Residual Strength Evaluation and Life Prediction Method for Gas Storage Reservoir Injection and Extraction Pipelines

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Abstract. The operation of gas storage reservoir is characterized by alternating loads and cyclic reciprocation, which puts the tubular column in a complex stress state for a long time. At the same time, the corrosive environment downhole also threatens the service life of the tubing column, and it is of great significance to carry out the residual strength evaluation and residual strength prediction of the tubing column in gas storage reservoirs for the safe and smooth operation of the reservoirs. At present, the main object of casing safety evaluation for gas reservoir casing is casing column, and the content of injection and extraction tubing column is less reported. This paper proposes the safety evaluation method of gas storage reservoir injection and mining pipe column on the basis of SY/T 7370 and SY/T 7633, establishes the residual strength model and residual life prediction model of injection and mining pipe column based on the mechanical and wall thickness inspection data of the pipe column, specifies the internal pressure, external extrusion and tensile (compression) strength of the injection and mining pipe column and the safety inspection cycle of the pipe column, and explains the axial force law of the pipe column based on the six effects of the packer-column, which is important for the safe and smooth operation of gas storage reservoirs. It also illustrates the axial force law of the column according to the six effects of the packer-column, which provides methodological and technical support for the safety evaluation of gas storage reservoir injection and extraction columns. The model is applied to the injection and extraction tubular column of a gas reservoir well in an oil field.

Keywords: gas storage reservoir; injection molding column; tube and column strength; safety evaluation

1 Introduction

The total number of underground gas storage facilities built worldwide exceeds 700, with a total storage capacity of $4100 \times 10^8 m^3$. As of the end of 2022, China has built a

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total of 24 gas storage facilities, with a working gas volume of $190 \times 10^8 m^3$[1]. The working gas volume of gas storage facilities continues to rise, accounting for approximately[2][3] of natural gas consumption. Underground gas storage facilities play an important role in China's natural gas peak shaving, valley filling, safe operation, emergency regulation, and large-scale reserves[4][5][6]. The injection production string is a safe channel to ensure gas injection and extraction. During the operation of the wellbore, it is affected by multiple factors such as casing corrosion, equipment sealing failure, poor cementing quality, misoperation, third-party damage, and earthquakes[7][8]. According to the standard design of gas storage facilities, it is necessary to ensure the safety of steady-state injection and production of gas in the pipeline for a period of 30 years or longer. The high-speed circulation of natural gas causes the pipe string to be in a complex stress state with periodic changes for a long time. The corrosive environment underground also threatens the service life of the pipe string, which can easily lead to insufficient resistance to internal pressure, external compression, axial tension or compression, and pipe wall corrosion, resulting in failure. Furthermore, there is significant safety significance in evaluating the stress load, strength verification, and predicting the remaining life of injection production pipe columns.

At present, the safety evaluation methods for conventional oil and gas wells both domestically and internationally are mostly found in numerical methods, analytical methods, experimental methods, and finite element methods. The influencing factors of the force and deformation of the pipe column not only include gravity, buoyancy, fluid pressure inside and outside the pipe, fluid flow viscosity, temperature, top hook load, constraint method at the bottom packer, operation sequence and other conventional external factors, but also need to consider the characteristics of non-linear distribution of wellbore pressure and temperature[9][10], injection production alternating load[11][12], temperature and corrosion on the strength of the pipe column[13]. Overall, the injection production string is mainly subjected to three types of forces inside the well: internal pressure, external extrusion pressure, and axial force. The injection and production tubing columns are all inside the production casing, and the external extrusion pressure and internal pressure can be converted into axial force through expansion effect or piston effect. The paper based on SY/T 7370 and SY/T 7633, calculates the scenarios under gas injection and gas extraction conditions, with the selected parameters as shown in Table 1.

Table 1. Selection of Gas Injection and Extraction Parameters

Calculated Result	Parameter	Standard Criteria
Compressive Strength Inside	Diameter, Wall Thickness, Minimum Yield Strength	SY/T 7633
Collapse Resistance Outside	Diameter, Wall Thickness, Minimum Yield Strength	
Safety Detection Cycle	Maximum Operating Limit of Gas Storage, Diameter, Diameter, Wall Thickness, Minimum Yield Strength	

Tensile Strength	Upper and Lower Limits of Gas Storage Operation, Diameter, Diameter, Wall Thickness, Changes in Annular Pressure Before and After Gas Injection and Production, Temperature Changes Before and After Gas Injection and Production, Annular Pressure Changes of Packer, Basic Parameters of Tubing String	SY/T 7370

2 Safety Evaluation Model for Injection Production Pipe Column

2.1 Residual Strength Model

2.1.1 Internal Pressure Strength Verification.

Internal pressure value of injection production string:

$$p_i = p_{s\max} / e^{1.11548\times10^{-4} G(H-h_V)} \tag{1}$$

Among them, p_{smax} is the upper limit of operating pressure, MPa; G is the specific gravity of natural gas, taken as 0.5548; h_v, vertical depth of casing calculation point, m; H, vertical depth of casing insertion, m.

Internal pressure resistance strength of casing:

$$[p_i] = \frac{2k_t f_{ymn} t_{c\min}}{D_{c\max}} \tag{2}$$

Among them, $[p_i]$ is the strength against internal pressure, MPa; k_t casing wall thickness deviation coefficient, taken as 0.875; f_{ymn} is the minimum yield strength of casing material, MPa; t_{cmin} is the measured minimum wall thickness, mm; D_{cmax} is the measured maximum outer diameter, mm.

Safety factor against internal pressure:

$$S_i = [p_i] / p_i \tag{3}$$

Among them, S_i is the safety factor against internal pressure, dimensionless.

2.1.2 Anti Extrusion Strength Verification.

Absolute external extrusion pressure value of casing:

$$p_o = p_{oh} + 0.00981 \rho_m h_V \tag{4}$$

Among them, P_{oh} is the annulus pressure outside the casing, MPa; For the cementing section, ρ_m is the outer layer water density of the casing, g/cm^3; h_v is the vertical depth of the casing calculation point, m.

Effective external pressure:

The pressure inside the pipeline is calculated based on the minimum operating pressure of the gas storage tank for the entire well

$$p_{\mathrm{i}}' = p_{\mathrm{smin}} / e^{1.11548\times10^{-4} G(H_{\mathrm{v}}-h_{\mathrm{v}})} \tag{5}$$

p_{i}'——Minimum tube pressure, MPa, p_{smin}——Minimum operating pressure of gas storage facility, MPa.

Effective external pressure calculation:

$$p_{\mathrm{oe}} = p_{\mathrm{o}} - p_{\mathrm{i}}' \tag{6}$$

p_{oe}——Effective external extrusion pressure, MPa

Anti extrusion strength of injection production pipeline:

$$\begin{aligned}
p_{yp} &= 2f_{ymn}[D_{c\max}/t_{c\min}-1]/[(D_{c\max}/t_{c\min})^2] \\
P_p &= f_{ymn}[A_c/(D_{c\max}/t_{c\min})-B_c]-C_c \\
P_T &= f_{ymn}[F_c/(D_{c\max}/t_{c\min})-G_c] \\
P_E &= 46.95\times10^6/[(D_{c\max}/t_{c\min})/(D_{c\max}/t_{c\min}-1)^2]\times0.00689476
\end{aligned} \tag{7}$$

Among them, p_{yp}, p_{p}, p_{T}, p_{E} are yield crush strength, plastic crush strength, transition crush strength, and elastic crush strength, respectively.

When $D_{\mathrm{cmax}}/t_{\mathrm{cmin}} \le (D_{\mathrm{cmax}}/t_{\mathrm{cmin}})_{\mathrm{yp}}$, it is yield collapse;

When $(D_{\mathrm{cmax}}/t_{\mathrm{cmin}})_{\mathrm{yp}} < D_{\mathrm{cmax}}/t_{\mathrm{cmin}} < (D_{\mathrm{cmax}}/t_{\mathrm{cmin}})_{\mathrm{pt}}$, it is plastic extrusion failure; When $(D_{\mathrm{cmax}}/t_{\mathrm{cmin}})_{\mathrm{pt}} < D_{\mathrm{cmax}}/t_{\mathrm{cmin}} < (D_{\mathrm{cmax}}/t_{\mathrm{cmin}}\ \mathrm{t})_{\mathrm{te}}$, it is a transitional collapse;

When $D_{\mathrm{cmax}}/t_{\mathrm{cmin}} \ge (D_{\mathrm{cmax}}/t_{\mathrm{cmin}})_{\mathrm{te}}$, it is elastic collapse.

Among them,

$$\begin{aligned}
&(D_{c\max}/t_{c\min})_{yp} = \{[(A_c-2)^2+8(B_c+C_c/f_{ymn})]^{1/2}+(A_c-2)\}/[2(B_c+C_c/f_{ymn})] \\
&((D_{c\max}/t_{c\min})_{yp})_{pt} = [f_{ymn}(A_c-F_c)]/[C_c+f_{ymn}(B_c-G_c)]((D_{c\max}/t_{c\min})_{yp})_{pe} = [2+B_c/A_c]/[3(B_c/A_c)] \\
&A_c = 2.8762+0.15489\times10^{-3}f_{ymn}+0.44809\times10^{-6}f_{ymn}^{\ 2}-0.16211\times10^{-9}f_{ymn}^{\ 3} \\
&B_c = 0.026233+0.73402\times10^{-4}f_{ymn} \\
&C_c = -3.2125+0.030867f_{ymn}-0.15204\times10^{-5}f_{ymn}^{\ 2}+0.77810\times10^{-9}f_{ymn}^{\ 3} \\
&F_c = 3.237\times10^5[(3B_c/A_c)/(2+B_c/A_c)]^3/\{f_{ymn}[(3B_c/A_c)/(2+B_c/A_c)-B_c/A_c][1-(3B_c/A_c)/(2+B_c/A_c)]^2\} \\
&G_c = F_cB_c/A_c
\end{aligned} \tag{8}$$

Anti extrusion safety factor:

$$S_o = [p_o]/p_o \tag{9}$$

Among them, S_{o} is the anti extrusion safety factor, dimensionless; $[p_{\mathrm{o}}]$ is the strength of the casing against external compression.

2.1.3 Tensile (Compressive) Strength Verification.

2.1.3.1 Gravity Effect.

The depth of the well completion string is generally several hundred to several thousand meters, so gravity elongation is an important factor. The axial force caused by self weight gradually increases from bottom to top, and the axial tension is the highest at the wellhead. The completion string and mechanical model corresponding to the gravity effect are based on the basic condition that the completion string is produced when it enters the well.

Gravity of completion string in air:

$$F_w = W_s \times L \tag{10}$$

In the formula,

F_W—Gravity of the pipe column in the air, N; L—Column length, m; W_s—Unit length column weight, N/m.

Gravity of the completion string inside the well:

Due to the buoyancy effect of the liquid in the well on the completion string, the gravity of the completion string in the well should be equal to the gravity in the air minus the buoyancy.

$$F_\rho = F_w - F_{fu} \tag{11}$$

$$F_{fu} = \rho g V = \rho \times g \times A_s \times L \times 10^{-3} \tag{12}$$

In the formula,

F_ρ—Gravity of the column in the well, N; V—Column volume, cm^3; g—Gravity acceleration, g=9.801N/kg; A_s—Cross sectional area of pipe column, mm^2; ρ—Density of liquid in the well, g/cm^3.

2.1.3.2 Piston Effect.

There is a packer under the oil and gas well, and when the packer is set to seal the annulus, there is a pressure area difference, which creates the condition of plug effect. For the insertion tube packer, the piston force acts on the sealing tube in the packer sealing chamber, applying compressive or tensile force to the column. The force generated by the piston effect is calculated using equation (12).

$$F_{hs} = -((A_p\text{-}A_i)\Delta p_i - (A_p\text{-}A_o)\Delta p_o) \tag{13}$$

In the formula, F_{hs}—represents the force generated by the piston effect, N; Δp_i—represents the change in column pressure at the packer, MPa Δp_o—Changes in annular pressure at the packer, MPa; A_ρ—Internal cross-sectional area of the packer (sealing chamber cross-sectional area), mm^2.g—Gravity acceleration, g=9.801N/kg; A_s—Cross sectional area of pipe column, mm^2;

2.1.3.3 Ballooning Effect.

If the internal pressure of the pipe column is greater than the external pressure, the horizontal pressure acting on the inner wall of the pipe column will increase the diameter of the pipe column, shorten the length of the pipe column, and generate axial pressure. This bulging effect is usually called positive bulging effect. On the contrary, if the annular pressure of the pipe column is greater than the internal pressure, the diameter of the pipe column will decrease, the length of the pipe column will increase, and axial tension will be generated. The force generated by the bulging effect is calculated using equation (13).

$$F_{gz} = -0.6 \times (\Delta p_{ia} A_i - \Delta p_{oa} A_o) \tag{14}$$

In the formula, F_{gz}— represents the force generated by the bulging effect, N; Δp_{ia} — represents the change in average pressure inside the column, MPa Δp_{oa} —Change in average annular pressure, MPa; A_i —Internal cross-sectional area of the pipe column, mm^2, A_o —External cross-sectional area of the pipe column, mm^2.

2.1.3.4 Temperature Effect.

The basic condition for the temperature effect to occur is that the average temperature of the completion string changes, causing changes in length or force, regardless of pressure changes. The force generated by temperature effect is calculated using equation (14).

$$F_T = -\alpha E A_s \Delta T \tag{15}$$

In the formula, F_T—force generated by temperature effect, N; A_s —cross-sectional area of the pipe column; ΔT —the average temperature of the pipe column during injection and production operations; E—elastic modulus; α—Linear coefficient of thermal expansion.

Due to the non-linear distribution of wellbore temperature during fluid flow in the wellbore, and the temperature effect occurring throughout the entire length of the pipe string, the pipe string should be divided into micro element segments when calculating the temperature effect, and the average temperature change ΔT_i of each segment of the pipe string should be used for calculation, as shown in formula (15).

$$\Delta T_i = T_f - T_i \tag{16}$$

Among them, $T_i = \dfrac{T_{ui} + T_{di}}{2}, T_f = \dfrac{T_{uf} + T_{df}}{2}$.

In the formula,

T_{ui}—initial temperature at the top of the micro element column, °C; T_{di}—initial temperature at the bottom of the micro element column, °C; T_{uf}—final temperature at the top of the micro element column, °C; T_{df} —final temperature at the bottom of the micro element column, °C.

2.1.3.5 Bending Effect.

The buckling effect of the pipe column is relatively small, but the main significance of pipe column buckling is that the bent pipe column will exert a significant force on the wellbore, leading to a large frictional resistance between the pipe column and the wellbore, and even causing the pipe column to self lock. The axial force generated by the bending effect during the insertion (extraction) process of the injection production string is calculated using equation (16).

$$F_{wq} = \pm 0.060156 D_{leg}(D-2t)A_s \tag{17}$$

In the formula, F_{wq}—is the force generated by the bending temperature effect, N; D_{leg} —dogleg degree (°/30m); D —Nominal outer diameter of the pipe column; t—Wall thickness of the pipe column; A_s—nominal outer diameter of the pipe body.

2.1.3.6 Friction Effect.

For the injection and production pipe columns in gas storage wells, the frictional effect mainly comes from the frictional force generated by the gas flow on the pipe wall during the gas injection or production process. However, due to the complexity of the gas flow state, the frictional force generated by gas flow is rarely considered in the existing calculation and analysis process, and is generally considered from the perspective of increasing the safety factor. The gas flow generates frictional resistance on the inner wall of the injection production pipe column, and the direction of frictional resistance is consistent with the flow direction. The magnitude of frictional resistance is calculated according to equation (17).

$$F_{mz} = \frac{\pi}{4} d_i^2 \Delta P_f \tag{18}$$

In the formula, F_{mz}—represents the force generated by the frictional effect, N; d_i—represents the inner diameter of the pipe column, and ΔP_f —represents the frictional pressure drop inside the pipe column, Pa.

in the gas storage facility, based on the stress state and wall thickness detection.

2.2 Remaining Life Prediction Model

According to SY/T 7633, the calculation method for the safe service life of casing. The critical wall thickness for safe service of injection production pipelines under active working conditions is calculated according to formula (18).

$$t_{\mathrm{cr}} = \frac{[S_{\mathrm{i}}]K_{\mathrm{o}}p_{\mathrm{ie}}D}{2k_{\mathrm{t}}f_{\mathrm{ymn}}} + \beta \tag{19}$$

Among them, $[S_i]$—rated internal pressure resistance coefficient; K_o—Overpressure coefficient during casing pressure testing, generally taken as 1.1; p_{ie}—effective internal pressure, MPa; D—standard outer diameter of casing, mm; f_{ymn}—minimum yield strength of steel, MPa; k_t—deviation coefficient of casing wall thickness, generally taken as 0.875; β —Attenuation correction value at the thread of the casing.

Calculate the average corrosion rate based on the wall thickness/time lost due to corrosion:

V_{avg} = (standard wall thickness - average minimum remaining wall thickness) / age

V_{max} = (standard wall thickness - minimum remaining wall thickness) / age

The remaining lifespan can be expressed as:

$$T = \frac{t_{c\min} - t_{cr}}{V_{pj}} \tag{20}$$

3 Safety Evaluation of Injection Production String

In terms of model validation and applicability, we conducted an analysis of geometric dimensions, internal pressure resistance, external collapse resistance, tensile strength verification, and prediction of safety detection cycles for injection-production string based on a study of 12 injection-production wells in a domestic gas storage facility. Additionally, a case study was performed on a specific injection-production well. Taking a certain injection production well as an example, the maximum operating pressure of the gas reservoir is 31.35MPa, the minimum operating pressure is 14.0MPa, and the relative density of the natural gas stored in the reservoir is 0.6173. The average ground temperature gradient is calculated to be 3.07 °C/100m, and the basic data is shown in Table 2. The production casing cement is raised to the surface.

Table 2. Performance of a certain well casing string

<table>
<tr><th>Steel grade</th><th>Buckle type</th><th>External diameter (mm)</th><th>Wall thickness (mm)</th><th>Inner diameter (mm)</th><th>Line quality (kg/m)</th></tr>
<tr><td>L80</td><td>BGT1</td><td>114.3</td><td>6.88</td><td>100.54</td><td>18.21</td></tr>
<tr><th colspan="2">Internal pressure strength (MPa)</th><th colspan="2">Collapsing strength (MPa)</th><th colspan="2">Tensile strength (kN)</th></tr>
<tr><td colspan="2">58.1</td><td colspan="2">51.7</td><td colspan="2">1280.9</td></tr>
<tr><th colspan="2">Outer diameter range (mm)</th><td colspan="2">113.7285~115.443</td><th>Wall thickness range (mm)</th><td>≥6.02</td></tr>
</table>

Regarding the temperature effect in the model, this paper, based on the nonlinear heat transfer model of the injection-production tubing-casing-formation system, employs the concept of infinitesimalization and iteratively calculates the temperature changes in the wellbore before and after gas injection and production. The corrosion data is sourced from real field logging scenarios, where the reduction in wall thickness of the injection-production tubing is due to corrosion, leading to a decrease in the strength of the tubing string.

According to SY/T 7370 and SY/T 7633, the model calculation of the internal pressure resistance, extrusion resistance, and tensile strength of the pipe column is carried out to predict the remaining life of the pipe column and provide the safety inspection cycle of the pipe column. Taking a certain injection production well as an example, Figure 1 shows the basic information and inspection cycle of the injection production pipe column.

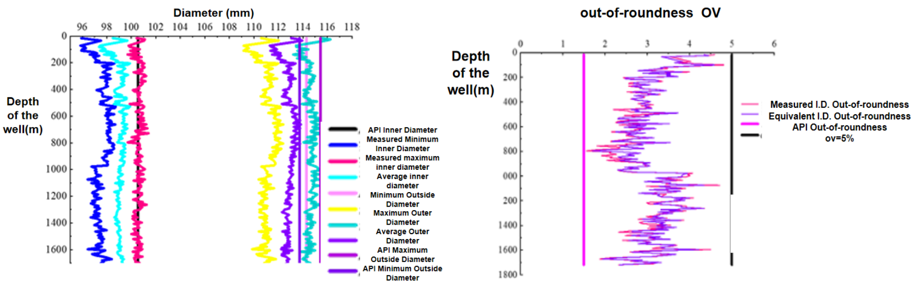

Fig. 1. Basic information of injection production string (taking a certain injection production well as an example)

3.1 Remaining Strength Evaluation

3.1.1 Evaluation of Internal Pressure Strength.

As shown in Figure 2 and Figure 3, the internal pressure resistance strength of the tubing string in the well section of 19.45m~2992.680m indicates that at the maximum operating pressure of 31.35MPa in the gas reservoir, the effective internal pressure of the tubing string in the well section of 19.45m~2992.680m is lower than the actual internal pressure resistance strength, and the internal pressure safety factor is greater than 1.15.

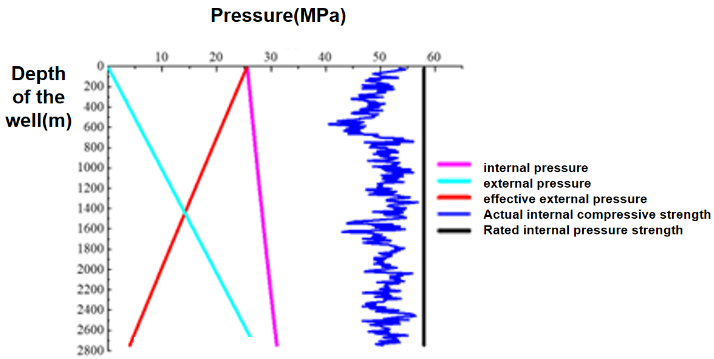

Fig. 2. 19.45m~2992.680m internal pressure resistance strength (taking a certain injection and production well as an example)

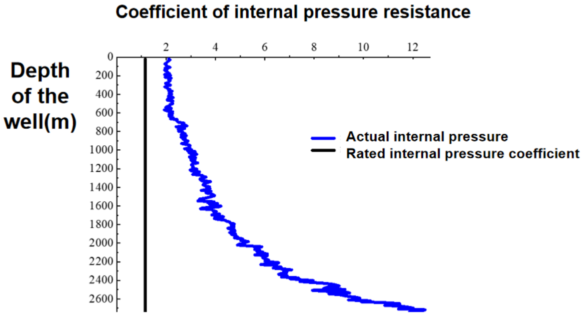

Fig. 3. 19.45m~2992.680m safety factor against internal pressure

3.1.2 Evaluation of External Squeezing Strength.

The actual anti extrusion strength, effective external pressure, and anti extrusion safety factor of the tubing string are calculated based on parameters such as the filling of the protective fluid in the annulus and the absence of pressure in the annulus, as shown in Figure 4 and 5.

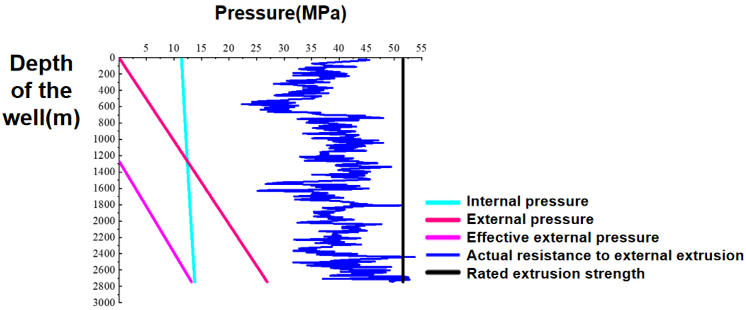

Fig. 4. Analysis of Squeezing Strength of 19.45m~2992.680m Injection Production Pipe Column

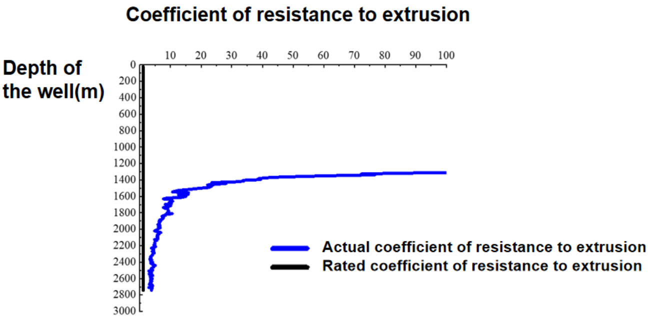

Fig. 5. 19.45m~2992.680m injection production pipe column anti extrusion safety factor

The results indicate that considering measurement errors, the anti extrusion safety factor of the tubing string in the 19.45m~2992.680m section of well Hua 2-4 is greater than 1.10.

3.1.3 Tensile (Compressive) Strength Evaluation.

(1) Condition 1: Axial load only considers the self weight of the pipe column, without considering buoyancy. Calculate the actual tensile strength, effective axial force, and tensile/compressive safety factor of the pipe column.

(2) Condition 2: Gas injection into the pipe column. Before gas injection, the pressure in the A annulus is 26.5MPa, and after gas injection, the pressure in the A annulus is 27.8MPa. The internal pressure is calculated based on the minimum operating pressure of the gas reservoir of 14.0MPa, the maximum daily gas injection volume from 2022 to 2023 of 575000 cubic meters, the highest gas injection temperature of 76.8 °C, and the natural gas relative density of 0.6261. The actual tensile strength, effective axial force, and tensile/compressive safety factor of the pipe column are calculated (Figure 6 and Figure 7). Axial loads consider additional axial loads, mainly including temperature effects, bulging effects, piston effects, and axial loads caused by airflow friction.

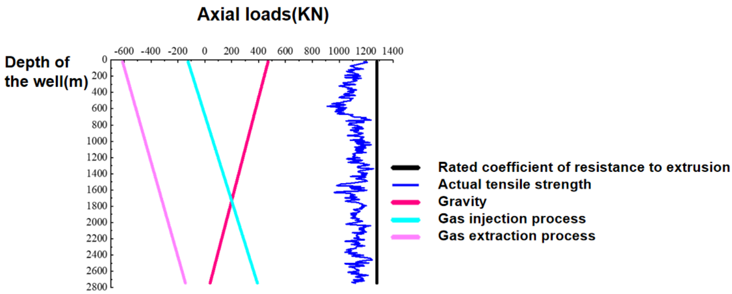

Fig. 6. Tensile Strength Analysis of Pipe Columns in the 19.45m~2992.680m Well Section

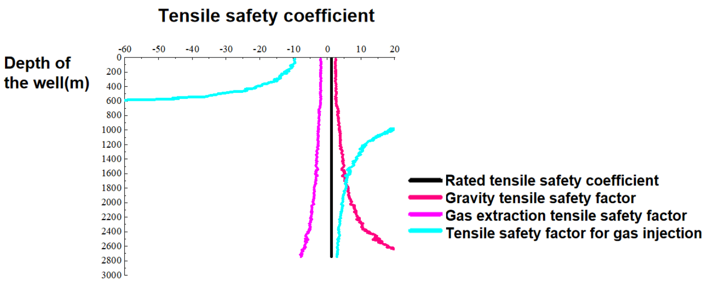

Fig. 7. 19.45m~2992.680m well section pipe column tension/compression safety factor (+represents tension, - represents compression)

Condition 3: Gas production using a string. Before gas production, the pressure at the annulus wellhead is 26.5MPa, and after gas production, the pressure at the annulus wellhead is 30.8MPa. The internal pressure is calculated based on parameters such as the maximum operating pressure of the gas reservoir at 31.35MPa, the maximum daily gas production from 2022 to 2023 at 539000 cubic meters, and the relative density of natural gas at 0.6261. The actual tensile strength, effective axial force, and tensile/compressive safety factor of the string are calculated. Axial loads consider additional axial loads, mainly including temperature effects, piston effects, bulging effects, and axial loads generated by airflow friction.

The results indicate that considering measurement errors, the anti extrusion safety factor of the tubing string in the 19.45m~2992.680m section of well Hua 2-4 is greater than 1.10.The results show that the tensile/compressive coefficients of the pipe column at 20.92m~2809.639m in the injection and production well are all greater than 1.30, which meets the requirements of the "Recommended Practice for Selection and Design of Injection and Production Pipe Columns in Underground Gas Storage" (SY/T 7370-2017).

3.2 Residual Life Prediction

According to the SY/T 7633 standard, the safety inspection period for injection production pipe columns is equal to the allowable reduction in remaining wall thickness divided by the annual corrosion rate, where the allowable reduction in remaining wall thickness is equal to the measured wall thickness minus the critical wall thickness.

According to the evaluation of the internal pressure resistance of the tubing string (the pressure inside the tubing is filled with natural gas and the maximum operating pressure of the gas reservoir is 31.35MPa, and the external pressure of the tubing is based on the density of the annulus protection fluid of 1.0g/cm3), the remaining life of the tubing string at different well depths is calculated as shown in Figure 8. Except for the safety valve section, the minimum remaining life of the tubing at a depth of 568.18m in other sections is 2-3 years. (Figure 8)

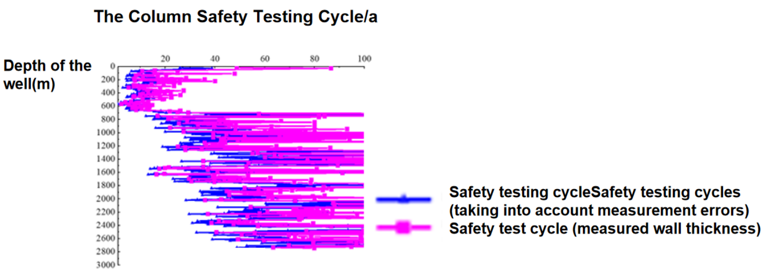

Fig. 8. 19.45m~2992.680m well section oil pipe safety inspection cycle

4 Conclusion

This paper focuses on the evaluation of residual strength and prediction of residual life of injection production pipe columns under complex stress states with periodic changes over a long period of time. The internal pressure, external extrusion force, and axial tension of the injection production pipe columns are verified, and the detection cycle of the injection production pipe columns is given based on wall thickness detection data. We have established models for the packer column piston effect and bulging effect, and introduced the concept of modularization to calculate temperature and friction effects. On the basis of existing standards, a safety evaluation method for gas storage injection and production pipelines has been proposed, providing technical support for the safe operation of gas storage facilities.

Taking the injection production pipe column of a certain gas storage reservoir as the application object, the force analysis of the pipe column during the injection and production cycle was carried out based on the model. The results showed that the internal pressure resistance, external compression resistance, tensile or compressive strength of the injection production pipeline met the selection and design requirements of the gas storage reservoir pipe column. Except for the safety valve well section, the minimum remaining life of the oil pipe at a depth of 568.18m was 2-3 years.

This paper primarily predicts the minimum remaining life of the pipeline segment based on a theoretical model, with results conforming to standards and the potential for widespread application. With the increasing availability of field logging data, correlation analysis and statistics based on big data technology can be applied to life prediction models, which will be the focus of our next research direction.

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