



Research article

The status quo and technical development direction of underground gas storages in China

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Abstract

UGS (underground gas storage) construction in China has stepped into a new development stage after years of exploration. The eleven UGSs that have been put into production play an important role in domestic natural gas peak shaving safety and supply guarantee, with designed working gas volume of $180 \times 10^8 \text{ m}^3$, but there are still various difficulties in UGS construction in China. Firstly, the increasing speed of working gas volume is slower than that of peak shaving demand volume. Secondly, the UGS building engineering is difficult in technologies and high in investment costs. Thirdly, safe operation is under high pressure and it is hard to identify and control risks. Fourthly, there are fewer candidate UGS sites in China and UGS building conditions are complicated. And fifthly, it is difficult for those UGSs to realize economic benefits only based on their own operation under the existing natural gas price systems. To sum up, the currently available UGS operation modes and building technologies in China are not sufficient to cope with the challenges resulted from markets and complex geologic conditions. Facing all these challenges, it is necessary not only to explore market driven operation modes, but also to strengthen technology tackling and carry out core technological research and development, including geologic evaluation, gas reservoir engineering, drilling and completion engineering, UGS injection and gas recovery engineering, surface auxiliary technologies and UGS integrity evaluation, so that UGS building efficiency can be increased greatly.

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1. Faster construction of UGS – a key measure to ensure safe supply of natural gas in China

The pipe network system supporting the great development of natural gas in China has basically been formed with the construction of various types of long distance gas pipelines like Shaanxi-Beijing Gas Pipeline, West-to-East Gas Pipeline, Sichuan-to-East Gas Pipeline, Burma–China Gas Pipeline, Offshore LNG Import Channel and Russia–China East Gas

Pipeline (to be constructed). In 2014, the apparent consumption of natural gas reached $1800 \times 10^8 \text{ m}^3$ in China; with the further large-scale exploitation and utilization of domestic conventional gas and shale gas as well as the further growth of demand for clean energy because of domestic environmental protection, the proportion of natural gas in the field of primary energy consumption would steadily increase in China. Based on prediction, gas consumption will reach $3000 \times 10^8 \text{ m}^3$ in 2020 [1] and $5000 \times 10^8 \text{ m}^3$ in 2030, and the dependence on foreign gas will also exceed 50%. Facing such an increasingly severe situation, natural gas production and sale enterprises have to undertake a major social responsibility to ensure the safe supply of natural gas.

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Underground gas storage (UGS) is not only the primary facility for ensuring the safe supply of natural gas but also an important part for ensuring the national energy security. Therefore, it is a significant strategic measure of ensuring the safe supply of natural gas to speed up the construction of UGSs in China. A batch of UGSs represented by Hutubi UGS in Xinjiang province have been built successively in recent years, and the construction of UGS has entered a new development stage up to now, which play an important role in the course of maintaining safe and steady supply of gas in China. However, there is still a big gap between the construction of domestic UGS and the demand of peak shaving. As of today, the peak shaving capacity of UGSs that have been put into production in China is only 2% of gas sales volume, far lower than the average level of 11% of UGS working gas volume in annual gas consumption abroad. As a result, gas supply enterprises are forced to realize production, supply and sales balance by reducing users, increasing the production of gas fields and supplying LNG, which have brought a tremendous pressure for gas sales, gas field development and safe supply of gas. Estimated based on the fact that domestic UGS working gas volume should reach the global average value of 11%, the demand for domestic UGS working gas volume will be $385 \times 10^8 \text{ m}^3$ and $550 \times 10^8 \text{ m}^3$ in 2020 and 2030 respectively. Obviously, the construction of UGS in China has a long way to go.

2. Main achievements in UGS construction in China

UGS construction started with a gas reservoir in the Daqing oilfield of China in the 1970s. At the beginning of the 1990s, with the construction of Shaanxi-Beijing Gas Pipeline, the construction of the first real commercial UGS – Dagang Banqiao Dazhangtuo gas condensate field UGS started in 1998, and was put into production and operation in 2000; subsequently, six UGSs were successively built and put into production in the Banqiao gas condensate field, and the Dagang Banqiao UGSs were formed in 2006. From 2000, for the sake of ensuring the safe and steady supply of gas of the West-to-East Gas Pipeline, evaluation on the first salt cavern UGS in China started, which was put into construction in 2005, and the old cavity was put into production and application in 2007, marking the birth of a real salt cavern UGS in China or even in Asia [2]. Represented by the above two UGSs, China opened the prologue of large-scale construction of UGS. After 20 years of development, China's UGS construction has made considerable achievements mainly embodied in the following two aspects.

1) The UGS construction is largely speeded up and the working gas volume has been increased obviously, which play an important role in peak shaving and gas supply insurance. As of today, a batch of UGSs have been constructed and put into production successively in the Hutubi gas field of Xinjiang Uygur Autonomous Region, the Xiangguosi gas field of Sichuan Province, the Shuang 6 gas field of Liaoning Province, the Suqiao gas field of Hebei Province, the Banqiao gas field of

Dagang oilfield, the Jingbian gas field of Shaanxi Province and the Wen 96 gas field of Henan Province in China, and 11 UGSs in total (Table 1), with designed storage capacity of about $400 \times 10^8 \text{ m}^3$, working gas volume of $180 \times 10^8 \text{ m}^3$, and constructed peak shaving capacity of about $40 \times 10^8 \text{ m}^3$. These UGSs have played an important role in peak shaving and gas supply insurance in China, especially in Beijing area, where the maximum daily peak shaving gas volume available in the UGSs in winter approaches $3200 \times 10^4 \text{ m}^3$, accounting for about 1/3 of daily peak gas consumption in the area in winter. Moreover, after the Hutubi and Xiangguosi UGSs have been put into production, large-scale gas injection started, which ensure the smooth running of import natural gas pipelines, and sufficiently exhibit the function of UGSs.

2) A series of problems related to UGS construction have been successfully solved, and great progress has been made in aspects like construction concept, technique and management of UGSs. In terms of optimization, operation and management of watered depleted gas reservoir UGSs, represented by the Dagang Banqiao UGSs, abundant experiences have been accumulated in various aspects like storage management, operation optimization and project adjustment. In term of construction plan of deep low-permeability carbonate UGSs, represented by Huabei Suqiao UGSs, UGS construction depth reaches 4500 m, creating a world record, and simultaneously, precious experiences in aspects like large size well drilling and completion techniques have been accumulated.

Table 1
Design parameters of UGSs constructed.

Name of UGSs	Storage capacity/ 10^8 m^3	Working gas volume/ 10^8 m^3	Daily gas injection capacity/ 10^4 m^3	Daily gas withdrawal capacity/ 10^4 m^3
Wen 96	5.9	2.9	200	500
Banqiao Group	69.6	30.3	1300	3400
Jing 58 Group	15.4	7.5	350	628
Liuzhuang	4.6	2.5	110	204
Jintan	26.4	17.1	900	1500
Shuang 6	41.3	16.0	1200	1500
Suqiao	67.4	23.3	1300	2100
Bannan	10.1	4.3	240	400
Hutubi	117.0	45.1	1550	2800
Xiangguosi	42.6	22.8	1400	2855
Shaan 224	10.4	5.0	230	417
Total	404.8	173.9	8780	16304

3. Difficulties in the construction of UGSs in China and their causes

3.1. Major difficulties

Although great progress has been made in the UGS construction in China, due to the existence of objective factors

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