



Assessing integrity of the gas-lift valves by analyzing annular-pressure-transient response

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ABSTRACT

Gas-lift valves (GLV) by definition are designed to allow influx of the annular gas into the tubing and prevent any backflow even when a pressure differential exists toward the annulus. However, elements, such as erosion, corrosion, scale, fatigue, vibration, and temperature and pressure effects may cause the GLV to leak, thereby posing a serious safety issue. Because of the well-integrity concern, suspected GLVs are often retrieved with a wireline from the side-pocket mandrel for inspection. Proactive testing is a way to minimize such costly intervention.

This paper details a methodology for determining a GLV's integrity that avoids retrieving the valve and relies on examining the annular transient-pressure response. Based on the models developed, we propose a robust, nonintrusive test procedure saving time and expense. The proposed method is validated with field data from three offshore wells. We also present a forward model that helps design test methodology.

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1. Introduction

The use of gas-lift technology dates back to the 1940s. Recently, Decker (2008) provided some insights into modern design and use of injection-pressure-operated gas-lift valves. Accurate models are also available for calculating critical flow rate across Venturi valves, especially for high-pressure gas-lift systems, as proposed by Almeida (2011). Given the widespread use of gas-lift as an artificial-lift mechanism, integrity of GLV is of great interest to the industry. Accordingly, some operators (Xu et al., 2012; Carlsen et al., 2010) have taken proactive measures to ensure the GLV safety, beyond those suggested by the API recommended practices (1999, 2008, 2010). To improve well safety, Gilbertson et al. (2013) offered a passive, thermally actuated safety valve for offshore wells.

The use of artificial intelligent agents, such as the one described by Stephenson et al. (2010) to diagnose the lift system has significantly helped manage data gathering and interpretation, and subsequent actions. Models have also been offered to design and analyze flow instability; the studies of Poblano et al. (2005), Blick et al. (1988), and

Asheim (1988) are cases in point. More recently, Garcia (2013), Eikrem et al. (2008) and others have offered stability analysis when cyclic variations in pressure and production rates occur resulting in significant disturbances to the downstream processing facility.

Despite the long operational history of the gas-lift system, methods for testing GLV integrity appear limited in the open literature. This paper attempts to provide some insights into model development and interpretation of field data. Specifically, this study presents a methodology for computing flow rate of the tubing liquid across the GLV into the annulus by drawing down the annular gas and the subsequent buildup of pressure measured at the casinghead. These two tests allow estimation of the liquid leakage rate independently, thereby instilling confidence in solutions.

Field data from three offshore wells were used to validate the models. In particular, the liquid-level data, gathered during the acoustic well-sounding test confirmed the solution quality. These models are predicated upon the use of mechanical energy-balance equation and thermodynamic relations for estimating the annular-gas temperature. Computations showed that the use of both the constant geothermal gradient and polytropic expansion/compression yielded very comparable solutions. Our expectation is that the lessons learned can set the stage for testing subsea completions wherein discharge of annular gas can be done remotely and where direct measurement may be impractical or uneconomic.

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2. Model development

The model relies upon calculating the total amount of gas in the annulus at each timestep. From knowledge of the liquid level in the annulus and the casinghead pressure, the total volume of gas and its density can be calculated, leading to the computation of total mass of gas as a function of time. Here, we are assuming that all fluid influx into the annulus is through a faulty GLV. Flow through leaky tubing or flow through faulty cement sheath can contribute to fluid influx into the annulus; the model presented here is not designed to distinguish the source.

Because density varies nonlinearly with depth, the annulus is subdivided into a number of cells for numerical integration. The average pressure and temperature of a cell is used to calculate the gas density, which is then used to evaluate the mass in that cell, as well as the pressure difference across the cell. Fig. 1 depicts a typical gas-lift system.

To represent the PVT behavior of gas in the annulus, the generalized thermodynamic relation is given by

$$pV = ZnRT \quad (1)$$

Eq. (1) may be used to write an expression for gas density, needed to estimate pressure profile in the annulus, which is given by

$$\rho_f = \frac{29\gamma_g p}{ZRT} \quad (2)$$

The model is based on the application of mechanical-energy balance to the annular gas. Neglecting work done and heat received, the general mechanical-energy balance in integral form is written as

$$\int_{p_1}^{p_2} \frac{dp}{\rho_f} + \frac{g}{g_c}(z_1 - z_2) + \frac{(v_2^2 - v_1^2)}{2g_c} + \frac{fv^2(z_1 - z_2)}{2g_c d} = 0 \quad (3)$$

Eq. (3) relates the gas pressure difference to potential, kinetic, and frictional losses. Although gas does flow up the annulus during a bleed-down test, the velocity is small enough such that energy losses owing to kinetic energy change and friction (less than 0.01% of total) are neglected. Under these conditions, the last two terms on left side of Eq. (3) may be neglected. Therefore, one can solve Eq. (3) to obtain pressure p_2 at depth z_2 from known pressure p_1 at depth z_1 , with the following expression:

$$p_2 = p_1 \exp \left[\frac{29\gamma_g(z_2 - z_1)}{ZRT} \frac{g}{g_c} \right] \quad (4)$$

In Eq. (4), $\bar{Z}$ and $\bar{T}$ represent average gas-law deviation factor and temperature of the annular gas, respectively.

We use an iterative procedure to calculate pressure p_2 at depth z_2 with Eq. (4), within a preset tolerance. Starting at the casing-head, this procedure calculates the gas-pressure profile in the annulus at any given time. Thereafter, the mass of gas in each cell is calculated using an average pressure and temperature for the cell and the following gas-law expression:

$$n_1 = \frac{(p_2 + p_1)V_1 M}{2ZRT} \quad (5)$$

In Eq. (5), M is the molecular weight of the gas. The total mass of gas m_t in the annulus at time t is estimated by simply adding the

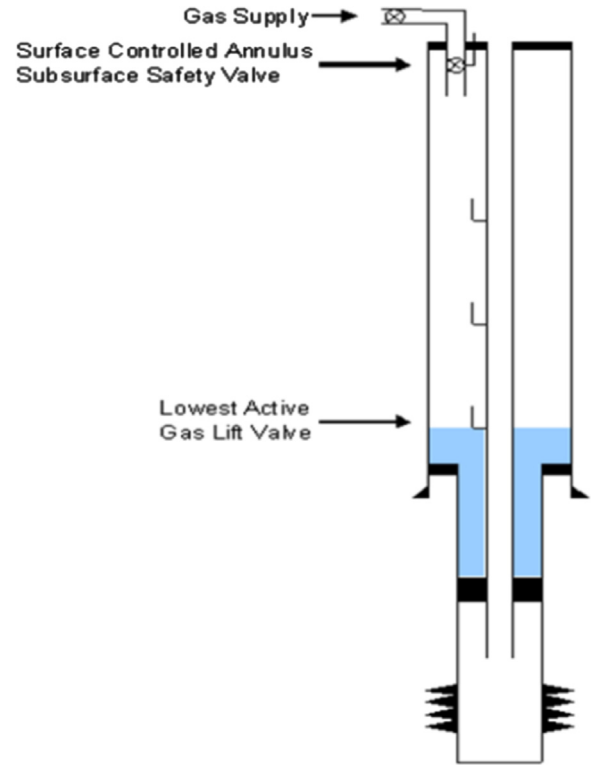


Fig. 1. Schematic showing the gas-lift valve configuration in a typical well.

mass in each cell, which is given by the following expression:

$$m_t = \sum_1^J \frac{(p_i + p_{i+1})V_i M}{2Z_i R T_i} \quad (6)$$

When gas is expelled from the annulus or compressed during a buildup test, adiabatic expansion or compression is a possibility. The short duration of the tests implies that the heat loss/gain from the system will be minimal and the process may be treated as adiabatic. Even when the expansion/compression is not fully adiabatic, a polytropic (POLY) expression can represent the gas temperature change with pressure, which is given by Smith et al. (2005) as

$$T_2 = T_1 \left(\frac{p_2}{p_1} \right)^{\frac{\lambda-1}{\lambda}} \quad (7)$$

For an adiabatic process, $\lambda = c_p/c_v$, is the ratio of the specific heats of a gas; for a polytropic process, λ is an empirical constant with a slightly different value, ranging from 1.1 to 1.4. In our analyses, we used a value of 1.1.

Our general computational approach for various conditions relies upon the use of Eq. (6) to calculate the total mass of gas in the annulus at time t , and compare that to the mass calculated at the next timestep $t+1$ to determine the net gas flow rate. This approach is schematically shown in Fig. 2 and specific applications of this methodology under various conditions are discussed below.

3. Model validation with field data

This section discusses analysis of field data for three different types of tests, such as pressure buildup (PBU), constant-pressure bleed-down (CPB), and drawdown (DD) test. Of course, the PBU test follows annular bleed off. Three independent tests on two

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