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A new approach to risk control of gas kick in high-pressure sour gas wells

Hu Yin [a,*], Pu Liu [a], Qian Li [a], Qiang Wang [b], Dewei Gao [b]

[a] School of Petroleum Engineering, Southwest Petroleum University, Chengdu 610500, PR China
[b] Northwestern Sichuan Gas District, Petrochina Southwest Oil&Gasfield Company, Jiangyou 621700, PR China

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ABSTRACT

During drilling in high-pressure sour gas well, the occurrence of gas kick may cause serious consequences. Generally, in order to prevent gas kick, higher density of drilling fluid is adopted to keep adequate positive pressure difference in hole bottom. The requirement of positive pressure difference in China is 5 MPa. However, due to the narrow mud weight window in most high-pressure sour gas well, this method could not keep both equivalent static density and equivalent circulation density within the safe window. The lower density of drilling fluid could not ensure hydrostatic pressure higher than a pore pressure of 5 MPa; while higher density may cause leakage and therefore trigger blowout. In this paper, an improved approach is proposed to solve this problem, which involves bottom-hole pressure control methods and necessary equipment. A case study shows that the conventional method cannot develop a reasonable mud density while the improved method can ensure a bottom-hole pressure within the narrow pressure window. The results show that the improved method not only solves the problem of circulation loss that occurs in conventional drilling, but also meets the Chinese standards of well control in high-pressure sour gas wells, providing a new technique for the risk control of gas kick.

1. Introduction

The exploration and development of high-pressure sour gas wells are accompanied by high operating risks and serious potential hazards. One of the greatest technical challenges is the toxicity of hydrogen sulphide, which is as toxic as hydrogen cyanide or carbon monoxide (Guidotti, 2010; Reiffenstein et al., 1992; Selene and Chou, 2003). Therefore, drilling engineers must prevent the formation fluids from displacing the drilling fluids into the wellbore. The flow of formation fluids into the wellbore is called a kick, and the uncontrolled flow to the surface is known as a blowout. If a blowout occurs during the sour gas well operation, there is a high possibility of grave calamity, like the “12.23 Blowout Accident” in Kaixian County, Chongqing City, in 2003. The Luojia 16H well blew out rich hydrogen sulphide gas up to 30 m, with a hydrogen sulphide concentration above 100 ppm. More than 93,000 people were affected, and over 65,000 people were forced to evacuate, with 234 deaths, and the direct economic loss was RMB 82 million (Chen, 2005; Jiang and Deng, 2011; Li-bing, 2013; Li et al., 2011).

Complexity of pressure systems is another technical challenge in drilling high-sulphur gas reservoirs. In some sections of this type reservoirs, the high-pressure gas layer, the leaky layer, and even the fracture layer can coexist which will cause the narrow mud weight window (NMWW). Leakage, spray and even collapse might occur in NMWW, all of which could possibly extend the drilling time and cause HSE (health, safety and environment) problems. Furthermore, the problem of gas kicks will become more serious in this case because a variety of different factors can cause the kicks (Choe and Juvkam-Wold, 1997; Hornung, 1990; Low and Jansen, 1993; Nas, 2011). Generally, there are four main causes:

(1) **Insufficient mud weight.** Insufficient mud weight directly results in a pore pressure that exceeds the bottom-hole pressure; fluids begin to flow from the formation into the wellbore, and a gas kick occurs afterward.
(2) **Fail to keep the borehole full during trips.** When the drill string is pulled out of the hole, the mud level falls because the drill string no longer displaces the mud. As the overall mud level decreases, the borehole should be periodically filled with mud to avoid the reduction of the hydrostatic pressure.

* Corresponding author.
E-mail address: yinhu@swpu.edu.cn (H. Yin).

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(3) **Lost circulation.** A decreased hydrostatic pressure derives from a shorter mud column because of an increase in the mud density to a value that exceeds the lowest fracture pressure/loss pressure. When a gas kick occurs from loss of circulation, the problem may become severe. A large amount of kick fluid may enter the hole before rising mud level is observed at the surface.
(4) **Swabbing of formation fluids into the borehole.** If the drill string is pulled out of the borehole too quickly, the condition known as "swabbing" and other undesirable hydraulic effects will occur. Swabbing involves a reduction of total hydraulic pressure in the hole and a less-than-normal pressure for the hydrostatic pressure of the static drilling fluid column.

Among the causes mentioned above, loss of circulation is the most commonly overlooked. In most cases, the cause of gas kicks or blowouts is unrelated to low mud density that cannot balance pore pressure but is due to the high mud density that leads to a loss of circulation in the NMWW condition.

Many scholars have been trying to develop an effective method to avoid blowout in the NMWW stratum. There are two main technical methods: 1) Extend the mud weight window. The core of this method is to increase the fracture pressure with physical or chemical methods, such as pre-treatment of wellbores to strengthen the rock (Adachi et al., 2004; Alberty and McLean, 2001; Aston et al., 2004) and the utilization of non-invasive drilling fluid (Ivan et al., 2002; Santos and Olaya, 2002; Sweatman et al., 2001). 2) Control the annulus pressure and ECD (equivalent circulating density). The narrow mud weight window demands a rigorous ECD management to prevent the fracture pressure from being exceeded, otherwise it may result in severe fluid losses (Fraser and Aragão, 2001). Therefore, this method focuses on improving the drilling conditions without changing the mud weight window, and mainly concentrates on adjusting the rheology of the drilling fluid (Van Riet, Reitsma and Vandecraen, 2003) and optimizing the casing program.

However, these methods are limited to only a few situations. In this paper, an improved approach which involves bottom-hole pressure control and necessary equipment is proposed to prevent gas kicks or leakage before spews.

1.1. Conventional pressure control method

In conventional over-balanced drilling, the upper limit of safe mud weight window is the fracture pressure, while the lower limit is pore pressure. To avoid or minimize gas kick occurrence during drilling, the bottom-hole pressure must remain within the safe window. Hence, the hydrostatic pressure in the well should exceed the pore pressure. A reasonable drilling fluid is the key to achieve this goal, especially when drilling high-pressure sour gas wells which have more potential drilling risks. According to The Professional Standards Compilation Group of People's Republic of China (2005) and DOP2-01, American Well Control Handbook, drilling fluid density is determined by the safety value and formation pore pressure. In China, this means adding a safety value between 0.07 g/cm^3; and 0.15 g/cm^3, or ensuring that the bottom-hole pressure exceeds the pore pressure of 3 MPa–5 MPa. Often, the approach to be adopted depends on the depth of the well: a mud weight of 0.07 g/cm^3 to 0.15 g/cm^3 in shallow wells, whereas a bottom-hole pressure of 3 MPa–5 MPa in deep wells. Drilling in a formation containing hydrogen sulphide gas should adopt the upper-limit value.

This technique is relatively economical, because it requires the least expertise and easiest well control. However, it has the lowest rate of penetration due to the usage of heavy mud and could lead to a loss, stuck piping, or formation damage (Adams and Charrier, 1985; Bourgoyne et al., 1986). Fluid losses, especially severe or total fluid losses, will cause high cost and risk, such as drilling fluids replacement, and in extreme cases, losses in hydrostatic pressure can cause an influx of gas or fluid, potentially resulting in a blowout of the well.

In the process of conventional drilling without a wellhead backpressure supply, the bottom-hole static pressure is equal to the hydrostatic pressure, and the bottom-hole dynamic pressure circulation is the sum of the hydrostatic pressure and the annular pressure loss. The following equations are used to describe this situation.

Under static conditions:

$$P_{bm} = P_H \tag{1}$$

Under dynamic conditions:

$$P_{bm} = P_H + P_f \tag{2}$$

where P_{bm} is the bottom-hole pressure, P_H is the hydrostatic pressure and P_f is loss of annular pressure.

The conventional pressure control method is illustrated in Fig. 1, which shows that the safety value of the mud density causes the mud density window to become narrower. In this case, the bottom-hole dynamic pressure will exceed the formation fracture pressure or the hydrostatic pressure will be lower than the required value. Thus, there is a dilemma of whether to violate well control regulations or risk leakage. This scenario is described in detail in the following case.

1.2. Case analysis

Well C is located in the northern Sichuan basin. The drilling purpose is to exploit the marine strata, in which the hydrogen sulphide concentration is 11.39 g/m^3. Chinese national industry standards suggest that with the design of drilling fluid density in high-pressure sulphur formations, an additional safety density should take the upper limit of the prescribed scope (0.07 g/cm^3 – 0.15 g/cm^3), or an additional bottom-hole pressure should take the upper limit of the prescribed scope (3 MPa–5 MPa). Well C strictly followed the standards. However, a considerable loss of

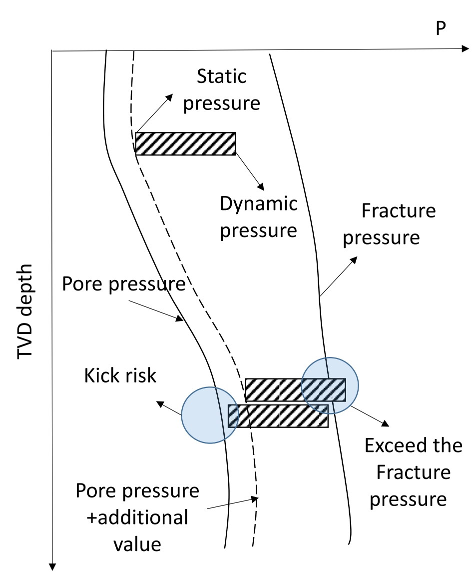

Fig. 1. A schematic for conventional pressure control.