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Discussion on the Construction and Operation Management Modes of Salt Cavern Gas Storage in China

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***ABSTRACT**: At present, China's natural gas abroad dependence is as high as 45 %. To establish the gas storage facilities and improve their efficiency of operation and management are greatly significant for the gas supply of China. Salt cavern gas storage has the advantages of fast peak adjustment, high turnover rate, less cushion gas and suitable investment, etc. So it is a significant choice for the construction of gas storage caverns in salt formations in Central and Eastern China because of the rich underground salt resources in these regions. However, the construction and operation of salt cavern gas storage in China is not smooth. The main problem lies in the lack of scientific and reasonable construction mode and management and operation mode. To solve these problems of the salt cavern gas storage in China, a series of research are studied in this paper. At first, the current situation and operation mode of salt cavern gas storage in Europe and America are investigated. And then, the current situation of salt gas storage in China is also surveyed and analyzed, and the existing problems in construction and operation are also pointed out. Thirdly, combining with the experiences abroad, a new mode suitable for the construction and operation of the salt cavern gas storage of China is proposed, including of the using of some suitable old caverns for gas storage, the integration of "brine extraction-cavern construction-gas storage", as well as the multiple investment management mode for investment and operation. This new mode can effectively shorten the cavern construction period, reduce the cost for brine leaching and improve the economic benefits for salt mining companies and gas storage companies. In addition, due to the multiple investment mode, the risks and benefits among different investors are effectively divided.*

***KEY WORDS**: Salt cavern gas storage; Construction and operation; Old cavern utilization; Brine extraction-cavern utilization-gas storage; multiple investment.*

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I. INTRODUCTION

Natural gas has the advantages of high calorific value and less pollution. With the progress of China's "Coal-to-Gas" and "Environment-Friendly Society" development, the use of natural gas in China has been rapidly increased in recent years. The annual consumption of natural in China exceeded 270 billion m^3 in 2019. It is expected to reach 300 billion m^3 in 2020, accounting for 10 % of the national energy. According to the national plan, China's natural gas consumption will reach 450 billion m^3 in 2030, and the proportion of natural gas in the nation's energy will increase to 15 % [1]. However, China is not a country rich in natural gas resources and gas production. Although the current natural gas accounts for only 8 % of the energy, its external dependence is already as high as 45 %. And it is expected to soon exceed the 50 % safety threshold. Moreover, there is imbalance between the supply and use of natural gas. China's natural gas production areas and import pipelines are mainly located in the western regions, while the main consumption regions are located in middle and eastern China. Moreover, gas consumption has periodicity and seasonality, such as the gas use in winter is much larger than that in summer. Therefore, where the middle and lower reaches of natural gas pipelines are close to big cities, large gas storage facilities should be generally constructed to cope with peak shifting, emergency and security [2].

At present, the world's gas storage facilities are basically built underground, mainly including three types: depleted reservoir gas storage type, brine aquifer type and salt cavern type [3]. According to the international standard, the working gas volume of the gas storage must reach more than 10 % of the annual consumption of natural gas to effectively ensure the stability of the natural gas market [1]. At present, China has a total of 25 underground gas storage sites, distributed in 11 blocks, with an accumulative working gas volume of about 11 billion m^3 (only 3.6% of the annual gas use in 2019), mainly distributed in northwest, North China, northeast

China and other regions. There is only one gas storage site in the central and eastern regions with high natural gas consumption [1]. In the central and eastern regions of China, depleted gas reservoirs and aquifer formations are lacking, but there are abundant underground salt mines available for the construction of gas storage [4]. As early as 2007, China National Petroleum Corporation (CNPC) used 6 abandoned salt caverns in Jintan Salt Mine of Jiangsu province to store gas, with a total working gas volume of 81 million m^3, starting the operation journey of salt cavern gas storage in China [4]. Since then, CNPC and China Petrochemical Corporation (SINOPEC) had demarcated blocks in the Jintan Salt Mine for exploration, cavern-construction and gas storage. By April 2019, the accumulated gas production in Jintan gas storage site exceeded 2.4 billion m^3 [5]. Since 2007, China had also planned salt cavern gas storage sites in Huai'an, Yingyun, Qianjiang, Pingdingshan and Anning, respectively. And these above sites have also been included in the 13th Five-Year Plan of China [6].

China's salt cavern gas storage has experienced almost 13 years of development. But up to now, only over 30 caverns (550 million m^3 of working gas volume in total) have been put into operation for gas storage in Jintan salt caverns. The rest of salt gas storage projects are still under planning or construction, but no official gas storage has been reported [1]. This indicates that the construction, investment and management of salt cavern gas storage in China is not smooth. On the one hand, China's salt mines are all bedded salt rocks, and the complicated geological conditions lead to great difficulties in cavern construction, many accidents and slow progress, which leads to the lag of cavern construction and gas storage [7]. On the other hand, the comprehensive cost of salt cavern gas storage is much higher than that of depleted gas reservoir. And thirdly, so far the tiered-price of natural gas has not been implemented in China, which influences the investment enthusiasm for gas storage facilities. In addition, the volume of salt cavern is generally small, so its gas storage capacity is far less than the depleted gas reservoir, which further reduces the enthusiasm of CNPC and SINOPEC to invest salt cavern. In fact, some experts and engineers have made efforts to solve the current problems for the salt cavern gas storage in China. For example, some scholars proposed to make full use of the existing salt caverns to store gas so as to shorten the construction period and save investment [1]. Moreover, it is proposed that if gas companies cooperate with salt mining enterprises and pay attention to the integration of brine extraction and cavern construction, the investment in gas storage can also be largely reduced [8]. In recent years, European and American countries have paid more and more attention to salt cavern gas storage [3]. This is because of its innovation in management mode of gas storage. For instance, 1) gas companies cooperate with salt mining enterprises by leasing the salt caverns [9]; 2) increase the gas injection and production conversion frequency to increase the accumulated gas production [10]; and 3) multi-party cooperation investment and management are adopted. These provide good reference for the reform of investment management of salt cavern gas storage in China.

This paper firstly investigates the current situation of salt cavern gas storage in Europe and America, and recognizes the advantages of its operation and management. Then the construction and operation of salt cavern gas storage in China are investigated and the existing problems and deficiencies are pointed out. Finally, combining with the successful experience of foreign salt cavern gas storage, the reform methods and evolution direction of salt cavern gas storage in China are put forward. This study provides an important reference for the investment reform and operation management of salt cavern gas storage in China.

II. STATUS OF GAS STORAGE IN EUROPE AND AMERICA

2.1 European salt cavern gas storage

Europe's consumption of natural gas accounts for 25 % of its energy, with an annual consumption of 530 billion m^3 of natural gas. About 230 billion m^3 of natural gas is imported. Natural gas resources in Europe are scarce. With the exhaustion of the North Sea gas fields in recent years and the cutting of the gas pipelines from Russia to Europe in intervals, some problems about the security of natural gas market are caused in Europe [3]. Therefore, European countries attach great importance to the construction and efficient operation and management of gas storage facilities. The three main types of gas storage reservoirs and working gas volume in Europe are (2018): depleted reservoir gas storage (108.058 billion m^3), salt cavern gas storage (19.624 billion m^3) and aquifer gas storage (21.445 billion m^3) [11]. The total working gas volume of all the three types of gas storage reservoirs reached 154.357 billion m^3, accounting for 29.1 % of the annual natural gas consumption and is far much higher than the global average of 10 %.

The working gas volume of salt caverns only accounts for 12.7 % of the total, but the extracted gas volume is as high as 30 % of the total [12]. This is because the salt cavern has the advantages of quick switching between gas injection and withdrawal, thus much more gas can be extracted in the same period. Depleted gas reservoirs and aquifer reservoirs generally circulate once per year, while salt caverns gas storage circulate once a month [13]. The natural gas market is unpredictable, and only the salt cavern gas storage which can respond quickly to the gas injection and withdrawal can meet the flexible demand of gas market. According to the data of GIE Storage (2016) [14]: during the gas storage under construction in Europe, the working gas volume of salt caverns is 2.5 billion m^3, accounting for 42.2 % of the total amount under construction. In terms of quantity of gas storage site and working gas volume, salt caverns account for 66.1 % and 24.3 % of the planned gas storage. It can be seen that salt caverns are becoming increasingly important in the European gas market. In Europe, the five countries which own the most amount of gas storage in salt caverns are Germany (14 billion m^3), France (11.55 billion m^3), Belarus (11.03 billion m^3), British (7.3 billion m^3) and Poland (760 million m^3). Germany has the largest amount of working gas volume of salt cavern under construction, which is about 840 million m^3. British plans to build the most new salt cavern gas storage, reaching 3 billion m^3 of working gas volume. It can be said that in recent years, there has been a boom in the construction and planning of salt cavern gas storage in Europe.

The Salt cavern gas storage in Europe is represented by Germany. In the northern and central parts of Germany, there are very rich salt mine resources, which provide good geological conditions for the construction of salt cavern gas storage in Germany [3, 15]. According to GIE (2018) statistics [11], the working salt cavern gas volume in operation in Germany exceeds 14 billion m^3, accounting for 50 % of the working salt cavern gas volume in the world and 3/4 of that in Europe. Therefore, it is of great significance to take the salt cavern gas storage in Germany as the research object and reference template. These salt cavern gas storage are distributed in 17 places and operated by 21 companies. In addition, the same mining base often has many companies jointly operating the gas storage. For instance, the Epe base has the most salt cavern gas storage. Four companies operate 45 gas storage caverns with a total working gas volume of 2.224 billion m^3 (the average working gas capacity of each single cavern is about 50 million m^3). The largest salt cavern gas storage site is the Epe Uniper H-gas, which has a working gas volume of over 1.6 billion m^3. The smallest salt cavern gas storage site is the Neuenhuntorf, with a working gas capacity of as small as 17 million m^3.

The Fig.1 below shows the distribution map of salt cavern gas storage in Germany [11]. They are mainly located in the northern and eastern regions of Germany, adjacent to the natural gas pipelines that enter Germany from Russia through Poland and the Czech Republic. These salt caverns not only provide gas storage service in civil, but also provide gas storage service for other countries with gas transit.

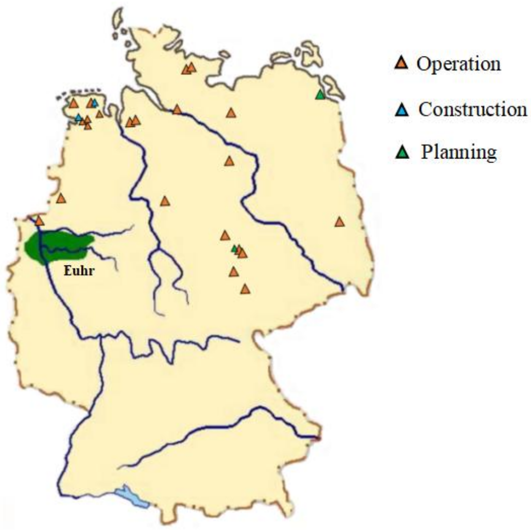

Fig. 1 Distribution map of salt cavern gas storage in Germany (revised from literature [11])

2.2 Salt cavern gas storage in the US

By the end of 1998, the United States had 27 salt cavern gas storage, with a total working gas volume of 39.34×10^8 m^3 and a peak output capacity of 3.23×10^8 m^3 per day [12, 16]. The salt cavern gas storage sites in US are mainly distributed in the salt domes along the Gulf of Mexico, and there also have the Strategic Petroleum Reservoirs of the United States. The three main types of gas storage in the United States are depleted gas reservoirs, aquifers and salt caverns. The total working gas volume was 1103.42×10^8 m^3 (1998), and type of salt caverns only accounted for 3.57 % of the total. Therefore, from the point of view of working gas volume, the proportion of salt cavern is very small. All the gas storage in the United States can provide a daily peak regulating gas volume of 21.996×10^8 m^3, but the salt caverns can provide a daily peak regulating gas volume of 3.23×10^8 m^3, accounting for 14.7 % of the total. Therefore, from the perspective of emergency peak regulation and rapid gas supply capacity, the advantage of the salt caverns is obvious, which is about 4 times that of the depleted gas reservoir and aquifer under the same working gas quantity.

After entering the 21st century, the salt cavern gas storage in the United States had also developed rapidly. Although the storage capacity of salt cavern gas storage was small, it developed rapidly due to its strong operation flexibility, fast injection and withdrawal speed, short cycle, low cushion gas volume and the ability to better adapt to peak regulation demand. The number of salt cavern gas storage had increased steadily from 28 in 2001 to 39 in 2012. Fig. 2 shows the proportion of the working gas volume in the salt cavern gas storage in the United States and the working gas volume in the national gas storage in the United States from 2001 to 2012.

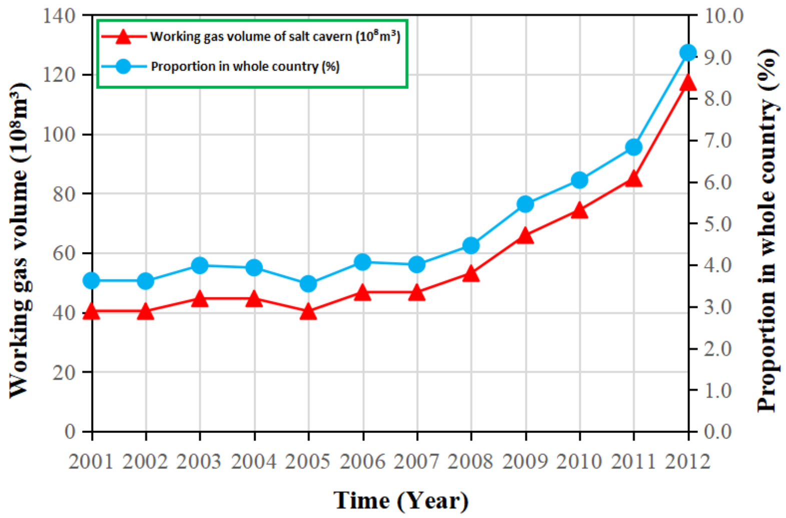

Fig. 2 Development trend of salt cavern gas storage in the United States from 2001 to 2012 (cited from [16])

As can be seen from Fig. 2, the working gas volume of salt cavern gas storage in the United States had achieved rapid growth, steadily increasing from 40.5×10^8 m^3 in 2001 to 117.43×10^8 m^3 in 2012, accounting for 9.09 % of the total working capacity of gas storage in the United States from 3.62 % in 2001 [16]. According to the standard conversion in 1998, the daily peak adjustment capacity of the salt cavern gas storage in 2012 could reach 9.6×10^8 m^3, which could undertake 40 % of the national daily peak adjustment capacity. In addition, if several switching between gas injection and withdrawal in a year is considered, the accumulated gas supply that can be provided by the salt cavern will be very considerable.

2.3 Operation characteristics of European and American gas reservoirs

(1) European Union

The 149 gas storage sites belong to more than 50 different companies. Before the 1990s, they adopted the general vertically integrated management mode and were attached to pipelines. After the 1990s, market-oriented reforms were carried out to separate the natural gas industry chain and operate independently [17-18].

(2) The United States

The 480 gas storage sites belong to more than 150 different companies, among which gas companies account for 33.5 % and pipeline companies for 66.5 %. In the early stage, it is managed by natural gas suppliers. In the middle and late stage, it is separated from pipeline transportation business and used by leasing. Gas companies are the largest users [19].

III. SITUATION OF SALT CAVERN GAS STORAGE IN CHINA

The construction of salt cavern gas storage in China began at the beginning of this century. In 2007, six old caverns were used to store gas in Jintan salt mine, Jiangsu province. The total gas storage capacity was 110 million m^3, which could provide about 80 million m^3 of working gas [1]. After that, CNPC and SINOPEC selected the salt mine blocks in Jintan for cavern constructing. As Fig.3 shows, several salt cavern gas storage sites planned in central and eastern China include Yingyun salt mine of Hubei, Qianjiang salt mine of Hubei, Pingdingshan salt mine of Henan and Huai 'an salt mine of Jiangsu [20]. These gas storage sites are still under construction or demonstration, so far there is no report of gas storage.

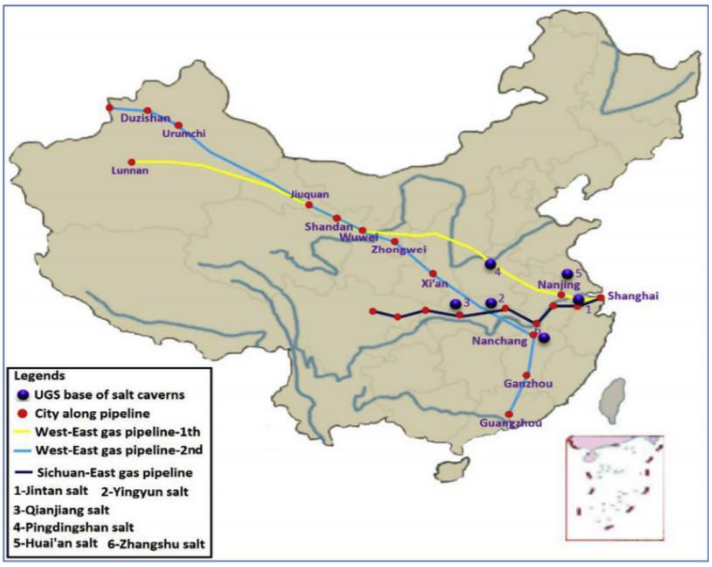

Fig. 3 Salt cavern gas storage in middle and eastern China (cited from [20])

3.1 Jintan salt cavern gas storage

The Jintan Salt Gas Storage of CNPC in Jiangsu province is the first salt cavern gas storage project in China and even in Asia. It is the affiliate facility for the First-line of the West-East Gas Transmission Project. The designed storage capacity of the first-phase project is 790 million m^3, with a working gas capacity of 500 million m^3. By the end of 2017, a total of 32 salt caverns had been put into use in Jintan, including 6 old caverns, 23 newly built ones, and 3 owned by Ganghua Gas Group. In 2017, the total gas production was 730 million m^3. By April 2019, the cumulatively extracted gas of Jintan gas storage had exceeded 2.4 billion m^3 [5], playing an important role to guarantee the security of gas supply in the Yangtze River Delta. At present, there is no report on the annual gas withdrawal amount for 2019 or 2020, but we estimate that it is between 800 and 900 million m^3. That is to say, although the current gas storage workload of Jintan gas storage is only about 600 million m^3, the annual gas production capacity can reach about 1.5 times of its working gas volume, which is completely impossible to achieve for depleted gas reservoir or aquifer.

3.2 Existing problems

Since the construction of salt cavern gas storage was began in 2007, up to now, no salt cavern gas storage has been formally put into operation except Jintan gas storage site. The reports are mostly about gas storage planning, investment and construction. In fact, under normal circumstances, the construction time of a salt cavern is 4-5 years, and the debrining and gas injection period is about one year [20-22]. However, the existing several salt cavern gas storage sites have been planned and constructed in China for more than 10 years, and there is still no report on the second gas storage in salt caverns, which fully indicates that there are problems in the construction of salt cavern gas reservoir in China. The author summarizes as follows:

(1) Large integrated investment

Several salt cavern gas storage sites currently planned in China are under the ownership of CNPC and SINOPEC. Their investment and construction models are as follows: 1) Oil companies set up a gas storage project department and purchase mining rights to acquire salt mine blocks; 2) Carry out systematic geological exploration, site selection and feasibility evaluation; 3) Ground construction, cavern design and water-soluble cavern construction; 4) At the same time, the affiliated pipe network shall be constructed. After the cavern construction is completed, gas injection and brine displacement shall be finished to realize gas storage. All the businesses are carried out by the same company, and most of the related businesses are undertaken by the internal branches of the group company. As a result of undertaking integrated management business, huge investments have been made, especially in recent years, the profits of oil-gas companies have declined. As for the investment-oriented gas storage sector, the enthusiasm of oil companies has declined, which has also affected the process of gas storage construction in salt formations.

(2) Technological difficulties in cavern construction

In China, the companies that choose to build gas storage sites are only two parts, CNPC and SINOPEC, and most of the technicians are transferred from the teams of geophysical exploration, drilling and oil extraction. In fact, many managers or technicians have very limited understanding of salt cavern construction. However, most of the salt formations in China are thinly bedded structure, which are characterized by containing many non-salt interlayers, thin salt layers, and low content of halite, which objectively increases the difficulties of leaching cavern in such salt formations in China [22-23]. The success of Jintan salt cavern gas storage is due to its larger salt layer thickness and higher halite purity than that of other salt mines.

(3) Problem in brine treatment

The current salt cavern gas storage projects are dominated by CNPC and SINOPEC, rather than salt mining companies. The two companies have the advantages of standard investment and management, but in the face of relatively unfamiliar salt mining industry, they still face great confusion in the aspects of cavern leaching and brine consumption. Since salt cavern is used for gas storage, what matters is the shape and volume of the cavern, so the brine concentration obtained from mining is often difficult to reach the standard for salt industry. As a result, how to disposal the low concentrated brine becomes a big problem. In addition, to achieve the upper solution control of cavern, the oil-cushion method is often used to create caverns, which will also lead to the presence of emulsified diesel oil in the brine (about 3 ‰) [24]. The emulsified oil contaminates the brine, resulting in the inability to obtain refined brine. The oil-containing brine is either sold at a low price (only suitable for raw material of industrial salt) or sold after treatment with high oil removal cost. Therefore, the problems of low concentration brine sales and oil-bearing brine treatment is another significant difficulty the oil companies must solve.

3.3 National policies and Guidelines

In the "13th Five-Year Plan for Natural Gas Development" issued by The National Development and Reform Commission of China, it is clearly required to increase the storage capacity for the existing underground gas storage facility or add new storage sites in major domestic gas consumption areas [6]. It is particularly mentioned that a multilevel gas storage system should be established which includes gas suppliers, transmission and distribution enterprises and users. Salt caverns have also been included in the key national gas storage projects, which need to expand the storage capacity on the basis of existing salt caverns, such as Jintan, Liuzhuang Salt cavern and Jintan salt cavern. The sites to be built include Jianghan, Huaian, Yingcheng, Zhangshu, Pingdingshan, Zhaoji and the gas storage facilities of the Eastern China-Russia natural gas pipeline. That is to say, from the national policy level, it is to support the salt cavern gas storage construction.

In addition, to solve the bottleneck problems in construction and operation of gas storage capacity, so as to speed up the construction of the gas storage facilities, the National Development and Reform Commission, the Ministry of Finance, the Department of Natural Resources, the Ministry of Housing Urban and Rural Development, and the National Energy Administration jointly released “Suggestions on speeding up the construction of natural gas storage capacity”(shorted for “Suggestions”)[25].

Based on the “Suggestions” and the specific targets and tasks, the gas supply enterprises, the gas enterprises and the local governments should set targets for building gas storage capacity of 10 %, 5 % and three days of annual sales or consumption by the end of 2020. However, in terms of the actual situation, the progress of gas storage capacity construction is generally slow; especially the progress of gas enterprises and local governments in gas storage capacity construction is obviously behind.

Depleted gas reservoir has large investment and large gas storage capacity, which requires the cooperation of large oil companies and pipeline companies. This type of gas storage is suitable for seasonal peak regulation in large areas. Therefore, this part of the gas storage should be undertaken by the gas supplier is more appropriate. However, gas enterprises and local governments have small targets for gas storage and small scope of service radiation. Therefore, the use of depleted gas reservoir for them is obviously not suitable from the perspective of investment and management. The salt cavern gas storage has the characteristics of optional scale, appropriate investment and quick gas injection and withdrawal, which is especially suitable for gas enterprises and local governments to build gas storage capacity. It can be seen that the lagging construction of gas storage capacity of gas enterprises and local governments is mainly due to the lack of selection of appropriate gas storage types. If salt cavern gas storage is adopted as the gas storage target, the process will be much faster than now.

Considering that the storage capacity of a single cavern/reservoir is *P*, the recoverable coefficient of working gas volume is K, the annual frequency of injection and production is *N*, and the number of gas storage cavern/reservoir is *M*, then the produced gas volume of one gas storage site in one year is *W*:

$$W = m \times n \times P \times k \qquad (1)$$

Where, *P* is the storage capacity of a single storage cavern/storage reservoir, *K* is the extractable working gas coefficient, *N* is the annual injection and production frequency, and M is the quantity of gas storage.

For depleted gas reservoir, *K*=0.5, *n*=1, *m*=1. For example, take the Xiangguosi reservoir gas storage for example, which is the largest depleted gas reservoir in operation in China. Its total storage capacity *P*=4.2 billion m^3, and the recoverable coefficient of working gas volume *K*=0.5, so the available gas volume in a year can be calculated:

$$W = 1 \times 1 \times 42 \times 0.5 = 21 \times 10^8 \, m^3 \quad (2)$$

However, as a cave type gas storage, gas injection and withdrawal in a salt cavern can be several times per year. Take the Petal salt cavern gas storage, Mississippi, United States, for example, 12 times of gas injection-withdrawal is operated a year [26]. We assume that a single salt cavern has a storage capacity of P=50 million m^3, and the conservative estimate of recoverable working gas coefficient can be taken as K =0.5. If 20 caverns are used for simultaneous operation in a mining area (m=20, a medium gas storage scale). Then the accumulative withdrawal gas provided by this gas storage site in one year is:

$$W = 20 \times 12 \times 0.5 \times 0.5 = 60 \times 10^8 \, m^3 \quad (3)$$

It can be seen that, although the depleted reservoir gas storage has a large storage capacity, it has a high proportion of cushion gas and a low frequency of injection and withdrawal (only once per year). Compared with the salt cavern gas storage that can be injected and produced flexibly, in terms of the annual gas supply, the advantage of salt cavern gas storage is far greater than that of a depleted gas reservoir.

To sum up, although the cost of salt cavern gas storage is high and the construction period is somewhat longer, and the operation and management cost is also relatively higher. However, if the brine extraction and cavern storage can be integrated and the frequency of gas injection-withdrawal can be reasonably increased, the cost of cavern construction will be reduced and the value gain will be higher than that of depleted gas reservoir. This should be the future development direction for the salt cavern gas storage construction and operation evolution in China.

IV. OPERATION MODEL OF SALT CAVERN GAS STORAGE INVESTMENT

In previous studies, the issues, such as stability evaluation and leaching technologies of the salt cavern are much concerned, but the cooperation mode between gas companies and salt mine enterprises as well as the operation mode of gas storage are not mentioned much. Liu et al. [1, 27] firstly proposed that the cooperation between the two fields should be strengthened to utilize old or newly added caverns for gas storage to obtain economic benefits and save construction time [1], but did not discuss the specific cooperation model in detail. Based on the operation modes of salt cavern gas storage in European and American countries, this study proposes two operation modes of salt cavern gas storage for reference:

(1) Mode 1: salt mining enterprises only need provide salt caverns, which can meet the requirements according to the subsequent gas storage scale of the company, and then lease or sell them to the gas companies, leaving the operation and management entirely to the gas companies.

(2) Model 2: salt mine enterprises supply salt caverns, but the caverns must be created to meet the requirements of gas storage of the gas companies. And the salt mine enterprises can act as investment body to cooperate with the gas company. The gas company acts as the main investment body and undertakes the ground operation and management, and the salt enterprises are responsible for underground operation security.

The two modes have their own advantages and disadvantages. Model 1: the gas company invests more at one time. The salt mining company collects rents and provides some technical services, which is suitable for large enterprises in big cities. And Model 2 can help to reduce the financial pressure, as is known, for gas companies in small and medium-sized cities, there are difficulties in financing, investment and construction. At the same time, it also enables salt mining enterprises to better participate in management, and the profits obtained may be dynamic.

As for which mode to choose, it mainly depends on the consideration of gas enterprises and salt mining enterprises themselves, local policies and other factors. For example, Ganghua Gas company and Zhongyan Jintan company adopted the first model, in which Ganghua Gas company is responsible for the ground construction and pipeline construction, while Zhongyan Jintan company is responsible for the underground fairies (leasing cavern + technical services). Either way, it breaks the previous operation mode of salt cavern gas storage and runs smoothly.

V. CONCLUSIONS

(1) The current construction and management mode of salt cavern gas storage in Europe and the United States are summarized. The proportion of salt cavern gas storage in Europe is higher and higher, which shows the characteristics of rapid injection, rapid production and strong gas supply capacity in the same time. In addition, the management mode of salt cavern gas storage in European salt mining enterprises and gas supply companies is worth learning.

(2) The current construction progress of salt cavern gas storage in China is analyzed. At present, there is only one salt cavern gas storage site in Jintan in China, and the rest are under construction or planning. The main problem lies in the current investment management mode of salt cavern gas storage, which is the focus of China's salt cavern gas storage reform.

(3) In the construction and management of salt cavern gas storage, the integrated mode of "Brine extraction-Cavern construction-Gas storage" should be adopted. In other words, salt mining enterprises provide

partial of the old caverns or build new caverns according to the requirements of gas storage, and the cavern can be leased or sold to gas companies, which only need provide ground construction and gas storage operation and management. Salt mining enterprises and gas companies must increase cooperation and exchange, making full use of the advantages of salt mines to provide caverns for gas storage and simultaneously save cavern construction investment and time for gas companies.

(4) In order to give full play to the advantages of salt cavern gas storage, in the future management, special attention should be paid to increasing its gas injection and production turnover frequency to ensure that it can supply more natural gas in the same period. That is, it must be fully realized that the salt cavern gas storage is not the total gas storage but the gas supply capacity, especially in emergency situations. In this way, the advantages of salt cavern gas storage can be fully utilized, better economic benefits can be achieved, investors can be full of confidence in salt gas storage, and its rapid development can be promoted.

The construction and management of salt cavern gas storage is still in the primary stage in China, and there are many places worth exploring and improving in the future. It is still necessary to strengthen research and demonstration on the overall progress of the construction mode, investment mode, and operation management of the salt cavern gas storage.

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