Challenges of constructing salt cavern gas storage in China

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Abstract: After more than ten years of research and engineering practice in salt cavern gas storage, the engineering technology of geology, drilling, leaching, completion, operation and monitoring system has been established. With the rapid growth of domestic consumption of natural gas, the requirement of underground gas storage is increasing. Because high-quality rock salt resources about 1000m depth are relatively scarce, the salt cavern gas storages will be built in deep rock salt. According to the current domestic conventional construction technical scheme, construction in deep salt formations will face many problems such as circulating pressure increasing, tubing blockage, deformation failure, higher completion risk and so on, caused by depth and the complex geological conditions. Considering these difficulties, the differences between current technical scheme and the construction scheme of twin well and big hole are analyzed, and the results show that the technical scheme of twin well and big hole have obvious advantages in reducing the circulating pressure loss, tubing blockage and failure risk, and they can be the alternative schemes to solve the technical difficulties of constructing salt cavern gas storages in the deep rock salt.

1. Current situation of salt cavern gas storage in China

The first salt cavern gas storage in China was carried out in 2003.The preliminary alternative site included Jiangsu, Hubei, Yunnan, Henan and some other places. In 2007, the first domestic salt cavern gas storage was built in Jintan city of Jiangsu province. By the end of 2016, more than 60 wells had been drilled and more than 20 cavities had been put into use, and the storage capacity is close to $7\times10^8m^3$.

With the increasing of domestic natural gas consumption, the demand of underground gas storage is growing, especially in the east and south of China. However, there is little natural oil and gas reservoir in these places, and salt cavern gas storages will be an inevitable choice. The favourable construction depth of salt cavern gas storage is the range of about 900m~1200m, but such resources are scarce in China. Therefore, the salt cavern gas storage must be constructed in the deeper salt formations. The depth of salt formation may be 2000m or even deeper, which will be a trend for a long time in future.

Recent years, according to the experiences obtained in constructed gas storage wells or mining wells, construction in deep salt formations may face the problems of higher capacity of equipments, longer construction period, and more investment of the project, which are caused by increasing depth and the complex geological conditions. It is essential to take new technical solutions to solve these problems.

2. The main challenges for gas storage construction in deep salt formation

At present, the depth of salt cavern gas storages constructed in Hubei, Henan and some other places is more than 2000m, which will bring more challenges for salt cavern construction.

2.1. Difficulties from the increased depth

The deep salt formation may result in the longer casing and tubing, and higher temperature difference between wellhead and salt formation, which may cause some problems or new requirements:

(1) The performance parameters of tubing run in hole should be improved. In the case of Φ177.8mm leaching tubing, the J55 steel grade casing can meet the requirements of gas storage in Jintan, but in Hubei, Henan and other places at least N80 grade casing can meet the requirements.

(2) The increase of depth leads to the increase of fluid circulating pressure consumption during solution mining, which requires the higher pressure level surface equipments. At the same time, the consumption of electric energy also increases greatly, which has an adverse impact on the economy.

(3) The temperature difference between the bottom hole and the wellhead is larger. For saturated brine, the crystallization is easy to occur during the process of returning to the ground. The risk of tubing string blockage increases, the workload of workover will increase, and the solution mining speed will be difficult to improve, which should be avoided for the solution mining [1~3].

(4) With the increasing of depth, the plasticity of the salt layer is enhanced and the overburden pressure is also increased. This is also a significant increase in the performance requirements for the production casing working in the salt layer. For the selected larger size completion tubing, there is also a problem of tubing selection.

2.2. Difficulties caused by special formation characteristics

Different from the foreign dome salt cavern gas storage, China's salt resources are mainly sedimentary layered salt. Although the total thickness of salt layers in some areas is large, each single layer is quite thin, and only a few of them are more than 50m thick. The grade of salt is usually poor. The pure salt content is generally from 50% to 80%. At the same time, there are a large number of interlayers, and some of them are very thick. To construct gas storages in these multi-layer salt formations [4~5], there are more difficulties need to be considered:

(1) There are many mudstones in the salt formation, and the insoluble content is greatly different. The cavern shape is difficult to control during solution mining, and the developing trend is also hard to predict accurately, which result in low efficiency of solution mining.

(2) Some of the interlayers will be dissolved or collapse during the solution mining, which may result in the bending, deformation or fracture of the tubing, and it will increase the work of workover operation and affect the speed of cavern building.

(3) The lithology of interlayers is quite different. Some interlayers have sealing problems. Based on the understanding of gas tight test practice in the previous gas storage well[6], a poor sealed interlayer not only increases the wellbore or cavern gas tightness test operation time, may also reduce the expected working pressure, and even lead to individual cavern used for other purpose.

3. Alternative technical solutions for solving such problems

According to the construction experience of salt-cavern gas storage, there are mainly 2 types of cavern construction: single cavern with single well and single cavern with twin wells. In China, there are two completion methods: big borehole and conventional borehole. The different size casing completion method originates from the fact that Φ339.7mm casing is widely used in abroad, and Φ244.5mm casing is widely used as the production casing in China.

3.1. Technical scheme of twin well

This technical scheme is to use 2 wells to build caverns and finish the completion operation. The well structure is shown as Figure 1.

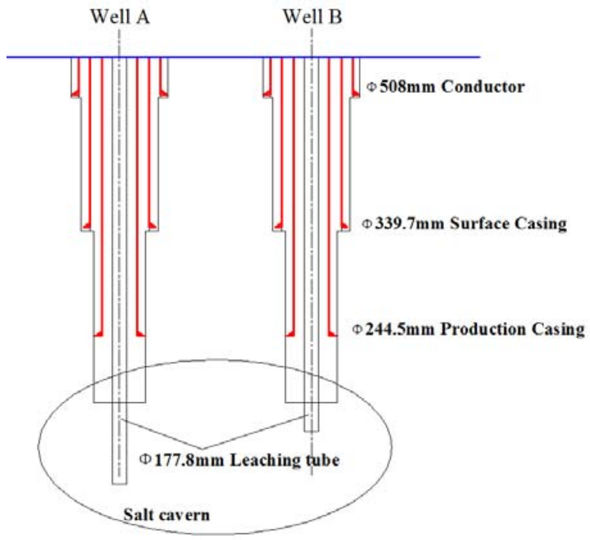

Figure 1. Well structure for twin well

In the first stage, 2 wells will be drilled with the same casing programme. In the stage of solution mining, water can be injected into 2 wells through Φ177.8mm+Φ114.3mm double tubing assembly. When the two small caverns are connected, Φ114.3mm tubing will be pull out of the bore hole and it becomes an assembly of Φ177.8mm+Φ177.8mm tubing. Fresh water can be injected from well A and brine comes out from Well B. Of course, fresh water can also be injected from Well B. In this stage of solution mining, the size of leaching tube is Φ177.8mm, which can not only decrease pressure loss, but also improve the mechanical ability of the tubing, which is benefit for improving the solution mining efficiency.

3.2. Technical scheme of big borehole

This scheme is to use the Φ339.7mm casing as the production casing. Thus, larger size leaching tube can be used for the cavern solution mining. Its wellbore configuration is compared with that of normal borehole, as shown in Figure 2.

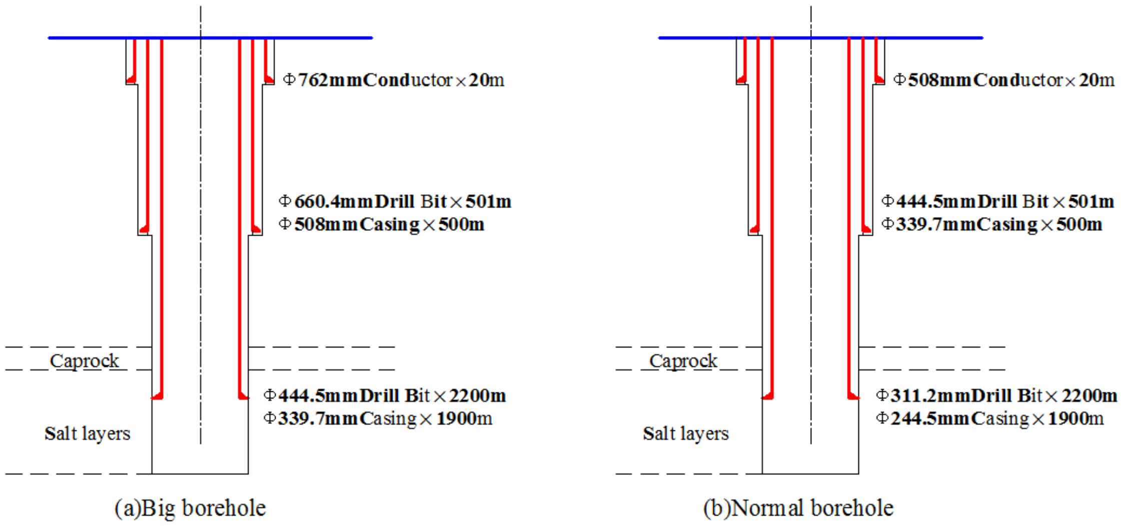

Figure 2. Comparison of two type structures

The production casing is larger when the big borehole scheme is used. There are more choices for the leaching tube assembly, such as Φ298.5mm+ Φ244.5mm, Φ244.5mm+Φ168.3mm, Φ273.1mm+Φ177.8mm, Φ244.5mm+Φ114.3mm, Φ273.1mm+Φ139.7mm and so on. Through hydraulic parameter calculation and considering the optimum annular gap, the Φ273.1mm+Φ177.8mm tubing assembly is the best scheme. Obviously, this assembly can reduce the pressure loss compared to the conventional assembly, and at the same time the tubing strength and the failure resistance are improved.

4. Comparison and analysis of different schemes

4.1. basic parameters for the calculation

In order to facilitate the comparison of calculation results from different schemes, the same basic parameters are adopted in different schemes involved in this paper. The well depth is 2200m, the tubing depth is 2150m, and the brine density is 1200kg/m^3. The wellhead temperature is 20°C, and the bottomhole temperature is 80°C. The thickness of 273.1mm casing is 12.57mm, the thickness of Φ177.8mm casing is 9.19mm and the thickness of Φ114.3mm tubing is 6.88mm. Other parameters refer to relevant standards and manuals.

4.2. Comparison of solution mining schemes

(1) Twin well method

Using double tubing assembly should meet not only the demand of brine flow rate, but also the matching of double tubing diameter. Only if the matching of two tubing diameter is reasonable, the technical requirements of large displacement, low pump pressure and high brine concentration are obtained. By simulating the drainage capacity of A and B wells with different sizes of casing and leaching tube, the best tubing assembly can be obtained. The results of simulation calculation are shown in Table 1.

Table 1. Comparison of displacement of casing and tubing assembly with different sizes under the same water injection pressure (Pump Pressure: 15MPa)

Group	Well A		Well B		Maximum output volume (m^3/h)
	Production casing diameter (mm)	Leaching tubing diameter (mm)	Production casing diameter (mm)	Leaching tubing diameter (mm)	
1	244.5	177.8	244.5	177.8	350
2	244.5	177.8	219.1	139.7	200
3	219.1	139.7	219.1	139.7	160
4	244.5	177.8	177.8	127	130

By comparing the results of Table 1 and considering the experience of building salt cavern gas storage in China, the assembly of Φ244.5mm casing as production casing and Φ177.8mm casing as leaching tubing can make full use of the potential of ground equipment and achieve high efficiency of solution mining.

(2) Big borehole scheme

The 3.2 part has indicated that Φ273.1mm+Φ177.8mm tubing assembly is the best choice for big borehole scheme. In order to fully illustrate the difference between the big borehole well and the normal borehole, the results of water injection pressure under different cavern making modes are obtained by simulation, as shown in Table 2.

Table 2. Comparison of water injection pressure under different solution mining methods

Cavern method	The maximum water injection pressure without considering the brine	The maximum injection pressure when brine concentration is close to

	concentration requirement, MPa	saturation after sump leaching, MPa
Conventional well	18.8	18.8
Twin well	11.7	11.4
Big hole	16.4	15.8

From the injection pressure, water injection pressure of twin well and big well is lower than that of the conventional well, especially the twin well.

Despite the big borehole scheme has advantages in building cavern, but there is still a big challenge in drilling engineering in two aspects.

(a) For deep wells, especially for wells with a depth of more than 2000m, the collapse strength requirement of Φ339.7mm production casing is greatly increased. If the high content of carbon dioxide gas is stored in the storage, the chromium anticorrosive material tubing must be used, and it is difficult to choose the proper casing. At present, there are few suitable casing products available in the worldwide.

(b) It is difficult to get high quality wellbore and the risk of tripping is high. At the same time, there is no experience in deep well cementing with such big size borehole, and the quality of cementing is also uncertainty.

4.3. Comparison of well completion schemes

The conventional well is composed of Φ177.8mm production tubing and Φ114.3mm brine discharging tubing. After the brine discharging is over, the brine discharging tubing is pulled out by snubbing operation. The scheme in domestic has been successfully applied in more than 20 wells. Compared with the conventional wells, big borehole completion tubing can be the same as the conventional wells. The gas tight test method is the same as that of the conventional well, but more test gas/nitrogen will be used obviously.

In addition, due to big borehole size, there may be some difficulty in choosing suitable downhole tools, such as outer packer and matching wellhead equipments. The big borehole scheme has no advantage in completion.

As for the construction plan of twin well, there are some special features. The Φ177.8mm casings are used as the injection-production tubing and the brine discharge tubing. They are separately located in well A and B. The depth of injection-production tubing in well A is the same as that of conventional borehole, and the brine discharge tubing of well B is close to the bottom hole. When the brine is displaced by gas, there is no snubbing operation. The features of the scheme can be summed up as:

(1) The brine discharge tubing remains in the wellbore. This plan may improve the well completion operation safety and save costs. When the well needs to be repaired or the brine is displaced, it can be used as a brine injection channel.

(2) The size of gas injection and brine discharging channel are larger, the ground equipment load is reduced, and the time for gas injection and brine discharge is less than that of conventional borehole.

(3) When the bottom of the salt cavern is irregular, there is an alternative measure to adjust the position of the brine discharge tubing, which is beneficial to the full use of the salt cavern space.

For the three kind schemes, there are advantages and disadvantages, and the cost of each project is also different. In view of the injection-production engineering, the conventional well bore scheme is mature and practical. For the big borehole scheme, there is some uncertainty in downhole tools selection and engineering risk. While the twin well scheme has special advantages, and the safety of production operation is higher.

5. Conclusions and recommendations

(1) It is an inevitable choice to build salt cavern gas storages in salt rock. And it will be a trend for a long time to construct the salt cavern gas storage in the deeper salt formations in future.

(2) The conventional well scheme has been implemented in many wells, and the risk of implementation is low. The disadvantage of the scheme includes long cavern construction period, and more engineering risks for deep salt cavern construction.

(3) The big borehole scheme has advantages in short cavern construction period and less investment. The disadvantages include that there is no such deep cases of implementation in China or abroad, the choice of tubing and well quality control is difficult, and it is also uncertainty about cementing quality.

(4) The advantage of twin well with single cavern scheme includes that the construction period of cavern is short, and there are more advantages of injection-production well completion than the single well. The disadvantage is that the investment may be a little higher.

(5) Big borehole and twin well scheme have some technical advantages to solve the problems of building deep salt cavern. But there is no technical basis and practical experience in domestic, it is essential to accelerate the development of big borehole and twin well engineering research and field test, and to provide technology and experience for domestic large-scale deep salt cavern construction.

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