Study on the Production Mode and Leakage Risk of Gas Storage Well Completion

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Abstract: The construction of natural gas storage reservoir can effectively guarantee the seasonal peak demand of natural gas, but at present, the research on the construction of gas storage reservoir and the prediction of production and leakage risk is not comprehensive. Therefore, through the analysis and study of typical completion string, production mode and leakage risk of gas storage, the characteristics of different types of gas storage reservoirs are obtained. Among them, salt cavern gas storage reservoir mainly uses water-soluble cavity technology to store natural gas in salt cavern formed after the underground brine is extracted. The cavitations stage is completed by the auxiliary construction of water injection string+brine discharge center pipe. After the discharge of halogen, the central pipe is lifted out through non-kill well equipment and then the gas injection underground storage is carried out. This type of gas storage reservoir has the characteristics of high gas discharge rate, low base gas quantity, strong corrosion resistance of pipe column but high leakage risk. Compared with the salt cavern storage, the production string of the gas reservoir is mainly composed of packer, underground safety valve and gas seal tubing, and the production well seat sealing under the waste oil reservoir is used for gas injection and extraction. In addition, this paper also establishes a gas leakage annular zone pressure mathematical model based on one-dimensional gas migration equation, which can effectively predict the permeability of leakage points through well pressure test values and calculated values, and effectively evaluate the leakage risk of gas storage.

1. Introduction
In order to meet the demand of global natural gas seasonal peaks and strategic reserve, statistics show that there are 715 different types of gas storage constructed all over the world with an average working volume of 393 billion m³, and the types of underground gas storage currently constructed can be divided into gas pool, salt cavern and aquifer type[1,2]. Among them, the working gas of underground gas storage type is the largest, accounting for about 75% of the total working gas, 12% of underground gas storage of aquifer type, 7% of underground gas storage of salt cavern type and 6%[3-6] of underground gas storage of oil reservoir type. For different types of underground gas storage reservoirs, there are certain differences in the completion pipe column and discharge and mining method. The design technology of completion pipe column for injection-production wells in foreign gas storage reservoirs is relatively perfect, and the pipe material of the highest level is selected according to the worst environment. There are many kinds of gas seal buckles in foreign countries, the
proprietary buckles are NEW, VAM, 3SB, TC-II buckles, which satisfy the connection strength and anti-viscosity energy and have good air tightness limits [7-10]. The casing pipes of domestic gas storage reservoirs are all connected by gas seal threads. After the connection of the gas seal threads, helium gas shall be tested for its air tightness. The difficulty of the operation of the gas storage reservoir is how to keep the gas from leaking and meet the demand of peak-shaving in the construction and application process. Therefore, this paper mainly discusses the characteristics of different types of gas storage reservoirs, such as production completion string and discharge and mining mode, and finally comes up with a mathematical model to evaluate the leakage risk of gas storage reservoirs, so as to effectively predict and formulate the leakage risk of gas storage reservoirs in future operation and formulate reasonable preventive measures.

2. Different types of gas storage introduction

2.1 differences in geological structure of gas storage
The gas in the salt cavern is stored in the large salt cavern cavity, the gas is concentrated, the gas injection resistance is small, and the daily peak-clipping capacity is strong. However, once the seal of the salt cavern reservoir is out of control, the gas will leak out quickly and cannot be remedied. And waste gas storage reservoir and a quifer gas storage gas storage in rock matrix pores and cracks, gas dispersion, injection wells. The resistance compared with type salt cavity gas storage is bigger, in the event of a dense, the slight failure caused by gas leakage risk small, late to repair the salt cavity gas storage is easy, but, load capacity and salt cavity gas storage is quite weak. In the long-term operation of salt cavern gas storage, the creep of rock salt will lead to the storage capacity loss due to the change of periodic stress. For example, the working pressure of salt cavern gas storage in Jintan city, Jiangsu province is 7~15 MPa. As the numerical simulation shows that its storage capacity will decrease by 3%~5% after 30 years, but deformation of rock skeleton structure is not obvious, the reservoir capacity loss is relatively small.

2.2 different gas discharge and extraction methods
In the case of emergency, the salt cavern can be injected and mined with large displacement, and the injection rate is fast. For example, the daily injection capacity of single well designed in Jintan salt cavern can be as high as 16~20×10⁴ m³, and the total working gas capacity can be as high as 17×10⁸m³ [13-14]. The rate of injection and production in reservoirs of depleted oil and gas reservoirs is limited by formation conditions, and the rate of injection and production depends on reservoir properties.

2.3 difference of injection-production string
Salt cavern gas storage for the first time, gas injection brine discharge inside the cavern, and must be within the injection-production string must be down to the row of halogen center pipe, and to satisfy displacement injection-production, injection-production string large diameter, high internal pressure strength requirements, casing and gas tightness of high requirements for underground auxiliary safety equipment, and due to its long-term contact with brine, the production string of higher corrosion resistance requirements. However, the gas storage reservoirs of depleted oil and gas reservoirs and aquifers are stored in the pores of the formation matrix. There is no need to discharge halogen and the injection and mining speed is relatively low. Therefore, considering its economy, its pipe column diameter is smaller than that of the salt cavern reservoir.

According to the analysis of the working modes of different types of gas storage reservoirs, the differences of the completion string and discharge and mining modes of the three types of gas storage reservoirs are summarized as shown in table 1.

3. Comparison of well completion methods of gas storage reservoirs
In order to meet the requirements of large displacement injection and production, rapid cavity formation and preventing salt crystallization from blocking injection and production string of salt
cavern reservoir, the combination of single well discharge and production string of X1 well in the first salt cavern reservoir in China is preferred to be 244.5mm, producing casing gas injection +177.8mm. The completion string is shown in Fig.1-a). The cavity velocity and cavity shape can be controlled by controlling the entrance depth of the brine column, the solvent resistance level, circulation mode and injection and production capacity, so as to guarantee the stability of the cavity and the requirement of the brine concentration. In the initial stage of the solution cavity of salt cavern gas storage reservoir, the cavity was constructed rapidly with large positive circulation rate and a certain window of cavity was formed. The cavity was constructed faster with reverse circulation. Under the same discharge rate, the concentration of halogen was 25g/L higher than that of positive circulation, and the cavity speed was increased by 10%. Furthermore, by reasonably optimizing parameters before cavitations velocity and halogen concentration and cavitations velocity, the cavity can be constructed rapidly and energy cost can be saved. In addition, after a certain period of cavitations, it is necessary to monitor the shape and structure of salt cavern cavity in time through the down-hole sonar equipment, adjust the injection and mining string and the drainage volume in time to optimize the dissolution cavity structure.

In China, the first underground gas reservoir (Dazhangtuo) injection-production well of gas reservoir is different from that of salt cavern due to its storage of natural gas through the matrix pores of the reservoir without cavity stage. In order to achieve underground control, the X2 of a well of the gas reservoir adopts the injection and production string combination of figure 1-b. The production string of the gas storage reservoir from well mouth to well bottom is mainly composed of these: gas-seal oil pipe+controlling pipeline+safety valve+expandable pipe + XD circular sliding sleeve+safety joint+permanent packer, upper seat joint+perforating gun. After cementing the X2 well with the gas storage reservoir, open the channel between the bottom of the well and the sealing layer through the perforating gun at the bottom of the pipe string. The storage and peak demand of natural gas can be completed through the gas sealing pipeline, and the underground safety valve can be controlled through the ground in case of war, natural disaster and other accidents, effectively shutting down the well to prevent the gas leakage hazard.

4. Research on prediction of inventory leakage risk

4.1. Analysis of gas reservoir leakage risk

No matter what kind of gas storage reservoir construction process is, it is composed of drilling well and discharge and mining construction. Improper construction and long-term periodic injection and mining cause gas leakage risk due to completion string, cement ring and formation damage. The possible leakage risk links of different types of gas storage reservoirs are shown in figure 2. Mainly including the drilling of formation damage, caused by improper cyclic gas injection casing/cement ring and/or mud ring two cementing surface micro-crack formation, cement ontology by the cycle stress of broken zone, fracture aperture, casing packer seal failure crack and subsurface safety valve leakage of seal failure points, etc., as a result, the gas storage well drilling, well completion and rank
construction should have real-time monitoring and early prevention of the leakage risk of these potential sites.

![Figure 2: Key diagram of gas reservoir leakage risk](image)

4.2 prediction method of leakage risk of gas storage reservoir

When the gas leakage of the gas reservoir flows along the casing pipe, the gas rises continuously along the casing pipe between two layers, which can be approximated as a one-dimensional longitudinal Darcy flow. When the gas arrives at the well mouth and gathers at the well mouth, the continuous pressure of casing annular is formed. When the wellhead back-pressure of natural gas is balanced with the equivalent pressure of annular liquid column and formation pressure, the driving pressure difference of gas decreases to 0, the migration stops, and the annular pressure no longer increases. The rate of pressure increase is related to permeability, formation pressure and depth of damaged zone. Therefore, the leakage point location can be predicted through the modified one-dimensional gas Darcy formula, and the formula obtained is shown in figure (1). By assuming permeability $K_{\text{eff}}$ of the leakage path and substituted into formula (1), the annular pressure recovery value of the casing pipe of the well at different time points and the actual detection of annular pressure recovery value were calculated and substituted into formula (2) to calculate the average deviation. When the deviation met the set error requirements, it was assumed that permeability was the effective permeability of damaged zone.

$$q_s = \frac{K_{\text{eff}}AZT_s}{p_sT\mu Z} \left( p_{\text{leak}}^2 - p_{\text{mud}}^2 \right)$$

$$H = \sum_{i=1}^{n} (P_{ci} - P_{gi})^2$$

in the formula, $T_s$-standard state temperature; $T$- the temperature in the storage state, K; $P_s$-the pressure of natural gas in the standard state and the storage state, Pa; $Z_s$-gas compression factor in standard state; $Z$-Gas compression factor in the leakage state; $q_s$-the leakage rate of gas in the standard state, m$^3$/s; $K_{\text{eff}}$-the permeability of leakage channel, m$^2$; $A$-the cross sectional area of the damaged zone of cement ring, m$^2$; $L$- the distance from leakage point to well entrance, m; $\mu$- average viscosity of natural gas in flow; $P_{\text{leak}}$- pressure at the lack point , Pa; $P_m$-wellhead pressure ,Pa; $H$- the calculation error of the model; $P_{ci}$-the calculation value of the casing annulus pressure at the i time detection point, $P_{gi}$-the readings of the casing annulus pressure at the i time detection point , and the monitoring value of the casing annulus pressure at the i-th time point is $g / 1$. $n$-the number of monitoring points; $i$-the first time monitoring point.

5. Conclusion

(1) The gas storage ability of salt cavern gas storage to gas reservoir of gas storage/aquifer is high in
injection and production rate, and the strength and corrosion resistance of pipe column of injection-production well are more demanding. The construction technology of salt cavern gas storage reservoir mainly includes: water injection and halogen-drainage cavity technology, cavity body optimization technology, casing gas seal and anti-rot technology, and gas rapid injection and production technology.

(2) Different types of gas storage in construction risk could cause leakage, the dangerous leak place of gas storage mainly include casing/cement surface cracks, cement ontology/two cementing, casing damage zone formation, formation damage, broken cement, down hole packer and subsurface safety valve leakage location.

(3) Based on the Darcy law of gas, the mathematical model for predicting the damage degree of leakage location in gas storage well is derived, which can predict the damage degree of leakage location in gas storage well more accurately and provide technical indicators for the formulation of preventive measures.

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reference
[1] Zhang, G., et al. Challenges to and proposals for underground gas storage business in China (UGS). Natural Gas Industry B, 201, 4 (3) : 231-237.
[2] Li Guotao, Hao Guoyong, Zhu Guanghai, etc., considerations for well completion design of salt cavern gas storage reservoir and technical development [J]. Natural gas and stone Oil, 2012, 30 (1): 524.
[3] Li Guotao, Zhu Guanghai, Zhang Qiangetal. Al. Considerations in Salt Cave Gas Storage Well Completion Design and its Technology Development [J] Natural Gas and Oil, 2012, 30 (1) : 524.
[4] Su Xin, Zhang Lin, Li Yue, current situation and development trend of underground gas storage at home and abroad [J]. Natural gas and oil, 2007 (4) : 1-4.
[5] Su Xin, Zhang Lin, Li Yue. Status and Development Trend of Foreign Underground Gas Storage [J]. Journal of Natural Gas and Oil, 2007 (4) : 1-4.
[6] Wu Zhonghe, He Yu. Functions and functions of underground gas storage [J]. Natural gas and oil, 2004 (2) : 1-4.
[7] Danel, R., Etal. Monitor and Balance of Gas Flow in Underground Gas Storage. Procedia Earth and Planetary Science, 2013. 6:485-491
[8] Shaner, B., Appraisal of Underground Natural Gas Storage Rights in Depleted Reservoirs, Appraisal Journal2016, (2): 133-140.
[9] Zheng, Detal, Key evaluation techmques In the process Of gas reservoir being converted into underground gas storage. Petroleum Exploration and Development, 2017, 44 (5): 840-849.
[10] Pang Jing, Qian Genbao, Wang Bin, et al. Evaluation of scaling ability of underground gas storage converted from the Xinjiang H gas field [J]. Natural Gas Industry, 2012, 32(2):83-85.
[11] Yuan Guangjie, Tian Zhonglan, Yuan Jinping, et al. Influence factors of scaling property of salt cavern gas storage[J]. Natural Gas Industry, 2008(4):105-107.
[12] Ding Guosheng, Zhang Baoping, Yang Chunhe, et al. The creep deformation rule of gas storage salt cavern [J]. Natural Gas Industry, 2007(11):94-96.
[13] Jing Wenjun, Yang Chunhe, Li Luming, et al. Sensitivity analysis of influence factors of cavern shrinking risk in salt cavern gas storage [J]. Chinese Journal of Rock Mechanics and Engineering[12], 2012, 31(9):1804-1812.
[14] Ding Guosheng. Calculation and OPerating Simulationon the Single Cavern Storage Capacity for Jintan Cavern Gas Storage [J]. Oil & Gas Storage and Transportation, 2007(1):23-27.
[15] Yuan Jinping, Li Gensheng, Zhuang Xiaoqian, et al. Gas-injection production technology using underground gas-storage salt cavern to displace brine solution and contain injected gas[J]. Natural Gas Industry, 2009, 29(2):76-78.