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# Current Situation and Development Trend of Gas Storage Solution Mining Technology in Salt Cavern

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**Abstract:** The main solution mining method of gas storage in salt cavern is positive cycle in China. The solution mining speed is low which need from four years to five years to build a cavern with the volume of 200000 cubic meters. The method of solution mining is single. It is difficult to adapt to the rapid development of domestic underground gas storage. Many kinds of solution mining methods are required to be studied in order to increase the solution mining speed. By numerical calculation and field application, the process and advantages & disadvantages of all sorts of solution mining modes are described, the reasons to increase solution mining speed are analyzed such as reverse circulation, large hole, double well, double strings and so on. Research shows that the main solution mining modes of gas storage in salt cavern in the future are reverse circulation, large hole, double well and double strings, which can increase solution mining speed effectively. There are some shortcomings and difficulties of solution mining with large hole cavity and double well and double strings. Many key technologies need to be studied. Cementing is difficult for large hole method, it is difficult to control cavity for double well method, production casing is vulnerable to brine corrosion for double well method. The solution mining of reverse circulation is relatively mature with cavity controlling and cushion detection, which can improve solution mining speed effectively by more than 20% and can advance the construction process of gas storage in china.

**Keywords:** Gas Storage, Solution Mining, Salt Cavern, Reverse Circulation, Large Hole, Double Well, Double Strings

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## 1. Introduction

Gas storage in salt cavern is constructed in layered salt layer with low grade salt rock and thick layers in China. These gas storages use solution mining with single well convection method that the oil cushion is used as the protective liquid and the positive circulation is the main cycle [1-3]. Compared with foreign salt mound [4-5], the domestic cavity is complex and diverse, the actual shape and volume of the dissolved cavity are different from the designed cavern, the cavity is not easy to control. Solution mining time is long and there are accidents in the process of solution mining such as string bending and clogging [6-11].

Many domestic scholars have analyzed various problems existing in salt cave cavity, and they concentrate on interlayer collapse, string bending, large hole solution mining, constructing groove rapidly, etc. Jiang Deyi [12-14] has revealed the relationship between mechanical properties of insoluble interlayer and brine immersion time in the process of

salt water dissolving, and provided theoretical support for predicting and controlling the interlayer collapse. Li Jinping [15] has analyzed the vibration characteristics of internal and external string without space constraints, and revealed that self-excited vibration and dynamic instability in the confined space are the main reason that causes the string to bend and damage seriously. Yuan Guangjie [16] has developed quick solution mining tool that can increase the speed of constructing groove and used in the early stage in the process of constructing groove. Zheng Yali [17] has studied the applicability of large size string solution mining under special geological conditions in China, and the study results shows that large size string solution mining has obvious advantages in speeding up the progress of solution mining, saving cost and reducing energy consumption. Ban Fansheng [18-19] has studied the method of constructing groove quickly, and proposed three kinds of quick constructing groove techniques that are optimizing cavity parameters, reaming and using quick solution mining tool. According to the present situation

of solution mining technology in China, it is the main trend of the development of gas storage in salt cavern that solution mining with reverse circulation, large borehole, dual wells, directional well and double strings can improve the solution mining speed effectively.

## 2. Current Situation of Solution Mining

### 2.1. Harsh Geological Conditions

The geological condition of constructing cavern is harsh with bedded salt layer and low salt rock grade in Domestic places such as Jintan, Pingdingshan, Chuzhou, Qianjiang, Huaian, Yunying and so on. Salt layer thickness is 60 ~ 250 m, insolubles content of salt rock is 15% ~ 15%, interlayer is more and thick, part of gas storage in salt cavern is deep that objective layer is 700 ~ 2 200 m depth.

### 2.2. Single Solution Mining Method

The mainly solution mining method of gas storage in salt cavern in China is the single well convection method [20-21] (Figure 1), production casing diameter is 244.5mm, the cavity string is composed of the outer string (diameter 177.8 mm) and the inner string (diameter 114.3mm), the oil cushion is used as the protective liquid injecting from annulus between the production casing and the outer string, the positive circulation is the main cycle. The adjustment frequency of solution mining string is 2 ~ 3 times per year and the workover is more and the cost is high.

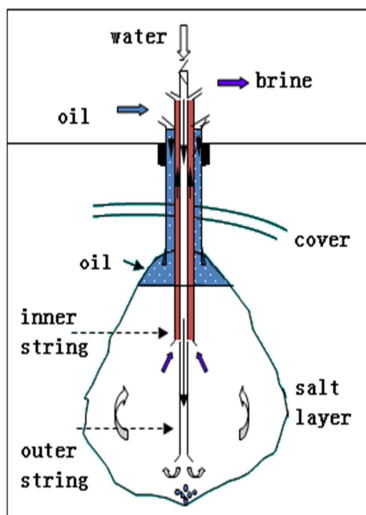


Figure 1. Schematic diagram of solution mining with single well convection method of gas storage in salt cavern.

### 2.3. Long Solution Mining Time

The shape of salt cavern is complex and diverse, and there is a miscible phenomenon [6-7] in part of salt caverns. The actual volume of salt cavern is quite different from the designed volume. The solution mining time of single well is about 5 to 7 years. The single cavity consumes electricity about  $1,000 \times 10^4$  degrees.

### 2.4. More Solution Mining Accidents

Solution mining in deep salt layer is complex that there are more accidents in the well, salt crystallization is powerful, brine string is easy to be blocked, string bending phenomenon is common. Oil cushion is used as the protective liquid in the process of solution mining. The oil cushion is detected by many instrument with wire transmission such as multi-sensor interface detector, optical fiber interface instrument and so on. The cable or fiber are easily worn or broken while they enters into well with the string.

## 3. Development Trend of Solution Mining Technology

The study on the use of salt caverns in China began in 1998 that it develops late compared with foreign countries. Solution mining is used by the method of single well convection, solution time is low and it is difficult to adapt to the demand for rapid development of domestic storage. It is the main trend of the development of gas storage in salt cavern that solution mining with reverse circulation, large borehole, dual wells, and double strings can improve the cavity speed effectively and reduce construction cost.

### 3.1. Solution Mining Technology with Reverse Circulation

Solution mining with reverse circulation is the main method in China after constructing groove of gas storage in salt cavern. The technology has absorbed the foreign salt cavern building, domestic salt extraction experience. Cavity control and detection technology are mature that have applied to the site. Compared with the mainly cycle of positive circulation, reverse circulation has the following characteristics.

- (1) The mainly cycle of reverse circulation. The mainly reverse circulation is used in the middle and late stage of solution mining, and positive circulation is used to repair cavity and to flushing with water in order to destroy crystal.
- (2) Large water injection velocity. Solution mining speed can be increased and the brine concentration from the cavity is large used by solution mining with reverse circulation. Larger water injection rate can be used and the maximum rate is up to  $150 \text{ m}^3/\text{h}$  in the later stage in the process of solution mining.
- (3) Lower string lifting times. We reduce times to lifting string in the solution mining of gas storage in salt cavern. More string lifting times improves cost and time of solution mining and lift the bottom of the cavity.
- (4) Higher solution mining velocity. It can improve solution mining velocity and shorten solution mining time with reverse circulation. The field application of three wells in Jintan has showed that the solution mining velocity with reverse circulation is larger than the velocity with positive circulation. The solution mining velocity is  $150 \text{ m}^3/\text{d}$  with reverse circulation that the water injection displacement is  $60 \text{ m}^3/\text{h}$ . The solution mining velocity is

85 m<sup>3</sup>/d with positive circulation that the water injection displacement is 100 m<sup>3</sup>/h.

**3.2. Solution Mining with Dual Wells**

Single cavity with dual wells drills two wells on the same salt layer, and one well is used for water injection, and another well is used for brine production. The solution mining with dual wells is suitable for solution mining in the thin salt layer. According to the well spacing, there are two types of single cavity with dual wells: dual straight well and horizontal Wells + straight Wells. The advantage of solution mining with dual wells is to reduce the circulation pressure and increase water injection displacement and shorten solution mining time, and the disadvantage is that it is difficult to control cavity shape and lacking monitoring technique for cavity shape.

**3.2.1. Double Vertical Wells**

The solution mining with double vertical wells of gas storage in salt cavern is the method that two vertical wells are drilled with 15~30 m distance and two solution mining strings are put in each well after two wells connected. Water is injected in one well and brine is discharged from another well. Two wells are drilled in the same salt layer that can forms good cavity in the aspect of stability. The cavity volume is small in thin salt layer. The method has been applied in Yunying.

Energy consumption is small and large water injection rate (up to 400 m<sup>3</sup>/h) is allowed and solution mining rate can be

increased obviously with double vertical wells of gas storage in salt cavern. As an example of cavern construction in 1000m salt layer in Jintan, the solution mining time of cavern with the 20×10<sup>4</sup> m<sup>3</sup> volume is shortened nearly 50% compared with the single well convection method based on the numerical simulation.

**3.2.2. Horizontal Wells and Straight Wells**

The solution mining of single cavern formed with horizontal docking well is the method that one vertical wells is drilled first and another horizontal well is drilled to connect with another cavity in the vertical well by constructing groove (Figure 2). Horizontal docking production group is formed and inner pipe is put in the vertical well. In the early stage of two wells connecting, water is injected in horizontal well in order to flush the sidewall and enlarge the cavity. Then cavern is solution mined by injecting water and brine alternately in two wells. Diesel is injected into vertical well to control cavity dissolved upward.

The horizontal well (directional well) and vertical well are drilled in the same salt layer that the advantage is to make full use of the salt layer to form a large cavity. For vertical well, the diameter of the casing pipe is 244.5mm and the diameter of the brine column is 177.8mm. For horizontal well, the diameter of casing pipe is 177.8mm. With small circulation pressure, the water injection displacement can reach 300 m<sup>3</sup>/h, and the speed is obviously improved. Currently, this method has not been applied in the field.

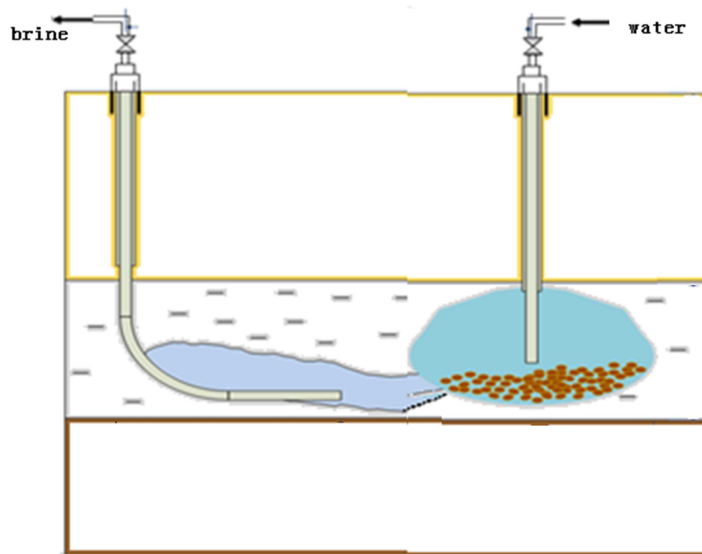


Figure 2. Horizontal and vertical well solution mining schematic diagram.

**3.3. Solution Mining with Large Hole**

Solution mining with large hole is a common method of gas storage in salt cavern in foreign countries. Water solution mining with single well convection method is used. The diameter of production casing pipe is 339.7 mm. The solution mining string with the outer tube (273.05 mm diameter) + the inner tube (177.8 mm diameter) is adopted that the advantage is small solution mining energy consumption and larger

injection displacement (up to 300 m<sup>3</sup>/h). As an example of cavern construction in 1000m salt layer in Jintan, the solution mining time of cavern construction with the 20×10<sup>4</sup> m<sup>3</sup> volume is shortened nearly 46% compared with the single well convection method based on the numerical simulation. For solution mining with large hole, the diameter of production casing pipe is 339.7mm and well cementing is difficult. At present, the solution mining method is still studying and has not been applied in the field.

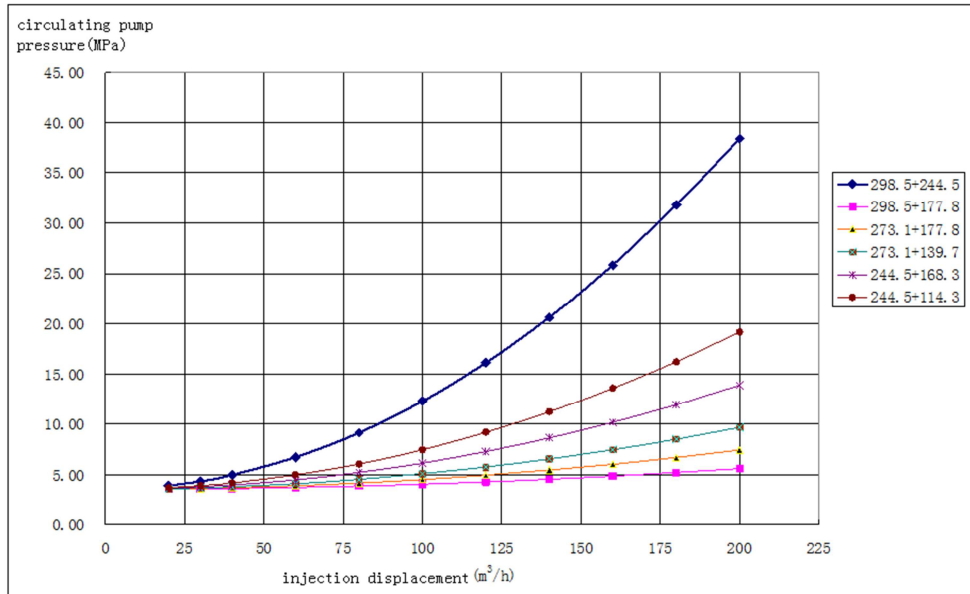


Figure 3. The relationship between water injection displacement and circulating pump pressure in two solution mining strings.

### 3.4. Solution Mining with Double Strings

The diameter of production casing pipe of solution mining with double strings is 193.7mm. The solution mining string with the outer tube (193.7 mm diameter) and the inner tube (114.3 mm diameter) is adopted. Diesel is used as protective layer before solution mining. Compared to the current solution mining method with the outer tube (177.8mm diameter) and the inner tube (114.3mm diameter) in China, the solution mining with double strings can reduce machine pump equipment load and reduce the energy consumption in the process of solution mining. It also has the following advantages. It is beneficial to the large water injecting displacement because of larger diameter of inner tube that can shorten construction time. The pressure in the larger diameter tube is small in the same injection displacement which can reduce water hammer and vibration. It can improve pipe life and reduce accident risk. The

gap between the two pipes is large, which is beneficial to the operation of the inner tube and the outer tube.

It can be seen from the relationship between water injection rate and circulating pump pressure (Figure 4) of two kinds of solution mining strings that the solution mining with double strings can reduce pressure consumption and increase solution mining speed and allow larger injection displacement, compared to current solution mining string in Jintan. The solution mining string combination in Jintan is the outer tube (diameter 177.8mm) and the inner tube (diameter 114.3mm). The solution mining string combination with double strings is the outer tube (193.7mm diameter) and the inner tube (114.3mm diameter). At the same time, production casing brine corrosion need to be studied because no enough diesel as protective layer controls dissolution upward. The solution method with double strings has been applied in Jintan.

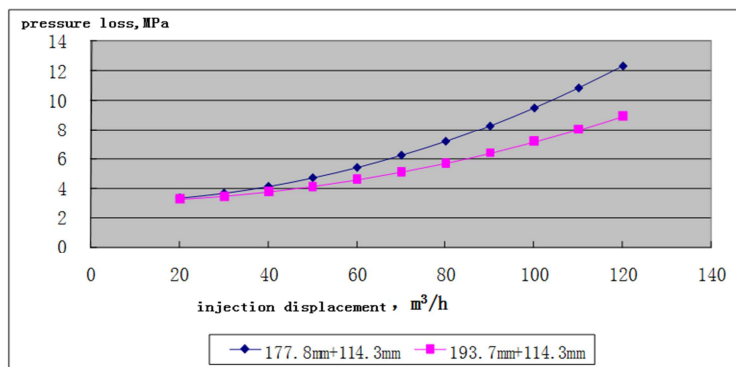


Figure 4. The relationship between water injection displacement and circulating pump pressure of two solution mining strings.

## 4. Conclusion

(1) The main solution mining method of gas storage in salt cavern is positive cycle in China. The solution mining

speed is low that it is difficult to adapt to the rapid development of domestic underground gas storage. Many kinds of solution mining methods are required to be studied to increase the solution mining speed.  
 (2) Safe and efficient solution mining is the construction

purpose of gas storage in salt cavern. The development trend of gas storage solution mining in salt cavern are reverse circulation, large hole, double well and double strings, which can increase solution mining speed effectively and reduce solution mining cost.

- (3) Well cementing is difficult for solution mining with large hole. It is difficult to detect and control cavity shape by the means of solution mining with double wells. The production casing brine is easy to be corroded because no enough diesel as protective layer to control dissolution upward. Each solution mining method has own shortcomings and difficulties and many key technologies need to be solved further.
- (4) Field application shows that the solution mining of reverse circulation is relatively mature, which can improve solution mining speed effectively by more than 20% and can advance the construction process of gas storage in china.

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## Biography



**Ban Fansheng** (male) is a senior engineer born in 1977. He has graduated from the graduate school of Chinese academy of sciences in fluid mechanics as a doctor in 2008. He works at engineering technology of underground gas storage. He has published more than 30 articles in academic journals in solution mining of gas storage in salt cavern.