouillard, 2002) are used to detect the internal flow field. This method is time-consuming, costly, and it rarely captures internal flow variation, sand velocity and pressure distribution accurately. Moreover, it has the problem of detection device interfering flow field.

The rapid development of computational fluid dynamics (CFD) provides a new and more cost-effective method for the study. Lisowski et al. (Lisowski and Filo, 2016) used CFD methods to analyze the flow characteristics of a proportional flow control valve and to improve it by means of geometrical modifications of the valve spool. Qian et al. (2016) investigated the mach number on multi-stage perforated plates inside a novel high pressure reducing valve and the linked pipelines with the aid of CFD software. Zhang et al. (2016) established the flow mode and erosion simulation model, and studied the influence of slurry concentration, particle size and other factors on the erosion wear of fracturing pipeline. Zheng et al. (2015) applied CFD with standard k-ε turbulence model and particle trajectory model to investigate the influence of outlet structure on velocity streamlines, pressure drop, proppant trajectories, proppant concentration and erosion rate. Liu et al. (2016) applied FLUENT to establishing gas-solid two-phase composite and flow dynamic models to analyze the erosion of the wellhead in nitrogen gas drilling. Zeng et al. (2014) predicted the erosion rate at several locations of the X65 carbon steel elbow, Pereira et al. (2014) and Rani et al. (2014) separately analyzed the erosion distribution of 90-degree carbon steel elbow under low concentration of particles. Nøkleberg et al. (Nøkleberg and Søntvedt, 1995, 1998) used CFD to predict the erosion of the needle throttle valve under solid particles, and compared with the experiments, and suggested to reduce the impact angle and used polycrystalline diamond (PCD) to replace hard alloy to solve the erosion issue. Brown (2002) analyzed the causes of erosion in slurry pipeline tee-junction, Wallace et al. (2004) used the commercial software FLUENT to study the erosion law of gas-solid phase flow in a cage throttle valve, Mazur et al. (2004) studied the erosion of solid particle in a steam turbine.

At present, the study on the flow erosion wear of two-phase flow of solid and liquid has evolved mature. Some scholars have applied the relevant theories and methods to the erosion research of throttle valve, and achieved some research fruits. However, there are few studies about the erosion of MPD throttle valve. The main purpose of this paper is to study the influence of drilling parameters (valve spool opening, drilling fluid flow rate, drilling fluid density, mass flow rate of solid particle etc.) on the flow patterns (motion trajectory, velocity, etc.) of solid particles in inner chamber of MPD throttle valve and the effect of the erosion rate of the cavity wall by solid particles. Thereby finding out the method to reduce the erosion and prolong the life of MPD throttle valve.

Our study mainly includes the following three stages:

(1) According to the working principle of the MPD throttle valve, establish the calculation model of throttle valve's three-dimensional flow field.
(2) Carry out indoor erosion experiments of MPD throttle valve, and verify the CFD calculation model.
(3) Apply CFD technology to study influence of different drilling parameters on the MPD throttle valve erosion.