Annular pressure evaluation of high temperature high pressure gas well

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Abstract. The integrity of high temperature and high pressure (HTHP) gas well is one of the challenges to the safe and stable production of Tarim Oilfield. As a result, conducting test and evaluation on these wells are of great significance. In this paper, the state of the art of researches related to annular pressure are firstly reviewed, which is followed by the summary of the characteristics and applicable scenarios of the well integrity techniques. In terms of the fact that there are a lot of HTHP gas wells with annular pressure but large scale logging or snubbing operation is unworkable, a method of preliminary integrity is developed. For this method, annular pressure relief and recovery are firstly carried out, with using the ultrasonic method to determine the liquid level of annular space, the pressure gradient and leakage of the annular space can be determined. By using this method, test and evaluation on annular pressure of a HTHP gas well in Tarim Oilfield are conducted and the failure of well barrier parts are determined. Study and filed test show that this simple method can be useful in the preliminary screening of HTHP gas wells before the large scale test operation and thus providing technical support for the logging and snubbing operations.

Keywords: Annular pressure, high temperature high pressure, gas well.

1 Introduction

At present, oil and gas exploitation in China continues to increase, and gradually turn to deep and ultra-deep complex oil and gas resources[1, 2]. With the increase of well depth, the underground working conditions become gradually complicated, and the problem of wellbore safety becomes prominent[3]. High temperature high pressure (HTHP) characteristics are common in gas wells, which increases the difficulty of safe and efficient production. Due to the differences in formation characteristics, production technology and wellbore status, there are few experiences for reference at home and abroad, which poses great challenges to production and management[4].

For most HTHP gas wells, sustained casing pressure has become one of the most important factors affecting the safe production[5]. If the gas in the production layer breaks through the barriers, it will have a significant impact on the environment and safety. Especially because natural gas is highly combustible, the consequences are very serious once it leaks to the ground[6]. In recent years, scholars all over the world

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have conducted extensive research on the sustained casing pressure, including theoretical analysis and testing.

The current research on annular pressure is mainly based on theoretical analysis, and the control of annular pressure is carried out through the sensitivity analysis of annular pressure. Zhang Ximing et al.[7] introduced the diagnostic testing and supporting equipment for a sustained casing pressure in offshore gas wells. Zhang Bo et al.[8] reviewed the existing detection technologies for deep oil and gas wellbore integrity, and formed a detection method with "acoustic wave + electromagnetic" as the core. However, systematic testing of producing wells is a costly and demanding task, and sometimes involves interrupting production. This paper introduces a method to evaluate the integrity of HTHP gas wells through annular pressure testing, which can evaluate the risk wells and controlling costs without affecting production.

2 Sustained casing pressure mechanism of HTHP gas well

For oil and gas production wells, the annulus between tubing and production casing is defined as A annulus, the annulus between production casing and technical casing is defined as B annulus, and other annulus are successively divided into C annulus and D annulus. Sustained casing pressure refers to the phenomenon that the annular pressure of a gas well should be close to 0 or the minimum annular pressure, but the actual high pressure is maintained continuously. Sustained casing pressure is very common in gas wells, of which sustained A annular pressure is the most common[9].

As shown in Fig. 1, the A annulus of a gas well is usually filled with a certain volume of annular protection fluid, and the valve on the tubing head is closed during normal production.

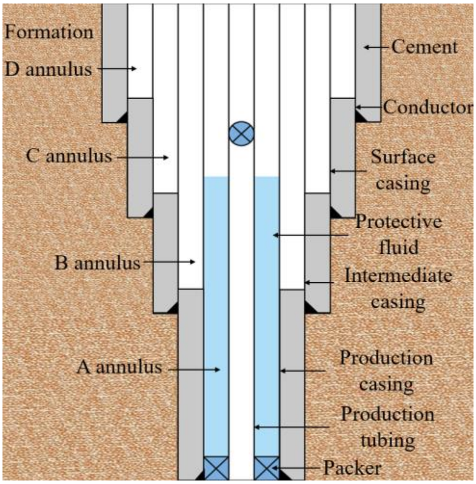

Fig. 1. Sketch drawing of the annular structure of gas well

Affected by underground high temperature, the annular protection fluid evaporates and rises to the top of the A annular, and the accumulated gas continues to hold pressure at the wellhead, which may cause accidents. Due to the thermal expansion and contraction effect, high temperatures underground can also cause thermal expansion of tubing and casing, cement sheath, and wellbore fluids. Thermal pressure caused by volume change is also a major cause of sustained casing pressure[10]. Normally, sustained casing pressure caused by temperature changes is easy to eliminate, and this also applies to situations where the annular pressure slowly recovers after pressure relief.

During the production process of HTHP gas wells, sometimes the pressure actively is injected into the annulus to maintain the pressure balance in the annulus space or to make the casing string properly stressed. Such pressure is simple to control.

The practice shows that one of the main causes of sustained casing pressure in HTHP gas wells is the failure of well barrier components. Annular pressure is caused by gas leakage, and this type of pressure is the most risk. For the influence of the factors, such as HTHP, corrosion, complex formation structure, etc., HTHP gas well barrier components fail frequently. For example, production packer leakage, production string corrosion perforation and joint seal failure, tubing hanger seal failure and other forms frequently occur [11]. The failure of barrier components often leads to annular connectivity, and some wells may also have multiple leakage points and multiple connecting channels. The number of leakage points, the types of leakage are complicated, and some leakage points are located below the annular protection fluid, which brings great challenges to well integrity detection [12, 13].

3 Analysis of the annular pressure of a wellbore

The total pressure gradient of the fluid in the wellbore is mainly composed of three parts: acceleration pressure gradient, gravity pressure gradient, and friction resistance pressure gradient, as shown in Equation 1.

$$\frac{dp}{dz} = \left(\frac{dp}{dz}\right)_a + \left(\frac{dp}{dz}\right)_h + \left(\frac{dp}{dz}\right)_f \tag{1}$$

where $\left(dp/dz\right)_a$ is the accelerating pressure gradient, $\left(dp/dz\right)_h$ is the gravitational pressure gradient, and $\left(dp/dz\right)_f$ is the frictional pressure gradient. According to the relationship between these three parameters and the pressure can be derived from the pressure change model, as shown in Equation 2.

$$dp = -\frac{d\left(\rho v^2\right)}{2} - \rho g dz \cos\theta - f\frac{\rho v^2}{2d_{ci}} dz \tag{2}$$

where p is the pressure in the wellbore, ρ is the fluid density, v is the fluid velocity, z is the column length, θ is the slope angle of well, f is the coefficient of friction, d_{ci} is the column inner diameter.

Equation 3 shows the fluid density calculation method, derived from the gas equation of state. By combining equations 2 and 3 with the mass, momentum, and energy equations, the wellbore temperature and pressure models are obtained.

$$\rho = \frac{pM}{Z_g RT} = 3484.48\gamma \frac{p}{Z_g T} \tag{3}$$

where M is the molar mass of gas, Z_g is the body compression factor, R is the gas constants, T is the gas temperature, γ is the relative density of gases.

In the radial direction only the conservation of energy needs to be satisfied, in the axial direction both of these need to be satisfied. Fig. 2 shows the temperature and pressure changes in the tubing when a leak occurs.

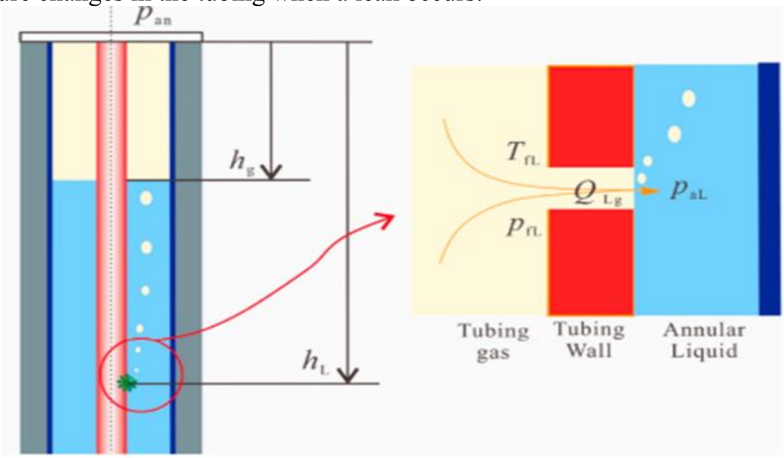

Fig. 2. Sketch of the gas leakage process

4 Annular pressure test on HTHP gas well

In recent years, a number of high-pressure gas wells in Tarim Oilfield have released combustible gas from A annulus during irregular annulus testing, which means that well integrity is at risk. In order to ensure the secure production, it is necessary to carry out the risk assessment of the producing well and determine the possible leakage path. It is a common approach for risk wells, where wells are thoroughly inspected with equipment to identify critical barrier components. However, according to the international classification method of risk wells, most high-pressure gas wells in Tarim Oilfield belong to orange or even red grade. The use of equipment to detect these wells not only has high operating cost but also has great influence on production.

When logging is not possible, management for risky wells is usually based on real-time monitoring of annular pressure and temperature data. Perform simple pressure relief and pressure recovery tests and then conduct qualitative analysis based on the results of the relieve-pressure recovery curve and combine the well classification results to determine whether engineering logging and quantitative risk analysis are necessary. Fig. 3 shows the physical measurement setup used for the test, wherein a number of sensors are designed to measure the temperature, pressure, and fluid depth of the wellbore.

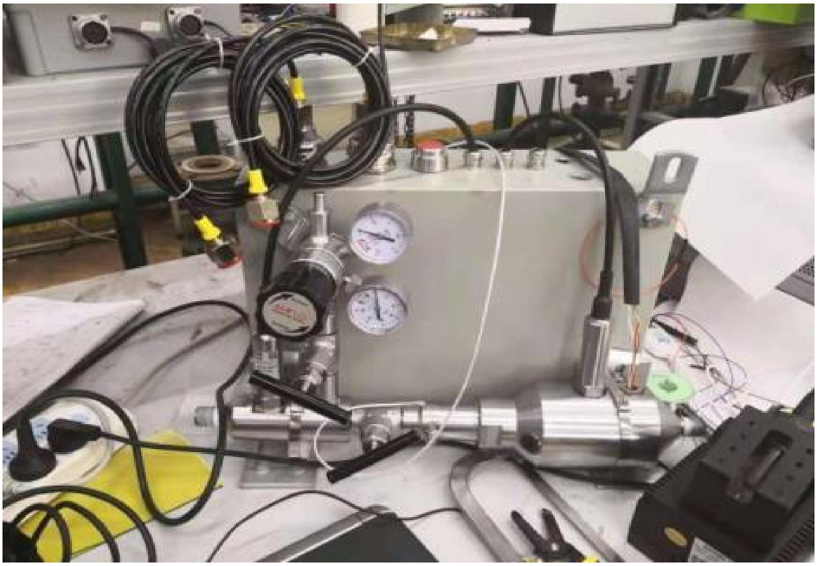

Fig. 3. Sketch of the gas leakage process

5 Annular pressure test and discussion

A HTHP gas well in Kela Gas field, Tarim Oilfield, with a depth of 6,310 m, formation pressure of about 106 MPa and temperature of about 151 °C, it was completed in September 2018. During the test in March 2023, it was found that combustible gas was released from annulus A, which carried risks. In order to further clarify the well barrier state, the well is qualitatively analyzed again.

Fig. 4 shows the tubing pressure and annulus pressure characteristics during the well relief period. A seal problem occurred in the A annulus valve during pressure relief, and the repair was completed before the second pressure relief, during which the A annulus pressure value was not monitored. Fig. 5 shows the tubing pressure and pressure characteristics of each annulus during the pressure relief period of the well on the B annulus (pressure values recorded every 5 seconds). During this period, the pressure fluctuated due to the operator rotating the handwheel twice to open and close the valve. Based on the annular operation record of the well, including the amount of annular protection fluid injected and the liquid level position, it is determined whether the production string of the well is intact, whether the casing hanger seal is degraded, and whether the technical casing hanger BT seal is invalid.

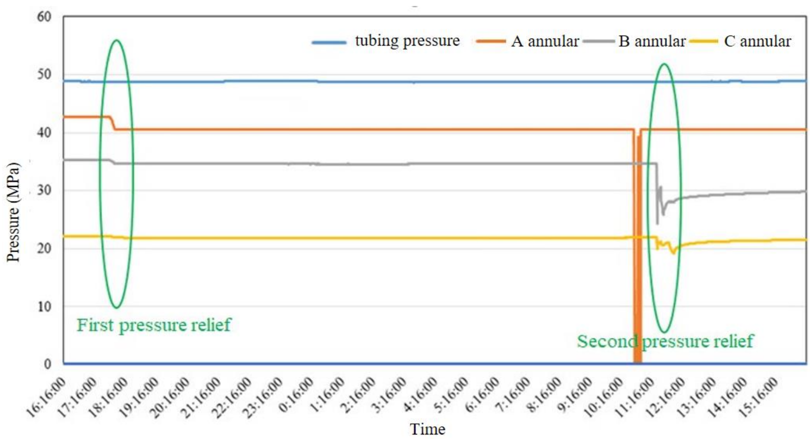

Fig. 4. The pressure characteristics of a well in the period of pressure relief

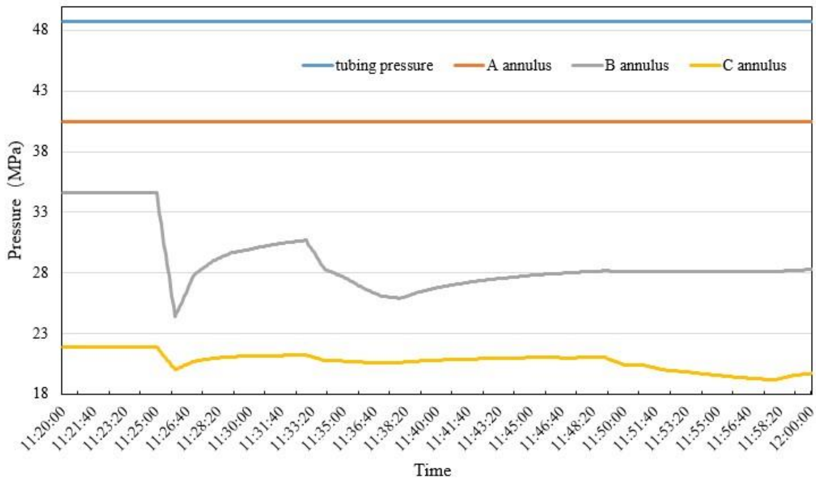

Fig. 5. The pressure characteristics of a well in the period of pressure relief for B annulus

6 Conclusions

In order to meet the needs of HTHP gas well integrity assessment, the existing well integrity detection techniques are compared. Considering that most gas wells in Tarim Oilfield are HTHP and the annulus is generally pressurized, it is impossible to carry out large-scale logging and workover. A preliminary assessment is proposed by means of annular pressure relief and recovery combined with ultrasonic measurement of liquid level.

In order to solve the integrity problem of HTHP gas well in Kela gas field of Tarim oilfield, a number of pressure relief and pressure recovery tests were carried out on A and B annulus respectively. Based on the annular operation records of the well, determine whether the production string of the well is intact, whether the sealing of the casing hanger has deteriorated, and whether the sealing of the technical casing hanger BT has failed. The integrity detection of HTHP gas wells should take gas as the leakage medium as far as possible to avoid measures such as string workover that may aggravate the failure of well integrity. Prior to extensive testing and workover with production instruments, the well integrity is initially assessed through annular pressure relief and recovery and ultrasonic level measurement (as many times as needed). After the location and severity of the leak are determined, further accurate testing and evaluation can be carried out.

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