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Underground Hydrogen Storage Problems in Russia

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1 Introduction

Utilization of organic fuel for covering the increasing demand for energy leads to global environmental pollution, greenhouse effect and lack of oxygen for the civilization. Therefore there is the necessity of reorientation from hydrocarbon to new universal energy resource. In this connection hydrogen is considered to be one of the most acceptable energy resources in the future. Hydrogen is a fuel for different purposes, it can be used as fuel and as chemical material. The conversion of transport, industry and household consumers to hydrogen doesn't request drastic changes in modern technology of fuel utilization. The important thing is that being burned hydrogen comes back to the atmosphere in the form of water. Increasing hydrogen consumption requires new kinds of hydrogen storage.

2 The Methods of Hydrogen Storage

At present the following methods of hydrogen storage are realized: gas bottles, gasholders (compressed gaseous hydrogen under the pressure of 40-100 MPa), stationary or transport cryogenic containers (liquid hydrogen under the pressure of 20 MPa), metal hydrides (metal absorption), underground storage. To evaluate the effectiveness of each particular method of hydrogen storage the functioning of the whole chain from production to consumption, including storing, transport and distribution, has to be analysed. Underground hydrogen storing will be necessary for regulation of seasonal, monthly and daily fluctuation of energy consumption and production when moving to the industrial use of hydrogen. The irregularity of gas consumption depends on the industry, way of life of the population and the climatic conditions of different regions of the country. The most effective ways of large-scale hydrogen storage is underground storage in depleted oil and gas fields, the subterranean aquifers, underground reservoirs in salt deposits, permafrost grounds. These methods should be located close to its heavy consumers. Due to less viscosity and density hydrogen has got greater mobility than natural gas does. Therefore hydrogen leaks through different seals or the storage cap are more probable.

3 Hydrogen Properties

It is reasonable to store a mixture of hydrogen and carbon dioxide. The dynamic viscosity coefficient of such mixture is higher than the dynamic viscosity coefficient of pure hydrogen and is close to methane (fig. 1). To get the mixture with necessary properties we can manage our composition by carbon dioxide inclusions.

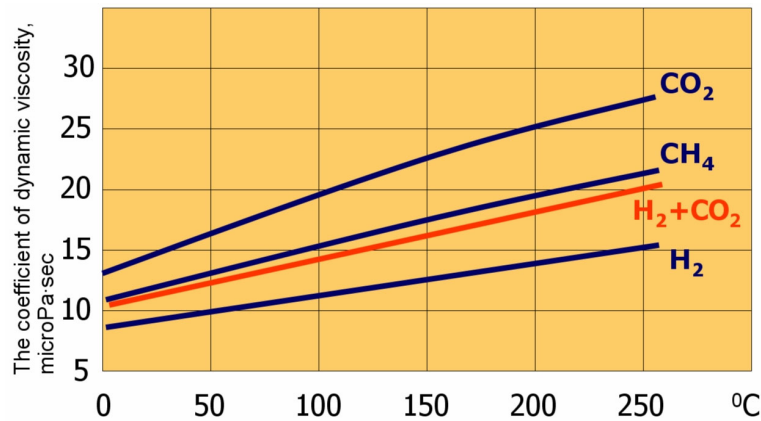


Figure 1: The dependence of viscosity from temperature at atmospheric pressure.

Practical impermeability, ability to stand at high pressures, opportunity of quick changing technology of injection and recovery while exploiting the underground storage, chemical inertness of rock salt to the stored products make storage of gaseous hydrogen in rock salt probably most effective for covering peak demands. The experience in exploitation of UGS in rock salts shows that the parametric variations during storage production are monotonous and sufficiently slow. The gas can be extracted from such storages very quickly. According to the estimations of the foreign authors, the underground hydrogen storage in such rocks costs more expensive than the cost of creation of underground hydrogen storage of the same capacity in depleted oil and gas fields, but on the other hand the operating costs when storing hydrogen in salt caverns are substantially lower.

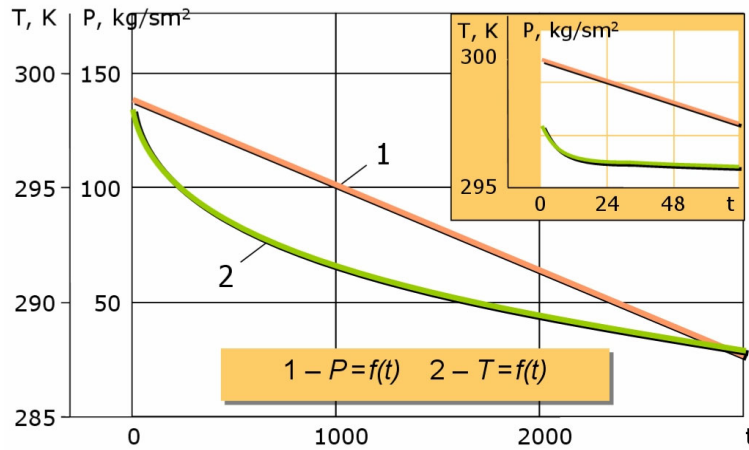


Figure 2: Hydrogen temperature and pressure variations during production from cavern.

Rock salt deposits of various shape and depth of occurrence are widely spread in Russia. According to the estimations of the specialists, the area of salt expansion reaches several tens and even hundreds of thousand square kilometers (for example, Podmoskovnoe - 50 th. km²). Rock salt deposits can be found in Caspian Sea region, central part of Russia, on the territories of Tulsкая, Belgorodskaya and Irkutskaya regions, also at the Urals and

other parts of the country. Its storage in aquifers, natural caverns and spent mines requires very expensive preliminary researches and operations for improvement its impermeability. Due to less viscosity and density hydrogen has got greater mobility than natural gas does. Therefore hydrogen leaks through different seals or the storage cap.

4 Underground Hydrogen Storage at Yakshunovskoe Field

The geological model of Yakshunovskoe UGS is on fig.3. The red zone is gas-water contact (Fig.3). Green is for the observation wells, red is for developing well. Fig.4. shows the dependence between pressure and time for methane and hydrogen while injection and producing, calculated in Gubkin Russian State University of Oil and Gas. Geotechnological methods of cavern production through drill holes allowing to create steady caverns of given geometrical proportions and shape are developed in Russia (underground desalinization of salt cavern by water, underground explosions).

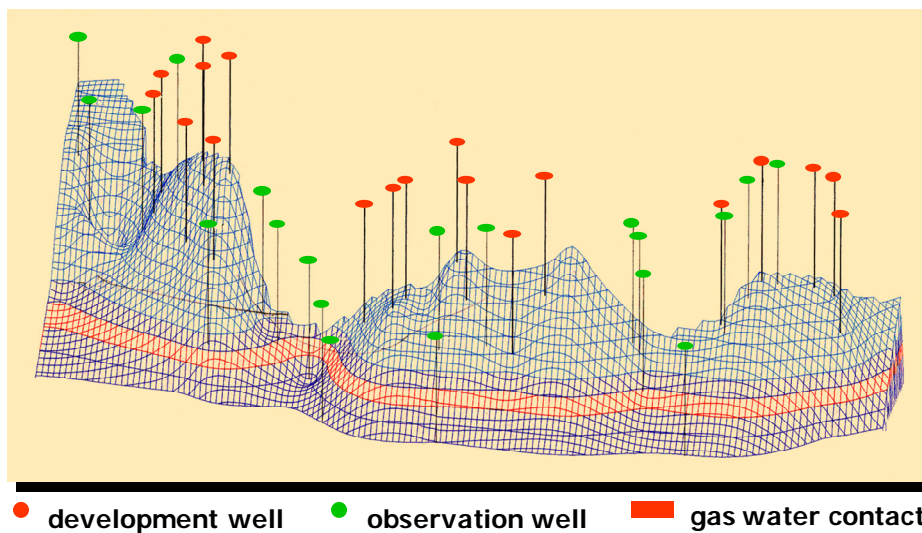


Figure 3: Jakshunovskoe UGS.

The underground desalinization technology is realized by four methods: desalinization in the bottom-up direction, desalinization in the top-down direction, combined method, cavern production without using nonsolvent. When designing the underground reservoirs in salt deposits it is very important to determine the permissible width of the cavern subject to production pressure, laying depth and its expected design shape.

5 Underground Hydrogen Storage in Salt Deposits

The permissible minimum laying depth of an underground storage H_{min} can be defined from

$$H_{min} = \frac{P_{max}}{\gamma_f g \rho_r} + C \tag{1}$$

where p_{\max} - maximum pressure at the shoe of the casing column, Pa; γ_f - reliability coefficient under the load, assumed equal to 0,85 in the case of lenticular salt deposits and impermeable overlying bed, and 0,75 – in other cases; ρ_r - averaged density of the rocks overlying the shoe of the casing column, kg/m³; C – uncased hole length, m.

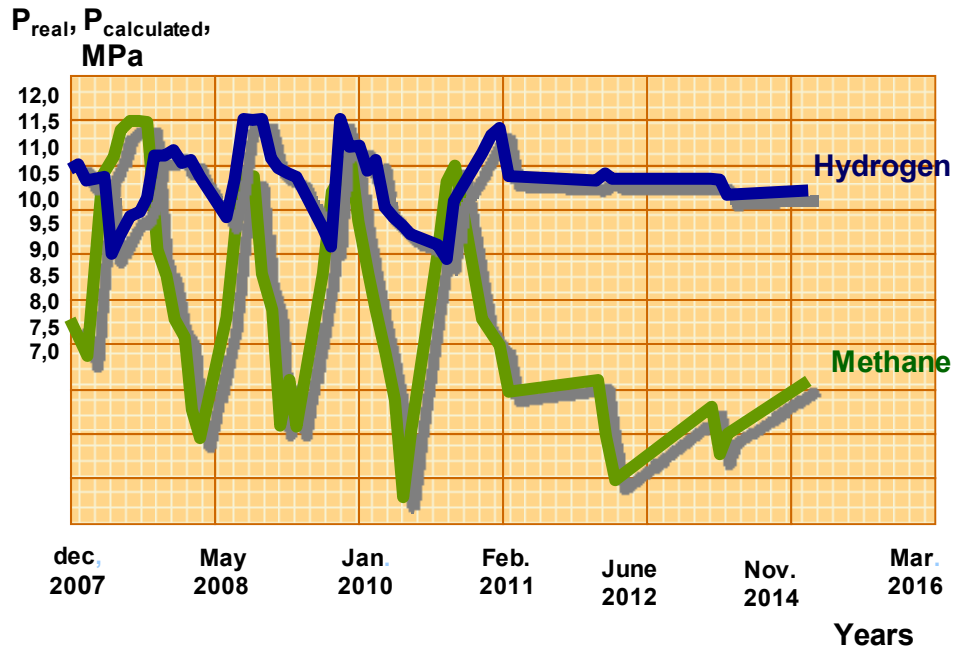


Figure 4: Recovery – injection of H₂ and CH₄ in Jakshunovskoe UGS.

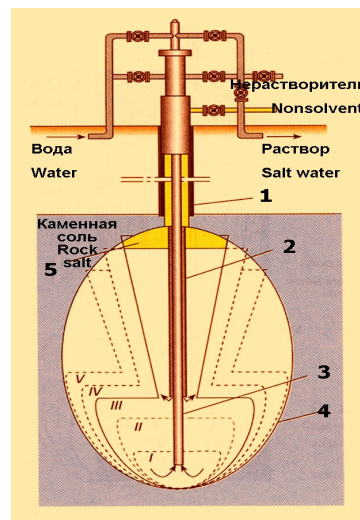


Figure 5: Combined method scheme: I-V – steps; 1 – casing column; 2 – production casing; 3 – central column; 4 – cavern production shape; 5 – nonsolvent.

$$\rho_r = \frac{\sum_{i=1}^n \rho_i m_i}{\sum_{i=1}^n m_i} \quad (2)$$

where ρ_i - formation density, kg/m³; m_i - formation thickness, m. The permissible minimum rock salt thickness M_{\min} is given by:

$$M_{\min} = H + m_1 + m_2 + C \quad (3)$$

where H – cavern height, m; m_1, m_2 - pillar thickness at the cavern roof and at the cavern sole respectively, m. Minimum and maximum production pressures in the cavern in the case of the brine production scheme are defined by the height of a brine column subject to possible changes of the brine density and the hydraulic losses. The permissible maximum pressure p_{\max} at the shoe of the casing column is defined from

$$p_{\max} = \rho_r g (H_k - C) \quad (4)$$

where H_k - interval from the ground surface to the cavern roof, m. The permissible minimum pressure p_{\min} produced by the stored product at the cavern roof level is given by

$$p_{\min} = \rho_r g H_k - \frac{2}{\sqrt{3}} \frac{c+1}{c} \sigma_i^\infty \quad (5)$$

where c and σ_i^∞ - parameters of the rock salt equation of state. The cavern width at the roof level l (m) can be derived from

$$l = \sqrt[3]{\frac{V_{adm}}{\alpha} \left(\frac{\sigma_i^\infty}{\rho_r g H - p_s} \right)^w} \quad (6)$$

where V_{adm} - permissible volume of the evanescent straining zone in the neighborhood of the cavern roof, m³; p_s - minimum production pressure at the cavern roof level, Pa; α, w – dimensionless parameters depending on height-to-width rate.

$$\tau \bar{w}_b = \sum R_i \quad (7)$$

where τ - total cavern production time, days; \bar{w}_b - average linear velocity of salt dissolution by almost fresh water, m/day; $\sum R_i$ - a sum of radii of a cavern produced by fresh water, m.

$$\sum R_i = R_1 + R_2 + \dots + R_n = nR_b + 0,5nhtg\alpha \quad (8)$$

where R_i – initial radius of each step where fresh water was used for the desalinization, m; n – number of desolution steps; h – height from the hydrocut roof (I step) to the cavern roof, m. A number of the desalinization steps in terms of the total cavern production time is represented by:

$$n = \frac{\tau \bar{\omega}_b}{R_b + 0,5htg\alpha} \quad (9)$$

Dissolution time is defined from the equation

$$\tau = z + 10^{-2} k_Q V \quad (10)$$

where z – constant coefficient equal to 45 days; V – underground storage design volume, m³; k_Q - dimension factor depending on water injection capacity Q , days/m³. The brine strength coming up to the surface when constructing the cavern is defined by

$$C = C_H - (C_H - C_0) \exp(-A) \quad (11)$$

where C – The brine strength coming up to the surface, kg/m³; C_H – limiting concentration of the saturated brine in the cavern, kg/m³; C_0 – solvent strength, kg/m³; A – dimensionless parameter depending on cavern production technology, size and shape of the cavern and rock salt properties. The brine extent radius in the reservoir bed around the bore-hole R (m) is given by

$$R = \sqrt{\frac{V}{\pi m_{\phi} n}} \quad (12)$$

where V – injected brine volume, m³; m_{ϕ} - effective height of the aquifer, m; n – effective porosity. For the layer dissolution process nonsolvent layer thickness h_H at the cavern roof remains constant for a single step and is assumed equal to 0,1-0,2 m. In our case the value of q_H (m³/h) is derived from

$$q_H = 2\pi r_k v_{p2} h_H \quad (13)$$

where r_k - cavern radius at the place of nonsolvent-brine contact, m; v_{p2} - horizontal dissolution velocity at the place of nonsolvent-brine contact, m/h.

6 Conclusions

Hydrogen can be used for different purposes. It is almost inexhaustible resource and the absence of harmful impact on the environment makes it possible to consider hydrogen as one of the most acceptable energy resources in the future. The most effective ways of hydrogen storage is its underground storage in depleted oil and gas fields, in the subterranean aquifers (by analogy with underground storing of methane and hydrocarbon liquids), underground reservoirs, salt deposits, permafrost grounds, etc. located close to its heavy consumers. Practical impermeability, ability to stand at high pressures, opportunity of quick changing technology of injection and recovery while exploiting the underground storage, chemical inertness of rock salt to the stored products make storage of gaseous hydrogen in salt rock probably most effective for covering peak demands.

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