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Comprehensive feasibility study of two-well-horizontal caverns for natural gas storage in thinly-bedded salt rocks in China

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ABSTRACT

Underground salt caverns provide ideal space for large-scale natural gas storage. But the current practice of constructing single-well-vertical (SWV) caverns encounter serious problems in the thinly-bedded salt rocks in China. Instead, two-well-horizontal (TWH) caverns are proposed to serve as a possible alternative for gas storage facilities. Therefore the comprehensive feasibility of the TWH-caverns as gas storage were thoroughly evaluated. First, the frame-work and criteria of feasibility evaluation of gas storage salt caverns were determined. Then the construction process and shapes of TWH-cavern were determined by physical simulation tests, and an optimum cavern shape was obtained by numerical simulation. Thirdly, the effects of mudstone interbeds, cyclic operating modes on the serviceability and safety of TWH-cavern were investigated. The cavern tightness was discussed as well. In the end, a feasibility comparison between a TWH-cavern and a SWV-cavern was made, which shows that TWH-cavern possesses better safety, higher flexibility and lower cost than SWV-cavern. Comprehensive results show that the TWH-caverns have high feasibility as gas storage in thinly-bedded salt rocks.

1. Introduction

Natural gas emits much less CO_2 than coal, and releases little dust, SO_2 and NO_X. Hence to control pollution and carbon emissions, China has largely increased the use of natural gas. In 2015, over 210 billion m^3 of natural gas was consumed in China. And by 2020, the consumption of natural gas will become approx. 300 billion m^3. The consumption of natural gas changes seasonally, diurnally and even hourly. To ensure the stability and reliability of gas supply, a large number of gas storage facilities should be developed [1,2]. However, by the end of 2016, the total storage of natural gas was 6.3 billion m^3, only 3.2% of the total consumption, far lower than the international level of 15–18% [3]. Consequently, a serious lack of gas supply exists in China, especially in winter or when encountering emergencies or pipeline accidents [4].

For large-scale gas storage, the key is to find the space that has large storage capacity, excellent tightness, high safety, suitable position, and acceptable investment. Depleted gas-oil reservoirs, aquifers and salt caverns are the three main types of underground storage in use for natural gas storage today [5]. Among them, underground salt caverns are the best option, because: (i) Rock salt has extremely low permeability, small porosity, excellent plasticity and self-healing capacity. (ii) Rock salt (NaCl > 90%) is water-soluble and large caverns are easy to create at low cost. (iii) Salt caverns have the fastest converting rate between withdrawal and injection [6], and the lowest cushion gas stock [7]. And (iv) salt mines are present all around the world. Therefore, salt caverns are widely utilized for energy storage space, such as oil/gas storage [8], compressed air energy storage [9,10] and even hydrogen storage [11].

China also has abundant salt mines [1,12], such as Jintan Salt Mine in Jiangsu Province, Pingdingshan Salt Mine in Henan Province, Yunying Salt Mine in Hubei Province, and Renqiu Salt Mine in Shandong Province. In recent years, underground gas storage (UGS) salt caverns also increasingly are being developed in China. In East and Central China, six bases of UGS salt caverns are under planning and surveying (Seen in Fig. 1). By expectation, the total storage of

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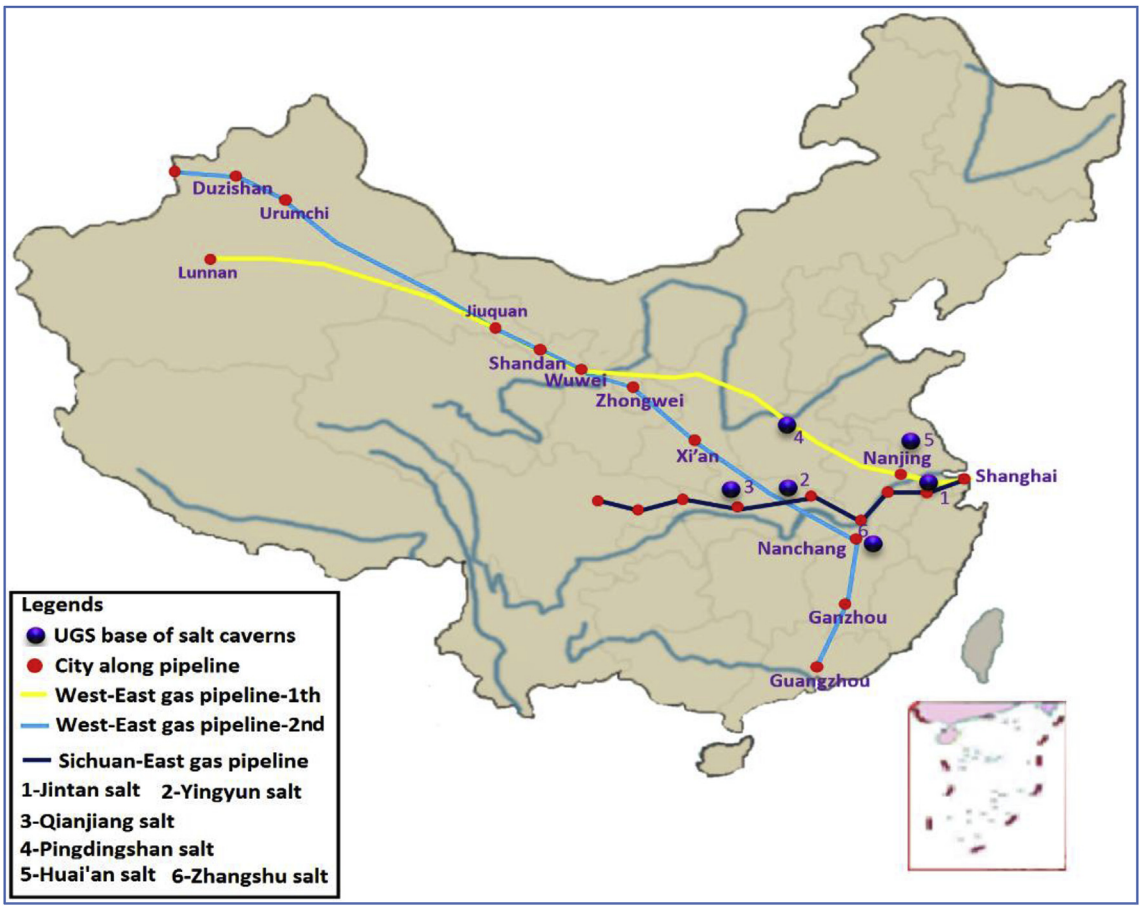

Fig. 1. The main gas pipelines and 6 planned bases of UGS in salt rocks in China.

gas will be up to 8.3 billion m^3, which can deliver 80% of peak-shaving of gas in these regions.

Generally the single-well-oil-blanket method is used to construct caverns in salt formations [13–15]. Vertical cavern can be created by this method, which have a greater height than transverse size (Fig. 2). However, the adoption of SWV-caverns must overcome a number of inevitable restrictions, such as: i) the purity of the halite should be over 80%; ii) the total thickness of the salt formation should be over 120 m; iii) tubing damages or blocking often occur; and iv) it takes as long as 5–7 years to create a SWV-cavern. In China the salt formations are thinly-bedded structures [12,13,16]. There are numerous non-salt interbeds intersecting the salt-formations [17,18]. The halite content of the bedded salt rocks is low. And at least 50% of the salt formations are smaller than

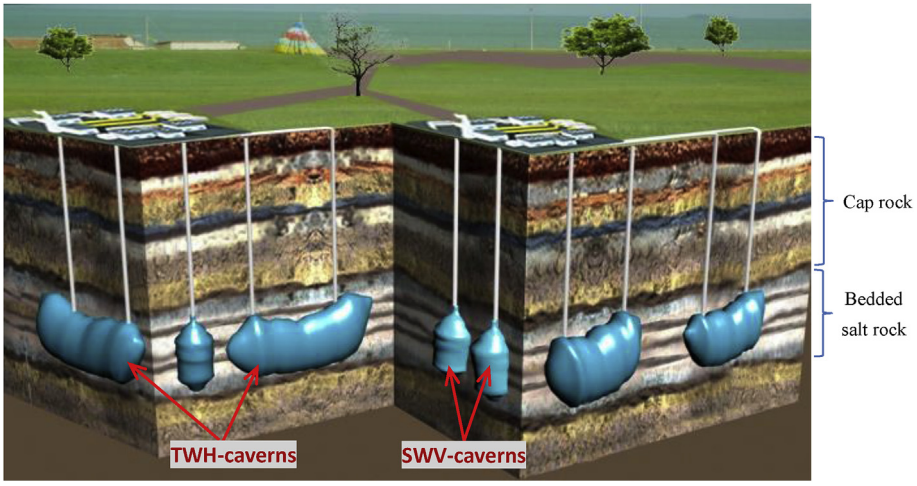

Fig. 2. Cavern cluster in thinly-bedded salt rocks of China: blue bubbles are SWV-caverns and TWH-caverns; non-salt interbeds are present in the salt strata. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)