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RESEARCH PAPER

Key evaluation techniques in the process of gas reservoir being converted into underground gas storage

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Abstract: Due to the significant differences in development modes and operation rules of underground gas storage (UGS) and gas reservoir, the design of UGS construction has its own particularity and complexity. Key evaluation techniques in the process of gas reservoir being converted into underground gas storage were proposed and field application was analyzed. The construction and operation experience of the first batch commercial UGS in China was summarized, the mechanisms of multi-cycle injection and production with large flux in short-term was examined and some concepts were proposed such as the dynamic sealing of traps, the effective pore volume of UGS and the high velocity unstable seepage flow with finite supply. Four key technologies of UGS, i.e., trap sealing evaluation, gas storage parameter design, well pattern optimization and monitoring programs design were created. Preservation condition, storage capacity, effective injection & production and safe operation technology problems of UGS were solved respectively. The geological program design technology system of UGS construction in a gas field was gradually enriched and improved. These technologies have successfully guided geological plan design and implementation of UGS construction in a gas reservoir, the effects of gas storage and peaking capacity of the ramp-up cycles were great, and the actual dynamic was very consistent with design indicators.

Key words: underground gas storage in gas field; dynamic sealing; gas storage parameter; productivity evaluation; injection-production well pattern; monitor scheme

Introduction

The underground gas storage in a gas reservoir is a kind of economic and effective gas storing and peak shaving facility, which plays an irreplaceable role in the safe and stable supply of gas. Main gas storage technologies are maturing abroad, but still in the infancy in China. At the end of the 20th century, six gas storages were built by transforming sandstone gas reservoirs in Dagang area successively. These gas storages have worked for 16 injection-withdrawal cycles, with a working gas volume of 18.6×10^8 m^3, making major contribution to the winter gas peak shaving of Beijing area. This storage group is the first batch of commercial gas storages built in China with limited design and running experiences, current evaluation shows that they have lower working gas volume ratio than the designed value, inadequate monitoring and higher gas loss. Therefore, the design, evaluation, and operation of gas storages must be improved. Large scale construction of gas storages in China started in 2010, when six gas storages, Hutubi in Xinjiang, Xiangguosi in the Southwest Oilfield, and Shuang6 in Liaohe Oilfield etc, were built by transforming gas reservoirs, marking the 2nd stage of gas storage construction in China[1]. Based on the construction and operation experience of the 1st batch of gas storages, design concept has been updated, and breakthroughs have been made in evaluation of gas storage, forming the basic gas storage construction system. Aimed at four bottlenecks in gas storage construction, i.e. sealing conditions, storage capacity, efficient injection and withdrawal, and safety monitoring, this study proposes four technologies: dynamic sealing evaluation of trap, effective storage capacity design, optimization of injection-withdrawal well pattern and monitoring scheme design technologies. These technologies have been used to guide the design of gas storage geologic plan and gas storage operation, and the results are analyzed.

1. Dynamic evaluation of the trap sealing property

Different from development of a gas reservoir in which the static sealing of cap rock and fault is the major concern, during the operation of gas storage, the formation pressure goes up and down alternately, inducing periodic disturbance of

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ground stress field, deformation and fatigue damage of cap rock, and activation of fault, so the trap may lose sealing capacity, and consequently gas may leak massively[2–5]. Therefore, the mechanism and main control factors and potential risks associated with dynamic sealing failure of cap rock and fault must be evaluated comprehensively by considering the stress disturbance to the cap rock and fault caused by high speed gas injection and withdrawal during gas storage operation with the time before gas storage construction as the node, to guide the pressure design and lower risks in gas storage operation.

1.1. Mechanisms of dynamic trap sealing failure

According to the features of ground stress disturbance in gas storage operation, the root causes of trap sealing failure are microscopic pore structure change and macroscopic mechanical deformation and damage of rock under alternating stress. Therefore, four kinds of sealing failure mechanisms, cap rock capillary sealing failure, tensile damage, shear damage and shear slip activation of fault, have been pointed out.

(1) Cap rock capillary sealing failure. Under alternating stress, microscopic pore structure may change and micro-fissures may expand in the cap rock, or the strong heterogeneous disturbance caused by high speed injection and withdrawal may lead to change of the original water driving system in the cap rock, causing cap rock capillary sealing failure and the exacerbation of initial slow diffusion of gas into leak.

(2) Tensile damage. High speed gas injection may lead to high pressure in local area, when higher than the minimum horizontal stress, the pressure would cause tensile damage to the cap rock.

(3) Shear damage. Ground stress disturbance in high speed injection and withdrawal may cause stress concentration in the abrupt structural change area, and consequently sliding deformation and shear damage in the abrupt structural change area or lithologic change weak plane of the cap rock.

(4) Shear slip of fault. When the shear stress acting on the fault plane is higher than the critical value due to ground stress disturbance during high speed injection and withdrawal, fault running through the cap rock will slip, breaking the integrity of the cap rock and causing sealing failure.

1.2. Evaluation for trap dynamic sealing property

The pressure limit a gas storage trap can withstand can be estimated by calculating the pressure withstanding limits of the cap rock and fault at the critical point of capillary sealing failure, tensile and shear damages, and shear slip of fault, then the upper pressure limit of the gas storage can be designed scientifically, and the room for upper pressure limit increase evaluated.

1.2.1. Capillary sealing capacity of cap rock

The capillary sealing capacity evaluation experiment of gas storage cap rock follows the same idea with gas reservoir development experiment, but simulates quite different working conditions. In the conventional method, on the basis of comprehensive geologic study and porosity, permeability and microscopic pore structure test of core, core samples are selected to test the critical breakthrough pressure by gas breakthrough pressure experiment. As ground stress disturbance during gas storage operation would cause deformation and micro-pore structure change of cap rock, on the basis of conventional static breakthrough pressure test, core fatigue damage experiment under alternating load needs to be conducted according to the actual ground stress and designed pressure range, to figure out the critical breakthrough pressure of cap rock core after cyclic injection and withdrawal and dynamic capillary pressure withstanding limit of cap rock.

1.2.2. Tensile damage risk to cap rock

The high speed gas injection and withdrawal during gas storage operation can aggravate the effect of reservoir heterogeneity, especially during gas injection, the bottom hole pressure may exceed the designed upper pressure limit of the gas storage. Pressure in local parts may be higher than the minimum horizontal stress, causing tensile damage to cap rock. Gas storages transformed from gas reservoirs of shallow burial depth especially have much higher tensile damage risk than shear damage risk. Therefore, in the evaluation of cap rock tensile damage risk, the trap ground stress must be tested accurately, especially for depleted gas reservoirs. The ground stress of reservoir and cap rock can be tested by hydraulic fracturing or leak off test and AE Kaiser effect experiment to evaluate tensile damage risk.

In order to take the effects of cap rock shape and rock mechanic heterogeneity into consideration, the dynamic 3D trap geo-mechanical model including reservoir and cap rock is built to predict the 3D stress field distribution in the cap rock under different working conditions with numerical simulation. The ratio of minimum horizontal stress under any formation pressure to original minimum horizontal stress of cap rock is defined as tensile damage safety index of the cap rock. When it is larger than zero, the cap rock is not damaged, when it is less than zero, the cap rock is damaged. This way, the tensile damage risk of cap rock under different gas storage operating pressure ranges can be evaluated quantitatively and visually by geomechanical numerical simulation to find out the pressure limit the cap rock can withstand.

1.2.3. Shear damage risk of cap rock

Rock mechanical heterogeneity caused by triaxial major stress difference, local stress concentration due to high speed injection and withdrawal, lithologic changes and sedimentary bedding may lead to shear damage of cap rock along mechanical weak plane. For gas storages with large burial depth, and complex structure shape and lithology, the shear damage risk of cap rock is higher than tensile damage risk.

Triaxial compression rock mechanical experiment and 3D