Journal of Natural Gas Science and Engineering 29 (2016) 440–452

Contents lists available at ScienceDirect

Journal of Natural Gas Science and Engineering

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

Evaluation of casing integrity defects considering wear and corrosion – Application to casing design

Tiejun Lin [a], Qiang Zhang [a], Zhanghua Lian [a,*], Xuejun Chang [b], Kuanliang Zhu [b], Yonghui Liu [b]

[a] State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation, Southwest Petroleum University, Chengdu 610500, China
[b] Drilling and Production Technology Research Institute, PetroChina Jidong Oilfield, Tangshan 063004, China

ARTICLE INFO

Article history:
Received 12 November 2015
Received in revised form
19 December 2015
Accepted 22 January 2016
Available online 27 January 2016

Keywords:
Casing integrity evaluation
Casing wear
Pitting corrosion
Casing design
Residual strength

ABSTRACT

Casing integrity is an important category of well integrity in drilling and well operations. Casing integrity defect due to wear and corrosion can cause casing strength degradation, casing deformation and even well abandonment. In this paper, a theoretical model for casing strength degradation due to wear is established in bipolar coordinate system. Another model is established to calculate stress concentration factor of casing with corrosion pit at inner wall. The effects of relevant parameters on residual strength of defective casing are analyzed according to parametric study. According to the stress distribution of casing after wear and corrosion under tri-axial stress, strength check is carried out based on Von Mises yield criterion and Lame thick-walled solution for the pipe. Then, in order to evaluate casing integrity of a real well, casing wear and corrosion experiments are conducted to study mechanisms and obtain relevant parameters for calculation. Finally, according to the established models and experimental results, a modified casing design of this well is proposed considering the effects of wear and corrosion on casing strength degradation. The work presented in this paper can provide a theoretical foundation and technological basis for casing integrity evaluation and casing design of highly-deviated wells or extended-reach wells in sour environment.

1. Introduction

Casing integrity is a significant attribute of well casing resistance to structural damage, as well as an important assurance for subsequent drilling and operations. As oil and gas wells are drilled to greater vertical depth and horizontal length, long rotating hour and big contact force between tool joint and casing lead to serious casing wear. On the other hand, when sour gas is contained in natural gas or CO_2 flooding is applied for enhancing oil recovery, casing corrosion is inevitable. Therefore, casing wear and corrosion are crucial factors affecting casing integrity (Liao et al., 2009). Casing integrity defect due to wear and corrosion can cause casing strength degradation, casing deformation and even well abandonment. However, current casing design doesn't consider these defects, so it is of great importance to study and evaluate casing integrity after wear and corrosion so as to provide reference for casing design and safety evaluation.

Researches on casing wear and corrosion have been conducted from various perspectives. White and Dawson (1987) established a wear-efficiency model which related casing metal loss to the amount of energy dissipated by friction. Both theoretical identification and field testing have verified that this model is relatively sound and efficient for casing wear prediction at present. Song et al. (1992) presented an accurate method for calculating the internal burst pressure of crescent-shaped worn casing. Their research laid the foundation for analytical solutions of residual strength of worn casing. Dou et al. (2007) simplified the worn casing as an eccentric cylinder and derived its stress distribution in bipolar coordinates. Moreira Junior et al. (2015) studied the remaining strength of worn casing through full scale experiment and numerical simulation. Their research considered both initial (ovality and eccentricity) and produced (casing wear) geometric imperfections, and numerical results can be extended to a broad range of pipes with different geometries and steel grades.

To analyze the effects of corrosion on casing strength degradation, different models were established. De Waard and Milliams

* Corresponding author.
E-mail address: milsu1964@163.com (Z. Lian).

http://dx.doi.org/10.1016/j.jngse.2016.01.029
1875-5100/

(1975) established a prediction model for CO_2 corrosion rate based on experimental results. This model is the so called DWM model which only considers the effects of temperature and partial pressure of CO_2. De Waard et al. (1991, 1993 and 1995) proposed improvements to the original model, the revised model involved the effects of pH value, Fe^{2+} concentration, corrosion product film and flow velocity. For the residual strength of corroded casing, Kai Sun et al. (2004a, b) derived formulae for stress concentration factor around cavities of various geometries including shallow-spherical, exact hemispherical, and deep-spherical cavities. These formulae can be applied into the casing burst and collapse strength to obtain residual strength of casing with pitting corrosion defect. However, in the previous models, experiments and simulations, casing integrity defects due to wear and corrosion are not studied systematically, nor have they been applied to casing design.

In this paper, the effects of wear and corrosion on casing integrity are studied. Two mathematical models are established to calculate the residual strength of defective casing due to wear and corrosion respectively. Finally, the casing integrity of a highly-deviated well is evaluated and a modified casing design is proposed accordingly.

2. The effect of wear on casing strength

Casing wear resulting from the friction between tool joint and casing in high dogleg section has a significant impact on the residual strength and integrity of casing string. Assessing properly the strength of the worn pipe can be the key to achieving a feasible technical and economical well design (Moreira Junior et al., 2015).

2.1. Residual strength of worn casing

Previous researches (Wang et al., 2013) have indicated that the morphology of worn area on casing is a typically crescent-shaped groove. To simplify the derivation, the crescent-shaped worn casing is taken as a pipe with geometric eccentricity in this paper (Chen et al., 2015). A bipolar coordinate system is established, as shown in Fig. 1. Bipolar coordinate system is a set of plane orthogonal curve coordinates to facilitate solving the eccentric pipe problem. In this system (Fig. 1), points N1 and N2 are the two focuses.

The mapping function $\omega(\xi)$ between the bipolar coordinates (α,β) and the Cartesian coordinates (x,y) is expressed as follows:

$$\omega(\xi) = x + iy = ic\coth(\xi/2), \quad \xi = \alpha + i\beta \tag{1}$$

where ξ is complex variable about the bipolar coordinates (α,β). The stress distribution of eccentric pipe can be obtained by complex potential theory (Timoshenko, 1970):

$$\begin{aligned} c(\sigma_\beta+\sigma_\alpha) &= 4cA + 2B(2\sinh\alpha\cos\beta - \sinh 2\alpha\cos 2\beta) - 2C(1 \\ &\quad - 2\cosh\alpha\cos\beta + \cosh 2\alpha\cos 2\beta)c(\sigma_\beta - \sigma_\alpha \\ &\quad + 2i\tau_{\alpha\beta}) \\ &= -2B[\sinh 2\alpha - 2\sinh 2\alpha\cosh\alpha\cos\beta \\ &\quad + \sinh 2\alpha\cos 2\beta - i(2\cosh 2\alpha\cosh\alpha\sin\beta \\ &\quad - \cosh 2\alpha\sin 2\beta)] + 2C[-\cosh 2\alpha \\ &\quad + 2\cosh 2\alpha\cosh\alpha\cos\beta - \cosh 2\alpha\cos 2\beta \\ &\quad + i(2\sinh 2\alpha\cosh\alpha\sin\beta - \sinh 2\alpha\sin 2\beta) + D[\\ &\quad \times[\sinh 2\alpha - 2\sinh\alpha\cos\beta - i(2\cosh\alpha\sin\beta \\ &\quad - \sin 2\beta)]\} \end{aligned} \tag{2}$$

Under combined effect of internal pressure and external pressure, the stress boundary conditions can be expressed as (El-Sayed and Khalaf, 1992):

$$\left.\begin{aligned} (\sigma_\alpha)_{\alpha=\alpha_i} &= -p_i \quad (\tau_{\alpha\beta})_{\alpha=\alpha_i} = 0 \\ (\sigma_\alpha)_{\alpha=\alpha_o} &= -p_o \quad (\tau_{\alpha\beta})_{\alpha=\alpha_o} = 0 \end{aligned}\right\} \tag{3}$$

Therefore, the hoop stress distribution of inner boundary of worn casing can be expressed as (for detailed derivation, see Appendix A):

$$(\sigma_\beta)_{\alpha=\alpha_i} = -p_i + 2(p_i - p_o)\frac{R_{co}^2}{R_{co}^2 + R_i^2} \times \frac{\left(R_{co}^2 - e^2\right)^2 - R_i^2(R_i + 2e\cos\beta)^2}{\left(R_{co}^2 + R_i^2 - e^2\right)^2 - 4R_i^2R_{co}^2} \tag{4}$$

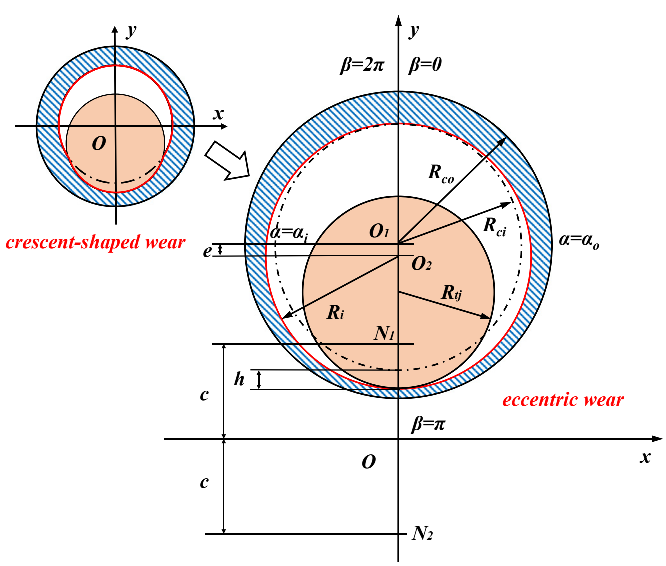

Fig. 1. The bipolar coordinate system for eccentric pipe.

2.2. Parametric study

Fig. 2 shows the hoop stress distribution of inner casing

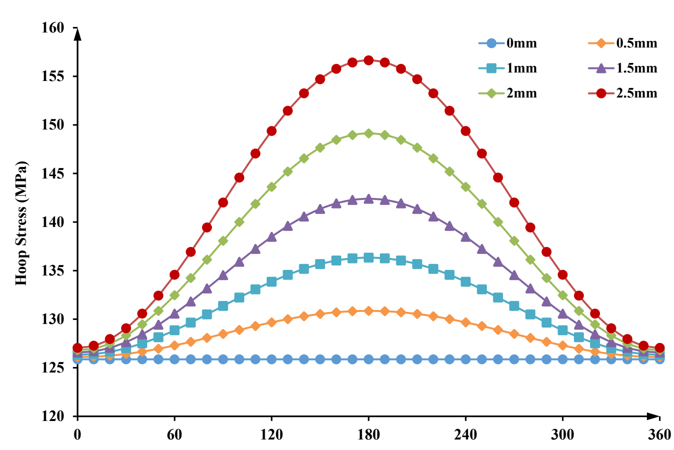

Fig. 2. Hoop stress distribution of inner boundary at different wear depth.