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Research and application of old well evaluation technology in underground gas storage

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Abstract. Gas storage has high requirements for new drilling well structure, cementing quality and wellbore quality. In order to ensure the sealing of the wellbore, cement is returned to the surface and special casing is used to ensure the sealing of the wellbore. Production Wells of crude oil reservoirs generally cannot meet these conditions for the gas storage converted from depleted oil and gas reservoirs. Therefore, production Wells will not be used in principle after the reconstruction of the gas storage. In order to improve the comprehensive economic benefit and reduce the construction cost, these production Wells are generally used as monitoring Wells, observation Wells and gas production Wells after quality review and evaluation. This paper introduces the research and application of quality review, detection technology and evaluation technology of old Wells in underground gas storage.

1. Introduction

At present, the underground gas storage in China is mainly reconstructed by depleted oil and gas reservoirs. The Wells in the underground gas storage can be divided into injection and production Wells, gas production Wells, monitoring Wells and observation Wells according to their functions. Oil and gas reservoir development and production Wells are generally not used as gas storage Wells because of their simple body structure, poor casing strength, sealing ability and poor cementing quality, which can not meet the requirements of high intensity and frequent injection and production of gas storage. They are generally not used as gas storage Wells and are sealed as abandoned Wells. Because gas production Wells, monitoring Wells and observation Wells have lower pressure than injection-production Wells, in order to reduce the number of new Wells drilled, reduce the construction cost of gas storage, and improve the comprehensive economic benefits, old Wells can be reused if they can meet the corresponding production parameters after quality review and evaluation.

The premise of the utilization of old Wells is to conduct wellbore treatment first, detect the production casing through logging and other means, evaluate the production casing tightness, residual strength, corrosion degree, cap tightness, overall cementing quality and other parameters, and determine whether to use and the function of utilization according to the evaluation results. Due to the lack of experience in the evaluation and utilization of old Wells in domestic gas storage, Huabei Oilfield Company carried out the quality review of old Wells in gas storage, and carried out shaft cleaning, logging, pressure test, work over, evaluation and other work on 6 old Wells.

Gas Wells in oil and gas reservoirs are completed according to the standard of development Wells, with low cementing quality, most of which are non-gas-tight casing, unreasonable borehole structure, complex material falling from the wellbore, and great pressure in the process of treatment. Gas storage in the process of operation, need a high frequency of high and low pressure in a relatively short run, the maximum pressure is usually bigger than the original formation pressure gas reservoir, gas peak winter tend to improve mining intensity and degree of compressed gas field can even reach the normal development of more than 10 times, resulting in collapse of formation pressure, formation pressure close to lower limit. During the 8-month gas injection period of the same year, the lower limit pressure is gradually returned to the original pressure, or exceeds the original pressure. Under the cyclic gas injection and differential pressure changes, the safety and life of the well will inevitably be greatly affected. In principle, the old Wells need to be completely permanently blocked and no longer used. However, in order to improve the gas recovery capacity and comprehensive benefits, and reduce the cost of drilling new Wells, the choice of reuse is generally made after the quality review and evaluation of the old Wells, and the Wells are repaired and put into production and use.

2. Wellbore integrity testing

2.1. Wellbore treatment and overall seal pressure inspection

Through drilling, grinding, set milling, fishing and other measures to deal with the shaft, to ensure that the shaft without falling objects, if there is falling objects to do not affect the production as the basic condition. Select the proper size of the well access rules to ensure the smooth entry of the completion tools. Check the scratches on the outer wall of the hole guide after pulling out the hole guide, and judge the casing change in combination with the logging diameter. Scratch the casing to remove the scale, rust and other debris on the inner wall of the casing to ensure the true diameter data measured. Finally, the overall pressure test of the wellbore was carried out, and the reservoir was blocked by the bridge plug or packer. The test was carried out according to the well drilling and completion pressure test standards. The clean water pressure test was 20 MPa, and the pressure drop in 30min was less than 0.5 MPa.

2.2. Well integrity logging

Reusing old Wells during gas storage construction and production requires not only evaluating casing condition, but also considering formation and surrounding environment. The main hazards are gas reservoir deformation, gas channeling outside the casing and secondary gas accumulation caused by human factors or technical reasons.

The following factors need to be evaluated in order to determine whether old Wells can be reused during gas storage construction and production:

- Casing technical status evaluation, according to the design injection and production pressure of gas storage to check the residual strength of casing string;
- The technical status of the butt string section during casing tie-back, the position of the sidetrack window, the deflection section and other positions that complicate the well structure;
- The casing damage location and characteristics, including mechanical wear, pipe string integrity damage, pipe joints are not sealed;
- The depth and structure of the casing string, as well as the position of each component;
- The deformation process of the gas reservoir, especially the underground gas storage built from depleted oil and gas reservoirs;
- Technical status of cement ring outside casing;
- Whether there is gas channeling outside casing;
- Whether there is a secondary gas accumulation interval above the gas reservoir structure.

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Based on the logging experience of previous gas Wells and the specific situation of old Wells, 9 logging methods were used to judge the gas channel outside the pipe, cementing quality and casing damage and corrosion, respectively, so as to provide effective data for evaluation. In actual engineering, a combination of multiple logging methods is often used for better integration. Evaluate the integrity of the wellbore, and display downhole information more abundantly. According to the geological conditions of the oil and gas reservoir of the proposed gas storage and the technological indicators of the injection and production wells, and at the same time referring to the drilling history, production history and current status of each well, a separate logging plan can be made for it.

The downhole condition is studied by using engineering logging method. It is mainly used to study the following contents:

- The well temperature, mainly the deviation relative to the vertical well temperature gradient;
- The fluid composition filled in the wellbore;
- The absorptive capacity of the rock to fast neutrons and its radioactivity on the borehole profile, which can be used to expose the accumulation of secondary gas;
- The filling characteristics and air tightness in the annulus between oil casing and outer casing;
- Casing cement cementing quality.

2.2.1. Logging method for determining gas channeling outside the pipe

Multiple detection methods of high sensitivity well temperature water holdup & pressure & fluid density & natural gamma ray & magnetic positioning are adopted. Comprehensive understanding of formation production dynamic parameters, through the well temperature display to understand the possible channeling, loss and other conditions. Use noise logging. In the shut-in state, under the condition that there is obvious possibility of collusion in the highly sensitive well temperature measurement, the collusion interval measurement can be accurately determined outside the pipe. Use natural gamma & neutron gamma. To understand the gas distribution location in the formation and determine the possible secondary gas accumulation formation.

2.2.2. Logging methods for cementing quality

CBL+VDL cementing quality test was used to understand the cement bond of the first and second interface outside the casing. SBT multi-sector cement Accurately measure the distribution of cement outside casing in 360° well circumference and the possibility of grooving in well section 300 m above the reservoir. It can provide parameters such as width and orientation of cement ring groove, interlayer cement isolation, compressive strength of cement ring, cement bonding ratio and so on.

2.2.3. Logging method for casing damage and corrosion

The damage and deformation of casing inner wall were comprehensively evaluated by 40 independent arm diameter combined with electromagnetic flaw detection. Mid-K electromagnetic flaw detection is used to understand the loss of ferromagnetic material in the multi-layer string. Combined with the 40 independent arm diameter, the damage inside and outside the casing can be comprehensively evaluated. The borehole ultrasonic imaging technology is used to perform 360° borehole circular acoustic imaging logging on special borehole sections, and the deformation and damage of borehole sections are described in detail.

3. Evaluation of old well reuse

Old well evaluation is a comprehensive, the complexity of the work, after wellbore whole sealing test, the cementing quality analysis, cover in the outside shaft cement ring seals, bearing capacity, the casing pipe corrosion and damage degree after preliminary assessment, evaluation of the core content and the difficulty is the production casing resistance to internal pressure, external pressure and whether can meet the production requirement.

3.1. Calculation of effective external compressive strength of production string

Under the condition of effective external pressure, that is, when the external pressure is greater than the internal pressure, the lower part of the casing bears the maximum load. For sections with limited string strength, the following formula can be used to determine the ultimate pressure (effective external pressure) when the maximum stress of the worn string is equal to the yield pressure of the pipe. The safety factor of external compressive strength is determined according to the following relation.

$$n_1 = P_L' / P_{oe} \tag{1}$$

Where P_{oe} -- effective external pressure, MPa.

$$P_{oe} = P_{1o} - P_{1i} \tag{2}$$

Where P_{1o} -- external pressure, MPa;

P_{1i} -- internal pressure, MPa.

The external pressure is equal to the drilling fluid column pressure equal to the cement ring in the uncemented zone, and to the water column pressure equal to the cement ring in the cemented zone (density: 1100 kg/m^3). In the absence of data on the density of objects outside the casing, the external pressure is calculated as the hydrostatic column pressure of a fluid with a specific gravity of 1.08×10^4 N/m^3. The internal pressure is equal to the gas-liquid mixture pressure at the depth of the strength calculation and can vary from the minimum formation pressure to the minimum wellhead operating pressure.

3.2. Calculation of effective internal compressive strength of production casing

Under the condition of effective internal pressure, that is, when the internal pressure is greater than the external pressure, the upper part of the reservoir casing bears the maximum load. For sections with limited string strength, the following formula can be used to determine the internal pressure when the maximum stress of the worn string is equal to the yield limit of the pipe:

$$P_s' = K \cdot P_s \tag{3}$$

Among them, K - reduction coefficient of internal pressure bearing capacity of worn pipe string, $0.1 \le K \le 1.0$;

P_s - The maximum stress of the new pipe body is equal to the effective internal pressure at the yield limit of the pipe. The value is determined according to the formula in API standard.

The safety factor of internal compressive strength is determined according to the following relation,

$$n_2 = P_s' / P_{ie} \tag{4}$$

Where P_{ie} -- effective Internal pressure, MPa.

$$P_{ie} = P_{2i} - P_{2o} \tag{5}$$

Where P_{2i} -- internal pressure, MPa.

P_{2o} -- external pressure, MPa;

The internal pressure can be determined as the maximum operating pressure at the wellhead. The external pressure is equal to the drilling fluid column pressure to a specified depth in the uncemented zone and to the water column pressure (density: 1100 kg/m^3) to a specified depth in the cemented zone. In the absence of data on the density of objects outside the casing, the external pressure was calculated as the hydrostatic column pressure of the fluid with a specific gravity of 1.08×10^4 N/m^3.

4. Field application

Taking Well 1# as an example, According to the temperature logging, the well temperature curve is obtained.

The characteristics of the curve reflect the stable temperature field in the well and are consistent with the rock structure along the well profile and the wellbore structure. No abnormal temperature changes due to unsealed downhole equipment or gas channeling outside the casing were found. The wellhead temperature is 15.9 °C, and the bottom hole temperature is 112.6°C. The wellbore from the wellhead to the depth of 664.6m is filled with natural gas with a density of 0.2g/cm^3, and the section 664.6 – 679.6 m below is filled with a gas-liquid mixture with a density of 0.7g/cm^3, and further down is a density of 1.0 – 1.1 g/cm^3 of liquid.

The location of each component of the borehole structure can be determined according to the data of EMP flaw detection log. The casing strings were magnetized in the well sections of 1806.8-1828.0 m, 1839.2-1850.4 m, 1872.4-1883.2 m, 1938.9-1949.8 m, 1992.0-2003.3 m, and 2046.3-2057.2 m. The calculated wall thickness of the tested string varies from 8.73-11.62mm. According to the EMP logging data, no defects, integrity damage, corroded or worn sections of the string were found.

Based on the diameter measurements, no areas of string deformation, fracture, or corrosion were found. The inner diameter value is consistent with the technical data.

According to the sonic log data, the cement outside the casing is returned to a depth of 1168 m. From this depth, the well sections are alternately cement-casing and cement-formation interfaces with tight and partially cemented sections and the results are shown in Table 1.

Table 1. Well 1# cement bonding quality situation

Consolidation characteristics	Cementing condition of cement stone & casing		Cementing condition of cement stone and formation rock	
	Total thickness, m	ratio, %	Total thickness, m	ratio, %
Cementation compaction	638.8	31.6	651	32.2
Part of the bond	1139.7	56.4	1129.2	55.9
No contact	241.5	12.0	240.0	11.9

Taking the casing of 177.8 mm reservoir in Well 1# as an example, the calculation of anti-effective external pressure is carried out, and the results are shown in Table 2.

Table 2. The calculation of residual strength of Well 1# production pipe column

No.	Corrosion Amount, mm	Limited interval, m	n_1	n_{1n}	n_2	n_{2n}
1#	1.5 ± 0.5	3125.6-3136.9	1.3	1.125	1.58	1.1

It can be seen that the casing of 177.8 mm reservoir meets the strength conditions of resisting effective internal pressure and resisting effective external pressure. This ensures that the well can operate at a maximum and minimum wellhead working pressure of 41.1 MPa and 4.0 MPa, respectively. The casing was then tested to meet the gas seal requirements and the well could be used as a production well.

Of the six old wells in gas storage, four wells can be used and two wells can be sealed. Among the four old wells, two of them are gas sealed by testing, and the cementing quality is excellent, which can be used as gas production wells. Among which Well 1# has a daily gas production capacity of 680,000 m^3, Well 2# has a daily gas production capacity of 310,000 m^3. The other two wells were well cemented to restore the sealing of the cement ring outside the casing Well 3# has been used as pressure monitoring well, and Well 4# has been used as observation well.

5. Conclusion

The utilization of old Wells for gas storage is a new field in domestic gas storage, which involves drilling, cementing, logging, reservoir geology, downhole operation, casing corrosion degree, residual strength calculation and other technologies. It has a wide range of expertise and is a comprehensive technology.

The old Wells of gas storage still face the test of gas injection and production high pressure in actual production, especially for gas production Wells, it is necessary to strengthen management, formulate single well management measures, and make reasonable shut-in parameters for wellhead safety control system, so as to prevent in advance. Timed monitoring should be strengthened, different monitoring measures should be taken for different Wells, timely measures should be taken when problems are found, reasonable production cycle should be established according to working conditions and utilization conditions, periodic inspection and reassessment after expiration, etc.

Underground gas storage can be built at a lower cost by using depleted reservoirs, reducing the cost of new Wells and achieving optimal operating benefits. In the process of gas storage construction, well logging, well workover, pressure test, sleeve replacement and other operations are needed for the old Wells that can be reformed to ensure the safety and stability of the gas storage operation. To evaluate the utilization of these old Wells, reasonable treatment of the existing old Wells can not only ensure the safety of gas storage, but also effectively protect the reservoir, improve the utilization rate of old Wells.

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