Journal of Natural Gas Science and Engineering 35 (2016) 291–298

Contents lists available at ScienceDirect

Journal of Natural Gas Science and Engineering

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

Casing wear analysis helps verify the feasibility of gas drilling in directional wells

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ARTICLE INFO

Article history:
Received 23 May 2016
Received in revised form
23 August 2016
Accepted 27 August 2016
Available online 29 August 2016

Keywords:
Casing wear
Gas drilling
Directional wells
Wear mechanism
Experimental study
Feasibility analysis

ABSTRACT

Casing wear during directional well drilling remains a prominent problem because it can cause casing strength degradation, casing deformation and even well abandonment. In order to obtain a better understanding of casing wear and quantify the wear amount in gas drilling of directional wells, theoretical and experimental study is carried out in this paper. Based on casing wear mechanism and energy principle, a prediction model of casing wear is investigated and programmed. Experimental study on casing wear is conducted and casing specimens are worn in air and mud respectively. According to wear morphology analysis, casing wear mechanisms can be recognized as adhesive wear and abrasive wear. Data processing and analysis reveals the influence factors of casing wear, including casing steel grade, rotary speed and contact force. Through linear fitting of test data, wear coefficients in air and mud are obtained and compared. Then the intermediate casing wear of an actual directional well is predicted using the methods and models proposed in this paper with special attention focused on the comparison of wear amount in mud drilling and gas drilling. Prediction results indicate that casing wear is not the major factor restricting the application of gas drilling in directional wells. The feasibility of gas drilling in directional wells is verified in the perspective of casing wear. Finally, optimization of drilling parameters and reducing friction coefficient are proposed for casing wear reduction. The work presented in this paper can provide theoretical foundation and technological basis for casing wear prediction and reduction in gas drilling.

1. Introduction

Gas drilling is an underbalanced drilling mode which utilizes the gas (including air, nitrogen, natural gas and diesel exhaust) as the circulating medium. Gas drilling technique has been proved to be effective in reservoir discovery, formation protection and drilling rate improvement. However, the application of gas drilling in directional wells is restricted by directional drill tool, cutting carrying and torque/drag problem. When directional wells are drilled by gas, it is commonly believed that increased contact force and friction will lead to serious intermediate casing wear. After casing is worn, decreased casing strength and structural integrity can cause casing deformation, blowout and even well abandonment. But related studies are rare to provide sufficient and reliable evidences for more serious wear in gas drilling. Therefore, casing wear prediction and analysis should be carried out to quantify wear depth and verify the feasibility of gas drilling in directional wells.

Casing wear, as a hot issue in petroleum engineering, has attracted many investigators to conduct physical or numerical modeling. Bradley and Fontenot (1975) carried out field measurements and rough estimates of casing wear and concluded that the major cause of casing wear was drill string rotation rather than tripping. White and Dawson (1987) related casing material loss to the energy dissipated by friction to establish a linear wear-efficiency model. This model is widely applied at present, and its accuracy and efficiency in casing wear prediction has been verified by field testing. Schoenmakers (1987) conducted four case studies for casing wear caused by rotating tool joint hardfacings based on laboratory simulations. It was concluded that casing wear can be controlled with sufficiently smooth hardfacings and restricted wellbore doglegs. Kuriyama et al. (1992) investigated the effect of wear and bending on casing collapse strength by experiments. They also derived empirical collapse formula for worn casing by eccentric cylinder model and found that the reduction in collapse strength was much smaller than the estimation of uniform wear. Hall and Malloy (2005) acquired the best fitting empirical function for the test data and confirmed the nonlinear relationship between casing wear volume and dissipation energy. Gao and Sun (2012)

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http://dx.doi.org/10.1016/j.jngse.2016.08.066
1875-5100/

predicted casing wear in horizontal wells based on the fact that the contact pressure is the appropriate parameter controlling the casing wear rate. Moreira Junior et al. (2015) conducted full-scale experiment and numerical simulation to study the residual strength of worn casing. Their research considered both initial and produced geometric imperfections. Lian et al. (2016) carried out casing wear experiment and investigated the influence factors of casing wear depth. The casing wear prediction model was greatly simplified through crescent-shaped model and wear-efficiency model. Although the basic understanding of casing wear has remarkably increased during the last four decades, many technical solutions are still carried out following “trial and error”. The application of gas drilling in directional wells requires a systematic approach for casing wear prediction and a deep understanding of acting mechanisms.

In this paper, casing wear prediction method is proposed and casing wear mechanism is studied through experiments. Besides, the established models and proposed methods are applied to an actual directional well. The intermediate casing wear of this well is predicted and evaluated to verify the feasibility of gas drilling in directional wells in the perspective of casing wear. Finally, effective prevention and reduction measures of casing wear is proposed.

2. Casing wear prediction

2.1. Casing wear mechanism

Wear, as a fundamental type of material loss, is characterized as the removal of material from solid surfaces by mechanical action (Fischer and Bobzin, 2009). Wear of material can be classified into adhesive wear, abrasive wear, surface fatigue wear and corrosive wear in terms of the fundamental mechanisms and characteristics of wear surface (Andersson, 2011). Casing wear caused by drill string rotation may be classed as typical adhesive wear and abrasive wear. Adhesive wear is the transfer of material between solid surfaces during relative friction motion and adhesive interactions between rubbing surfaces (Best, 1986). Abrasive wear is the material loss caused by hard tool joint protuberances (two-body abrasion) or by hard particles (three-body abrasion). Abrasive wear is characterized as a series of grooves on softer surface caused by hard surface or hard particles. Adhesive and abrasive wear may coexist in downhole casing wear. However, adhesive wear takes a leading mechanism under high contact pressure between tool joint and casing; abrasive wear is dominant when drilling mud contains high content of hard weighting agent or cutting.

Prediction of wear amount is complicated and difficult because the effect of different influence factors on wear amount is unclear. This paper aims to explore a simple and accurate casing wear prediction method and analyze the influence factors of casing wear, which can be applied to verifying the feasibility of gas drilling in directional wells.

2.2. Casing wear prediction model

Wear amount is generally related to contact pressure, energy transformation efficiency and sliding distance between rubbing pairs. According to energy principle, casing wear volume in the subsequent drilling operation is expressed as (Gao et al., 2010):

$$V_w = 60\pi \int_{h_0}^{h} f \mu_t F_N D_{tj} \frac{R_p}{V_p} dl \tag{1}$$

where, V_w is casing wear volume loss; f is wear coefficient; μ_t is circumferential friction coefficient between tool joint and casing; F_N is contact force; D_{tj} is outer diameter of tool joint; R_p is rotary speed of drill string; V_p is penetration rate; l is drilling footage.

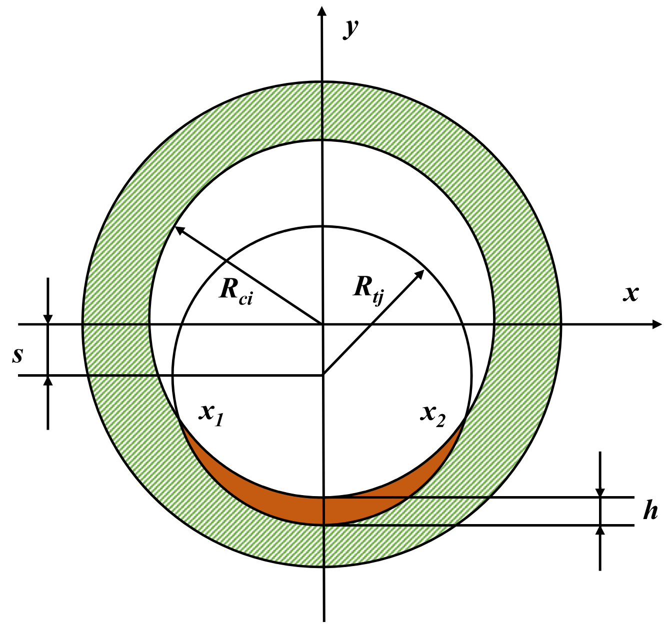

Fig. 1. Coordinate system for crescent-shaped casing wear.

This is the best-known wear-efficiency model which has been applied in most computer programs. Contact force between tool joint and casing can be calculated using the torque/drag prediction model proposed by Johancsik et al. (1984):

$$\begin{cases} F_N = \sqrt{(T\Delta\phi\sin\theta)^2 + \left(T\Delta\theta + W\sin\bar{\theta}\right)} \\ \Delta T = W\cos\bar{\theta} \pm \mu_a F_N \end{cases} \tag{2}$$

where, T is axial tension acting at lower end of element; ΔT is the increase in tension over length of element; $\Delta\phi$ is the increase in azimuth angle over length of element; $\Delta\theta$ is the increase in inclination angle over length of element; $\bar{\theta}$ is average inclination angle of element; W is buoyant weight of drill string element; μ_a is axial friction coefficient.

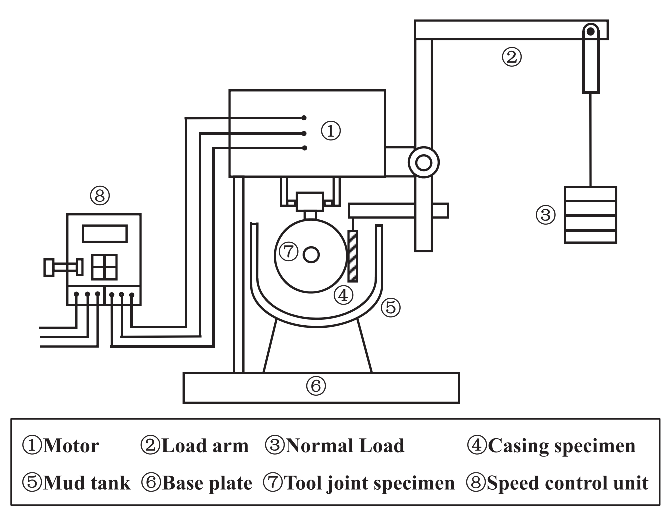

Fig. 2. Casing wear experimental apparatus.