Evaluation and treatment of casing pressure in injection/production wells of SQ underground gas storage

Siqi Wei*[a], Wei Rong[b], Xiaoping Yang[c], Zhong Pan[d], Liangwen Liu[e], Kang Yang[f], Yi Zhang[g], Huayan Li[h]

Oil&Gas Technology Research Institute of Huabei Oilfield Company, CNPC Renqiu, Hebei, China

Abstract: The evaluation and management of sustaining casing pressure (SCP) in injection/production wells of underground gas storage(UGS) is an important part of the wellbore integrity. SQ underground gas storage has experienced ten complete injection/production cycles, which puts forward high requirements on management of well integrity. At present, there are different degrees of SCP of injection/production wells of SQ UGS, which seriously threatens the safety of the UGS. This paper analyzes casing pressure in different injection/ production stages and working conditions of injection/production wells, combined with API RP 90-2, NORSOK, ISO/TS 16530-2, SY/T5724-2008 standards. We established an SCP evaluation process and a static and dynamic SCP risk evaluation system, and then proposed a four-level risk control mode for UGS injection/production wells. We formulated a production management method for wells with SCP, constantly improved the operating environment of UGS wells. We managed the injection /production wells with SCP higher than the MAWOP, especially the annular leak problem of well S7. The SCP treatment achieves effective plugging, guarantees the integrity of the injection /production wells, and achieves good repair effect, which has certain guiding significance for the evaluation of the integrity of the injection/production wells of the UGS and the management of the SCP.

1. Introduction

SQ underground gas storage group consists of S1, S2, G1, S3 and S4 underground gas storage with an average buried depth of more than 5000 meters, which is the deepest UGS in the world of which the bottom-hole pressure can reach 52MPa. During the injection and production period, many factors challenge the integrity of injection/production wells, such as high temperature, high pressure and alternating load[1].

The casing pressure in injection/production well refers to the phenomenon that the casing pressure at the wellhead returns to the value before the relief within a short time after the relief. The failure of casing, packer and wellhead device may cause natural gas to enter the annular, resulting in casing pressure. When natural gas escapes to the wellhead, it may cause serious accidents such as fire[2]. Due to cementing quality, alternating load, improper operation and downhole tool failure, casing pressure exists in UGS wells with large displacement, rapid and alternating production.

At present, there are 45 injection/production wells in SQ underground gas storage. 18 wells are newly drilled, 14 of which are with casing pressure, accounting for 78%. 21 wells are used old wells, 7 of which are with casing pressure, accounting for 33%. The SCP of the newly drilled wells mainly exists in the annular between tubing and production casing, the highest pressure can be 25.51MPa, which seriously threatens the safety and normal production of gas storage wells.

This paper mainly analyzes the causes of SCP in UGS injection/production wells, and works out an evaluation system and treatment measures suitable for SQ underground gas storage wells by combining relevant regulations and standards of SCP, so as to ensure the integrity of the wellbore and control the operational risk of UGS wells within a safe range.

2. Causes of casing pressure in injection/production wells

The NORSOK Standard, 4th Edition, defines well integrity as the application of technical, operational and organizational methods to reduce the risk of uncontrolled formation fluid release throughout the life of a well. For injection/production wells of SQ underground gas storage, one of the most important causes of wellbore integrity failure is sustaining casing pressure. Generally, the injection/production wells of gas storage are composed of multi-layer casing, so there are several annular spaces. For the convenience of expression, according to the different locations of the annulus, they are successively expressed as A, B, C annulus, etc. A annulus is the space between the tubing and the production casing, B annulus is the space

*[a]Corresponding author: yjy_wsq@petrochina.com.cn, [b]cyy_rongw@petrochina.com.cn, [c]cyy_yangxp@petrochina.com.cn, [d]cyy_panz@petrochina.com.cn, [e]cyy_liulw@petrochina.com.cn, [f]cyy_yk@petrochina.com.cn, [g]cqk_zhangyi@petrochina.com.cn, [h]cyy_lhy@petrochina.com.cn

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between the production casing and the technical casing, and so on[3]. The annular diagram is shown in Figure 1.

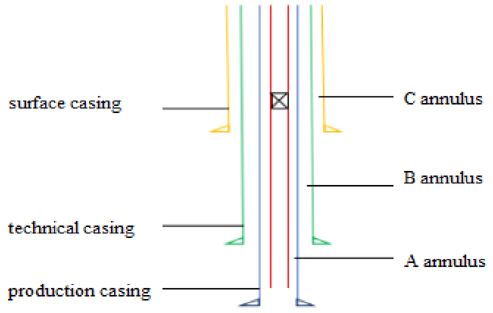

Figure 1. Annular diagram of injection/production wells

Normally, the annular space between the casing (or between the casing and the tubing) is closed. When the production is stable or the well is shut in for a long time, the pressure field and temperature field in the annular space tend to be stable, and the pressure in the annular space is basically stable. When the integrity of injection/production well shaft is not sound, the pressure generated by formation fluid and injection/production gas will make the casing pressure abnormal, and even lead to the pressure channel between annulus, resulting in major accidents and seriously affecting the safety and normal production of injection/production wells. The causes of casing pressure are as follows:

(1) Downhole pipe string leakage

Gas seal tube is used in gas storage injection/production wells. The upper buckle of gas seal tube is not up to standard, oil pipe corrosion, or seal failure of packer or other downhole tools will cause gas leakage, resulting in casing pressure in injection/production wells[4].

(2) The cementing quality is not qualified

The drilling fluid displacement is not thorough, easy to form continuous channeling, affecting the quality of cementing. Unreasonable design of cement slurry may lead to tensile fracture of cement ring, resulting in casing pressure of injection/production wells[5-6].

(3) The influence of alternating injection and production load

The injection and production alternating load will have an impact on the casing cement ring, especially the cyclic load under high pressure can lead to the cement ring micro-ring gap or crack, gas will escape through the channel [7] .

(4) Wellbore integrity is compromised by the operation

During compaction of kill fluid, casing perforation, or acid pressure modification, the cement ring may be damaged, resulting in micro-cracks between casing and cement or cement and formation, resulting in a loss of well integrity[8] .

(5) Corrosive damage

Corrosive gas, such as H_2S or CO_2, may exist in the formation and natural gas. Corrosive gas will not only corrodes the casing, but also corrodes the cement ring in a certain environment, and cases will lead to interlayer channing in serious[9].

3. Evaluation method of casing pressure in injection/production wells of SQ Underground Gas storage

3.1Casing pressure evaluation process

SQ underground gas storage construction and production, ISO/TS 16530-2 "Well integrity for the operational" is introduced on the basis of API RP 90-2 standard phase, SY/T5724-2008 "Casing String Structure and Strength Design" standard and casing pressure management specification for onshore high temperature and high pressure sulfur gas wells and gas storage injection/production wells, taking into account completion packer failure risk, completion packer crush and rupture risk, annular free casing section influence, annulus hydrostatic column pressure and other factors. The factors to be considered in the evaluation of casing pressure are more comprehensive. The safety evaluation process is shown in Figure 2.

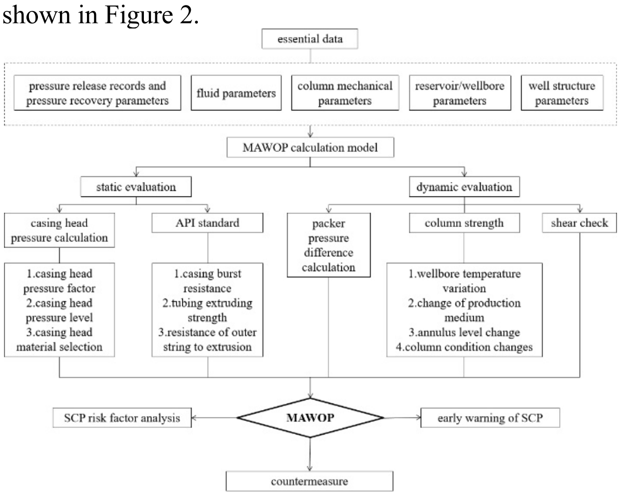

Figure 2. casing pressure safety evaluation process

3.2Casing pressure risk factor analysis

Through the nature of SQ underground gas storage reservoir itself, completion process measures and current production status factors, the casing pressure pre-analysis, to find the risk points.

3.2.1 Nature of hydrocarbon reservoir

For gas storage reconstructed from depleted oil and gas reservoirs, the properties of oil and gas reservoirs may lead to corrosion of pipe string, wellhead device and cement ring, which will further affect wellbore integrity. The influences of various factors on casing pressure are shown in Table 1.

Table 1. Hydrocarbon reservoir nature factors

Serial Number	Influencing factors	Harmful consequences
1	Formation pressure	The higher the pressure, the greater the partial pressure and the greater the risk.
2	H_2S and CO_2 partial pressure	Can induce electro-chemical corrosion, resulting in corrosion

		and perforation of the pipe column.
3	H_2S content	Leakage on the ground will pose a serious threat to human life.
4	Well depth, temperature	The deeper and hotter the well, the greater the risk of integrity failure.
5	Cl^-content	Has an effect on corrosion resistance of steel.
6	pH	Low pH increases the risk of oil casing corrosion.
7	Geographic location	Densely populated areas, gas leaks will cause secondary disasters.
8	Injection/production gas	Leakage of high injection-production gas is more serious.
9	Years of well construction	The longer the years of well construction, the worse the integrity of injection/production wells.

3.2.2 Completion process measures

See Table 2 for the influence factors of gas storage completion process measures on casing pressure.

Table 2. Factors of technological measures

Serial Number	Influencing factors	Harmful consequences
1	Embalming Scheme	Improper anti-corrosion measures can corrode the oil casing and cause gas leakage.
2	Gas seal detection	If the gas seal is not tested, the gas seal tubing may leak, resulting in casing pressure.
3	Casing remaining strength	Residual casing strength is reduced due to wellbore wear and perforation, and the risk of casing damage is increased.
4	Wellhead device performance and maintenance	Wellhead performance is critical to controlling downhole fluids.
5	Mechanical analysis of pipe column	Under the complex well conditions of injection and production, the pipe string may have the risk of fracture and fracture.
6	Downhole tool performance	Downhole tool failure, resulting in casing pressure and wellbore integrity failures.
7	Completion string structure	Proper configuration of string structure can reduce the risk of casing pressure.
8	Reasonable buckling torque	The buckling torque is not up to standard, which can cause the buckle to leak and cause pressure.

3.2.3 Current production status

The current production status of gas storage is a factor that characterizes the current risk status of injection/production wells and is the most important factor for the integrity of injection-production wells. The influences of various factors on casing pressure are shown in Table 3.

Table 3. Factors of current production status

Serial Number	Influencing factors	Harmful consequences
1	Fluid composition in annulus	H_2S and CO_2 entering the annulus will corrode the casing wall.
2	casing pressure rise rate	A sudden rise in casing pressure is evidence of a sudden leak source.
3	Pressure relief analysis	The location, direction and amount of leakage affect the degree of annulus pressure and need to be analyzed by pressure relief.

3.3Early warning evaluation of casing pressure

At present, the most important measures to deal with the problem of sustaining casing pressure are to control it within the safe operating range through the casing pressure management method based on pressure monitoring, so as to ensure the safe production of oil and gas wells. However, due to the restrictions of industrial areas and villages, it is difficult to monitor and discharge casing pressure in real time. Therefore, this paper puts forward a risk early warning management method of sustaining casing pressure based on pressure prediction model.

1) The static evaluation of annular allowable pressure

The pressure bearing capacity of each barrier component of the annulus is limited, and the casing pressure should be controlled within a reasonable range. According to API RP90-2 casing pressure Management standard, the calculation of the maximum allowable casing pressure value is specified as:

a) Calculation of the MAWOP in A annulus

The minimum value between 50% of the internal pressure strength of the production casing P_{ai} , 80% of the internal pressure strength of the technical casing P_{bi} and 75% of the extrusion strength of the tubing P_{ac} is taken, and the formula is expressed as follows:

$$\mathrm{P_A} = \min\left(0.5P_{ai}, 0.8P_{bi}, 0.75P_{ac}\right) \quad (1)$$

b) Calculation of the MAWOP in B annulus

Take the minimum value between 50% of the internal pressure strength of the technical casing P_{bi} , 80% of the internal pressure strength of the surface casing P_{cc} and 75% of the extrusion strength of the production casing P_{bc} is taken, and the formula is expressed as follows:

$$\mathrm{P_B} = \min\left(0.5P_{\mathrm{bi}}, 0.8P_{\mathrm{cc}}, 0.75P_{\mathrm{bc}}\right) \quad (2)$$

c) Calculation of the MAWOP in C annulus

The minimum value between 50% of the internal pressure strength of the surface casing P_{cs} , 80% of the internal pressure strength of the conduit P_{co} and 75% of the crush strength of the technical casing P_{ci} is taken, and the formula is expressed as follows:

$$\mathrm{P_C} = \min\left(0.5P_{\mathrm{cs}}, 0.8P_{\mathrm{co}}, 0.75P_{\mathrm{ci}}\right) \quad (3)$$

Only the maximum allowable pressure of the annulus is the alarm limit value, which can be used for short processing time and has great hidden dangers. Therefore, the critical value of casing pressure diagnosis is set up. The diagnostic critical line is 80% of the maximum allowable pressure of annulus, and the diagnostic critical limit is 80% of the pressure of nitrogen cushion (the lower limit pressure without nitrogen cushion is zero).

2) The dynamic evaluation of annular allowable pressure

The pressure of injection-production string will directly affect the allowable pressure of annulus when the gas storage is operated with multiple rounds of injection and production. Based on the analysis of key factors such as injection and production conditions, wellhead pressure, bottom hole pressure, fluid state, annular fluid level and wellbore perfection, the bearing capacity of packer, circulating slip sleeve, formation pressure strength and tubing are calculated. The bearing capacity of packer is calculated by using the safety factor of packer, and the bearing capacity of circulating slip sleeve is calculated according to 80% of the working pres sure of circulating slip sleeve. The internal pressure of casing bearing is calculated according to the internal pressure strength of casing at packer, the external squeeze strength of tubing bearing is calculated according to the external squeeze strength of tubing at packer, and the formation pressure strength is calculated according to the formation pressure rupture strength of 80%, and the internal pressure strength under uniform corrosion of pipe string is calculated according to SY/T5724-2008 (casing string structure and strength design standard). The dynamic evaluation of casing pressure in gas storage injection/production wells is established.

The formula of internal pressure strength of pipe column is as follows:

$$P_{rbo} = 0.875 \frac{2Y_p \delta_r}{D_c} \tag{4}$$

Where,

δ_r -the actual remaining wall thickness of the pipe column, mm;

Y_P -pipe yield strength, MPa;

D_c -pipe outside diameter, mm;

P_{rbo} -Residual internal pressure strength of pipe column, MPa.

3) Establish a risk control mode

According to the operation status of gas storage annulus in Huabei Oilfield, a "four-level risk control" model is put forward. Risk levels are classified according to risk sources and performance characteristics, and different disposal measures are taken after risk identification to ensure the safe operation of gas storage wells.

Table 4. Four-level risk control table of casing pressure in SQ underground gas storage

Risk Classifi-cation	Identifi-cation Color	Risk source or presentation	Method of disposal
Level 1	red	Tube pressure and casing pressure change simultaneously, the A casing pressure value is close to the MAWOP, and the casing pressure quickly recovers after release.	The casing pressure is monitored in real time to test the depth of the liquid level, and the annular protection liquid is supplemented. Decompression treatment, shut-in, work over.
Level 2	orange	The casing pressure is lower than the MAWOP, and the pressure continues to recover after pressure release.	Focus on monitoring the depth of the test liquid level of the casing pressure, and supplement the annulus protection liquid.
Level 3	yellow	Annulus discharge pressure can be lowered below the MAWOP.	Observe the monitoring test liquid level depth, Refill the annulus protection fluid.
Level 4	green	Pressure can be controlled within the MAWOP specified in API RP90-2 except as described above.	Normal Production

4. Pressure control of annulus in injection/production wells of SQ gas storage

The production management of the injection/production wells of SQ gas storage adopts wireless remote pressure gauge to realize real-time monitoring of the pressure of A, B and C annular, and regularly test and monitor the annular liquid level. According to the test data of the liquid level, nitrogen column is injected into the A annulus after reducing the level of the annular protection liquid in the wells where the liquid level is at the wellhead, which can effectively reduce the casing pressure. The nitrogen column pressure control capability curve is shown in Figure 3. For newly drilled injection/production wells, the amount of annular protective liquid is calculated, and the level of annular protective liquid is controlled at 90-130m during well completion, and nitrogen is injected to maintain the pressure of 2-5MPa.

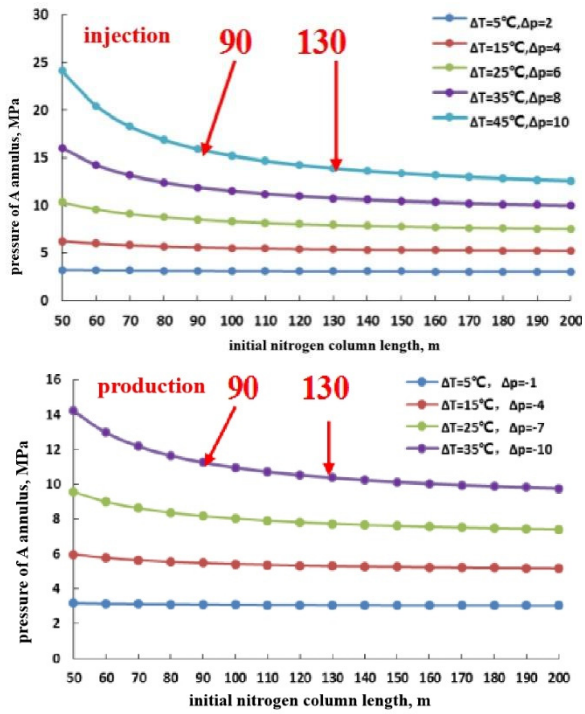

Figure 3. Nitrogen column pressure control capability curve

For wells with high casing pressure, the A casing pressure relief control measures are formulated. When the casing pressure does not reach the maximum allowable casing pressure value, the casing pressure dynamic monitoring or periodic release of casing pressure can reduce the effect of casing pressure. The pressure relief process can be established in the well site, and the annulus air body can be recovered through the gas production system of the well site, eliminating the safety and environmental protect ion problems that may be caused by blowout and combustion. The annulus fluid is sampled, analyzed and tested regularly, and the annulus liquid level is tested to identify the gas source and leakage path, and provide data support for the later workover operation. When the casing pressure exceeds the maximum allowable value, under the premise of considering factors such as operation cost and workover period, the main method for the pressure treatment of annular A is to replace the injection/production string and packer, test the wellbore integrity, and carry out the well completion operation again. As for the B/C casing pressure treatment, it is mainly to carry out the casing pressure detection and safety evaluation, plug the leakage point, and carry out integrity detection and treatment. Temperature, noise and optical fiber detection technology can be used to detect the leakage point in the flow state. At the same time, electromagnetic detection technology can be used to find the leakage point caused by tubing casing corrosion and perforation. For injection/production wells with abnormal casing pressure, temperament component analysis should be carried out at least once a year to track and analyze temperament changes, and temperament isotope analysis should be carried out to judge the source of temperament. Well S7 is an injection/production well of S1 gas storage in SQ gas storage group. The formation pressure coefficient is only 0.18, and the leakage during drilling is serious. In the early stage of operation, it was found that the square well bubbled after water injection, and the B annulus increased from 4MPa to 7MPa, resulting in annular channeling problem and forced to stop injection. After analysis, due to the unqualified cementing quality, there is a possibility that gas may enter the 177.8mm and 244.5mm casing cement ring from the position of the hanger below the permanent packer. In 2019, the 2908-2913m and 2779-2784m well sections of the well were perforated, and the plugging agent was squeezed and injected, as shown in Figure 4. And the casing pressure treatment was carried out, which realized effective plugging and made the S1 reservoir normal operation.

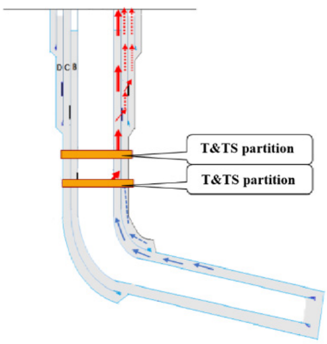

Figure 4. casing pressure treatment in well S7

The acidification operation was carried out in September 2020. After acidification, the maximum daily gas injection was 570,000 cubic meters, and the periodic gas injection was 12 million cubic meters. At the same time, there was no leakage at the wellhead, which proved that the safe gas injection capacity of well S7 was restored, the casing pressure treatment was successful, and a quasi-abandoned reservoir with a capacity of nearly 200 million cubic meters was revitalized.

5. Conclusions

(1) In view of the problem of casing pressure in injection/production wells of SQ gas storage, the situation of casing pressure was analyzed, a risk assess ment system of casing pressure was established, a four-level risk control mode of injection/production wells of gas storage was proposed, and a production management method of casing pressure killing was formulated.

(2) The casing pressure of the gas storage injection/production wells should be dynamically monitored, and the appropriate relief pressure can be recovered for testing. When the casing pressure exceeds the maximum allowable pressure, the wellbore integrity technology should be tested, and workover treatment should be carried out according to the test results.

(3) Through the evaluation of completion string, casing quality, cementing quality and other important parameters as well as wellbore integrity detection, to provide effective support for the safe operation of injection/production wells.

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