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A method to calculate the annular liquid volume of an immobile string

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ABSTRACT

Immobile string technology is often used to develop the production of multi-layer and thin low-permeability gas reservoirs. This type of reservoir is characterized by low productivities and high pressure drop rates. Simplified ground facilities and control choke technologies are often adopted to effectively reduce the investment. Because gas wells in low permeability gas reservoirs often have low productivities (for instance, the individual well production rates in the Sulige Gas Field range from only 3000 m^3/d to 5000 m^3/d), a large number of adopted down-hole sensors will result in gas fields that are unable to run properly. The water production data and the bottom pressure become difficult to measure. The casing pressure is controlled by both reservoir pressure and liquid accumulation. To predict liquid volume correctly, the superposed effects of the reservoir pressure and liquid accumulation should be stripped as a priority. Taking the dynamic reserve, production proration and production rate into consideration, we analyzed the casing pressures of dry gas wells. In addition, we quoted a parameter (the production rate in the unit casing pressure drop) to remove the influence of reservoir pressure drop and the output fluctuation "noise" on casing pressure. To strip out the effects of liquid accumulation, we discussed the casing pressure under different liquid accumulation rates. Through the above research, we created a method to calculate the annular liquid volume of an immobile string. This method applied to the Sulige Gas Field very well, and it can also be introduced to other similar gas reservoirs.

1. Introduction

Immobile strings (Ma et al., 2011; Yang et al., 2013; Zhang et al., 2013a) can simultaneously achieve multi-layer separated fracturing and commingled production. Because the production of many gas wells in low permeability gas reservoirs is low, a large number of adopted down-hole sensors will result in gas fields that are unable to run properly. To improve economic returns, simplified ground facilities (Wang et al., 2014) and control choke technologies (Li et al., 2009) are often adopted. Thus, the water production data and the bottom pressure are difficult to determine.

Many methods such as the Turner Model (Turner et al., 1969), the Coleman Model (Coleman et al., 1991), the Nosseir Model (Nosseir et al., 1997), Li's Model (Li et al., 2001), and the four-phase flow model (Gun et al., 2005), which is based on the minimum kinetic energy criterion and four-phase flow, address wellbore liquid prediction. These methods can estimate the liquid loading situation of the wellbore but cannot determine the liquid volume. In 2010, Schiferli (Schiferli et al., 2010) improved the Turner Model by controlling the properties of the wellhead. By using production data fitting, this method can describe the fluid changes associated with intermittent production. However, there was no research on the characteristics of the fluid changes under the normal production status, and the author also did not give the method for the calculation of liquid volume. In 2011, Yang et al. (2011) presented a method that compares the values of the calculated pressure and the observed pressure to determine the wellbore liquid. However, under the circumstances of the absence of observed bottom pressure, this method can only determine whether the liquid is accumulating in the wellbore.

In general, most of the research on liquid prediction has been focused on the liquid loading part. However, studies of the liquid volume calculation are still lacking, although Yang et al. proposed a method to calculate the liquid volume using a known pressure. In addition, the situation becomes more complex when a control choke exists in the wellbore. For example, compared with conventional production data, it is difficult to use the tubing pressure to analyze production performance directly. Considering dynamic

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reserves, production proration and production rate, we analyzed the casing pressure of dry gas wells and the casing pressure under different liquid accumulation rates. We use these results as qualifications to build a method to calculate the annular liquid volume of an immobile string.

This paper takes the Sulige Gas Field as an example to discuss the specific process of the proposed method. The Sulige Gas Field is a typical lithologic gas reservoir that is characterized by low permeability, low pressure, and low abundance. Many gas wells in this field have low production and high pressure drop rates. To realize effective development, the Sulige Gas Field adopted a series of "cost leadership strategies" (such as control choke technologies), simplified the ground facilities, and used immobile string technology to achieve high efficiency development.

2. Construction of an immobile string

The main components of an immobile string (Zhang et al., 2013a) include the well tubing, compensating pipe, cyclical backwash switch, safety joint, hydraulic anchor, mechanical packer, sand sliding sleeve and setting ball (Fig. 1). The production principle of an immobile string is the foundation of annular liquid volume prediction, mainly reflected in the following aspects: shoot several gas layers at one time, land the immobile string, insert the same-size steel ball and open the sand blaster to achieve multi-layer separated fracturing and commingled production.

In the process of liquid accumulation, when the liquid height is lower than the uppermost sliding sleeve (the conventional tubing shoe), the casing pressure is normal as the pressure decreases, and this decrease is affected by the reservoir pressure and liquid accumulation. When the liquid height is higher than the uppermost sliding sleeve, the casing pressure will become abnormal as the pressure increases, and this pressure increase is affected by both the reservoir pressure and the gas compression of the annular. Therefore, we should analyze the boundary of the casing pressure drop under different dynamic reserve and production proration conditions.

3. Methodology

3.1. Relationship between liquid accumulation and casing pressure

3.1.1. Characteristics of the casing pressure of dry gas wells

To determine the natural decline rate of the casing pressure, we used dry gas wells of the Sulige Gas Field as examples to analyze the characteristics of the casing pressure. In this paper, we mainly adopt the material balance method and the cumulative production method to calculate dynamic reserves of these wells (He, 2010; Zhang et al., 2013b).

3.1.1.1. Material balance method. For a normal pressure gas reservoir system, the material balance equation can be expressed as

$$G = \frac{G_p B_g - (W_e - W_p B_w)}{B_g - B_{gi}} \tag{1}$$

where G_p is the cumulative production, G is the dynamic reserve, W_e is the accumulate influx water, W_p is the accumulated production water, B_w is the water volume ratio, B_g is the gas volume ratio, and B_{gi} is the original gas volume ratio.

For closed volumetric gas reservoirs, Eq. (1) can be simplified as

$$G_p B_g = G(B_g - B_{gi}) \tag{2}$$

where

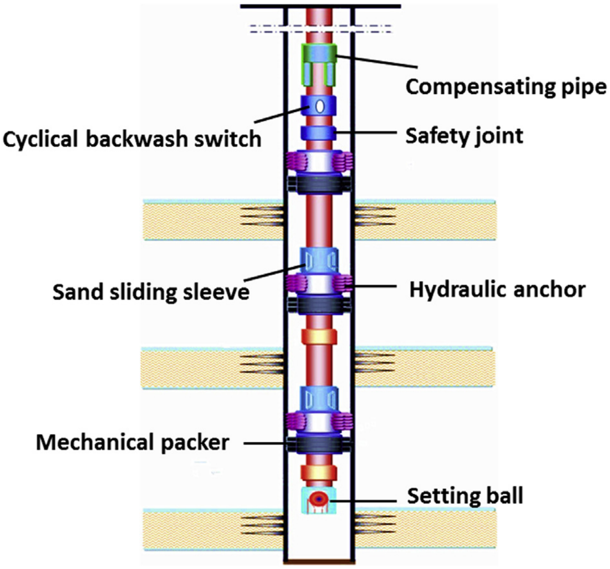

Fig. 1. Multi-layer separated fracturing immobile string.

$$B_g = \frac{p_{sc} Z T}{p T_{sc}} \tag{3}$$

$$B_{gi} = \frac{p_{sc} Z_i T}{p_i T_{sc}} \tag{4}$$

Substituting Eq. (3) and Eq. (4) into Eq. (1) or Eq. (2) can produce the method to calculate dynamic reserve.

The material balance method to calculate dynamic reserve adapts when the recovery percent of the reserves is larger than 10 percent.

3.1.1.2. Cumulative production method. The cumulative production method to calculate dynamic reserve is an empirical method. According to the mining experience, the relationship between cumulative production and time can be expressed as

$$G_p \cdot t = A_1 t - B_1 \tag{5}$$

When t tends to infinity, b/t tends to zero. Then, the G_p-t curve will tend to the horizontal asymptotic line. At this point, the value of A_1 approximates the dynamic reserve.

In most cases, the correction formula has a wider application:

$$G_p \cdot (t + C_1) = A_1 (t + C_1) - B_1 \tag{6}$$

Take two points on the G_p-t curve, coordinate values (G_{p1},t_1) and (G_{p3},t_3), take another point (G_{p2},t_2) between G_{p1} and G_{p3}:

$$G_{p2} = (G_{p1} + G_{p3})/2 \tag{7}$$

Then, the value of C_1 can be determined:

$$C_1 = \frac{t_2(t_1 + t_3) - 2t_1 t_3}{t_1 + t_3 - 2t_2} \tag{8}$$

This method to calculate dynamic reserve adapts when the recovery percent of the reserves is larger than 40 percent.

After having obtained the dynamic reserve, we analyzed the casing pressure under different dynamic reserve and production proration conditions (Table 1 and Fig. 2). According to the results, the maximum decline rate of the casing pressure of the dry gas