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A leakage diagnosis testing model for gas wells with sustained casing pressure from offshore platform

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ABSTRACT

Sustained casing pressure (SCP) caused by tubing leakage is mostly considered as the dangerous situation in gas wells, which is more likely to pose a serious threat to well integrity and environmental protection. In order to assess the downhole risk in early time and further provide maintenance strategies to optimize well performance, it is necessary to diagnose the source of downhole leakage accurately. This paper presents a pressure-balance-based approach for capturing two types of dynamic annulus pressure behaviors in a gas well with SCP caused by tubing leakage at different well depths. The approach includes models that take into account the influence of temperature and pressure distributions of tubing and annulus fluid, which are used to determine tubing leakage points. In addition, such an approach involves the calculation of maximum annulus pressure at the wellhead in a gas well with SCP under four main cases, representing the effects of the leakage location, bottom hole pressure, annulus liquid level and gas production rate on wellhead pressure. Afterwards, an integrated diagnostic testing system has been developed to monitor the synthetic state of annulus fluid and liquid level parameters, ultimately identifying the source of SCP correctly. In contrast to previous works, leakage diagnostic testing can be performed from an offshore platform, and it meets the requirements of offshore field testing and works without a shut-in condition, which is capable of overcoming limitations of downhole detection. A case study focused on an offshore gas well with SCP is presented to illustrate the feasibility of the proposed approach, and also to demonstrate that leakage diagnosis contributes to the mechanism investigation of SCP, as well as the design improvement of gas wells integrity.

1. Introduction

Sustained casing pressure (SCP) is becoming increasingly serious and common during offshore natural gas production process, which has a negative impact on the economy and even results in catastrophic consequences (e.g., a blowout accident without being well handled) (Rocha-Valadez et al., 2014a; Xu and Wojtanowicz, 2003). Typically, a collapse failure of production casing in BP Marlin project led to well loss, and even the casing in Gulf of Mexico wells was damaged, due to the excessive annular pressure buildup (Guan et al., 2016). The SCP may be caused by internal integrity failure (e.g., degradation or failures of casing, tubing or other well barriers), external integrity failure (e.g., cementing failures), fluid thermal expansion, and others (De Andrade and Sangesland, 2016). Tubing leakage among them is the most serious one, which is indicative of SCP as well as the risk of destroying wellbore integrity (Norsok, 2013). The regulations of API RP-90 require frequently diagnostic tests on a well with serious SCP so that the severity could be detected and evaluated (API, 2006; Xu and Wojtanowicz, 2017). Therefore, it is of vital significance to accurately monitor well parameters, detect leakage points, and evaluate the corresponding maximal annulus pressure (MAP) at the wellhead for ensuring the safety in production wells with SCP.

Generally, the commonly used methods for predicting SCP are based on theoretical models which mainly focus on behaviors of gas intrusion due to casing failures or cement degradation (Liu et al., 2015; Zhu et al., 2012). Tony Rocha-Valadez et al. have presented an analytical model to predict pressure profiles from early-time pressure buildup data for estimation of leakage severity (Rocha-Valadez et al., 2014b). A sustained production casing pressure prediction model has been presented for calculating the temperature distribution and annular volume change, contributing to the design of production casing (Yin and Gao, 2015). Two rising stages of annulus pressure have been predicted for high pressure gas wells given gas invasion, as well as the impacts of different factors on the annulus pressure (Zhang et al., 2015). However, with

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some theoretical models of predicting SCP, recently, being proposed, it is found that the pressure balance characteristic between tubing and annulus has a significant effect on SCP prediction (Rocha-Valadez et al., 2015).

Relevant researches indicate that several factors have contributed to the pressure change between tubing and annulus, including temperature, the gas solubility and compressibility of annular liquid (Liu et al., 2015; Zhang et al., 2015). Among them, temperature distribution is the most crucial one, and the fluid temperature changes with the well depth have an impact on the annulus pressure, not being assumed as a constant value (Hasan et al., 2010). The calculation formula for casing annulus temperature has been developed based on wellbore heat transfer process (Yang et al., 2013). With consideration of the temperature effect, the annular pressure will increase (Guan et al., 2016). In addition, it is also demonstrated that the production rate has an important influence on the annulus pressure behavior in a specific well (Liu et al., 2015). Based on the above-mentioned prediction models, the risk of gas wells at the wellhead under SCP can be comprehensively estimated if other influence factors (e.g., annulus liquid level) will be considered.

Conventional downhole detected techniques have been developed to diagnose SCP caused by the tubing leakage. The coupling model has been developed for CO2 flow and heat transfer during the leakage process with steady and unsteady state by temperature logging and profile (Zeng et al., 2012). An ultrasonic leak-detection tool has been presented for downhole applications based on ultrasonic-energy propagation detection, and continuous logging was used in locating anomalies (Johns et al., 2009). The acoustic technology has been applied to downhole leakage detection (Carpenter, 2017). Acoustic wireless pressure and temperature gauges have been used for monitoring annulus pressure in real-time (Sultan et al., 2008) and an integrated technology (Al-Hussain et al., 2015) has been proposed to detect downhole leakage in different scenarios. Other approaches have also existed for incident diagnosis and risk assessment, such as Bayesian network (Cai et al., 2016, 2017) and fuzzy comprehensive evaluation methods (Zeng et al., 2017).

However, several issues need to be further investigated when leakage diagnosis is applied to the offshore gas wells with SCP.

- The existing analytical methods cannot accurately capture the dynamic annulus pressure behaviors before and after leakage, and it is difficult to identify the specific source of SCP in a gas well, especially in the condition that the annulus pressure has no change in a deep liquid level.
- The position of leakage points has not been always located above and below the annulus liquid level, which is key to well barrier failure analysis and workover treatment of a gas well with SCP.
- The current implementation of logging and detection requires the instrument to be placed in the tubing, and the well operation needs to be shut down during diagnostic testing. This process is usually accompanied by high risk and high cost. Therefore, there is a need for performing leakage diagnosis and predicting the MAP in the offshore platform without interrupting the well production.

In order to overcome these limitations as mentioned above, the objective of this paper is to develop a new method based on pressure balance principle for leakage diagnosis of gas wells with SCP from an offshore platform. This method involves the calculation of the position of leakage points by capturing two types of dynamic behaviors of annulus pressure in the gas well with SCP caused by tubing failure. The fluid temperature distribution is taken into account for estimating the tubing and annulus pressure. In addition, Sensitivity analysis is conducted for estimating the MAP at the wellhead in the well with SCP integrating with the leakage location, bottom hole pressure, annulus liquid level and natural gas production rate. At last, leakage diagnostic testing can be performed from an offshore platform by an integrated testing system that has been developed to monitor the synthetic state of annulus fluid and liquid level parameters and to diagnose SCP correctly.

The rest of this paper is organized as follows. Section 2 presents the principle of leakage diagnosis in a gas well with SCP. In Section 3, a pressure-balance-based model is developed for determining the location of tubing leakage and MAP at the wellhead under different factors. In Section 4, the diagnostic testing system is developed for performing leakage tests from an offshore platform. A case study focusing on an offshore gas well with SCP in tubing-production casing annulus is introduced in Section 5 to demonstrate the applications of the proposed model. Conclusion and research perspectives are given in Section 6.

2. Principles

There are two main sources to explain the gas well with SCP after well completion: One is a leakage, and the other is the effect of thermal expansion of the downhole fluid. The SCP caused by the latter can be checked by the relief-pressure and recovery-pressure operation according to API-IP90 (API, 2006), so it is out of the scope of this study. This study mainly focuses on the gas well with SCP due to a leakage.

The tubing leakage is considered as a main possible cause of tubing-production casing annulus pressure buildup. It is essential to perform leakage diagnosis to predict SCP and assess the risk in early time. The principle of leakage diagnosis is shown in Fig. 1, where the state of gas flow from tubing to annulus and changes in pressure behaviors are illustrated. According to the principle of pressure balance between tubing and annulus when a gas well is leaking in a stable stage, the tubing pressure (P_{TL}) is equal to the annulus pressure (P_{CL}) at the leakage point of tubing. The relationship of pressure balance is expressed as follows:

$$P_{TL} = P_T - \Delta P_T \tag{1}$$

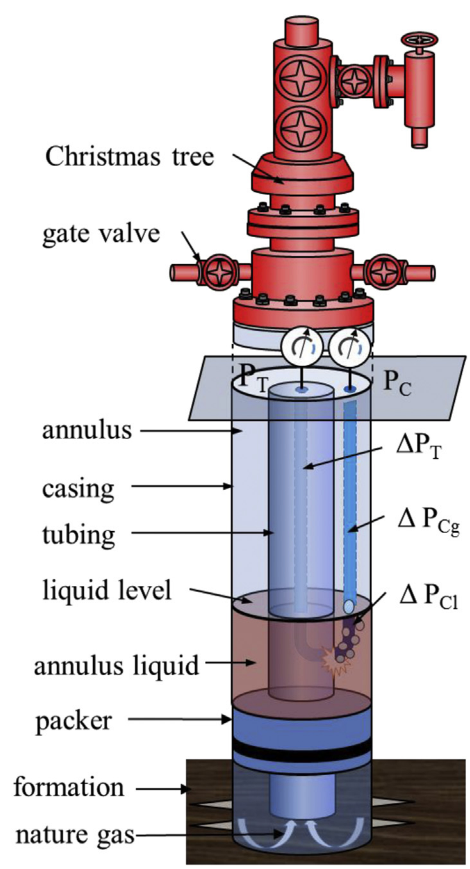

Fig. 1. Typical wellbore pressure distribution.