Modeling Hydrogeochemical Processes in the UGS Reservoir under the Project of Partial Replacement of Cushion Gas for CO_2

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Background

One of possible ways to reduce investments for the establishment of cushion gas volume in the reservoir is partial replacement of injected cushion natural methane gas for less expensive non-hydrocarbon gases, in particular CO_2.

There are two options: first one – partial replacement of already existing cushion natural methane gas volume at current UGS; second one – simultaneous injection of methane gas and less expensive non-hydrocarbon gases to create a combined cushion gas volume in newly developed UGS.

The application of carbon dioxide for partial replacement of cushion natural methane gas at UGS allows to address environmental issues related to environment contamination by carbon dioxide emissions to the atmosphere as well.

The disadvantage of reducing investments for the establishment of cushion gas volume in the reservoir by partial replacement of injected cushion natural methane gas for less expensive non-hydrocarbon gases is as follows. The mixing of injected high-caloric natural methane gas with non-hydrocarbon displacement gases leads to caloric value decline – "de-enrichment" of recovered from reservoir active gas. It may lead to the reduction of seasonal active gas recovery rate or it will require additional expenses for construction and operation of gas enrichment units.

Moreover, in case of special necessity caused by gas supply conditions or in case of planned UGS abandonment, the recoverable part of the cushion natural methane gas volume can be recovered from the formation and reused. The partial replacement of cushion natural methane gas volume by non-hydrocarbon gases significantly limits the possibility of reusing the recoverable part.

Simulation of partial replacement of cushion natural methane gas is aimed at substantiation of such engineering solutions, as UGS, which lead to lower mixing of natural methane gas with non-hydrocarbon displacement gases in the formation. To achieve this target under gas drive for displacement gas injection, poorly drained areas of heterogeneous formation should be used in the first place. In case of water drive the achievement of the target is mainly determined by displacement capacities of certain non-drained formation components of cushion gas volume which depend on the geological structure of the storage facility and UGS operation mode.

It is evident that the considered method of partial replacement of cushion natural methane gas by carbon dioxide can be most efficiently used at underground storages with less degree of natural methane gas and carbon dioxide mixing.

These are primarily the underground storages with the following properties:

- Trap capacity exceeds the capacity needed without replacement of cushion natural methane gas by non-hydrocarbon displacement gases;
- Gas drive or insignificant water drive of gas deposit;
- Gas bearing part of formation has poorly drained areas;
- During cyclic storage operation the ratio of reservoir pressure change amplitude and average cycle pressure is low.

It is evident that such properties are characteristic primarily for underground storages constructed or under development in large depleted or partly depleted gas fields under gas and insignificant water drive conditions. The cyclic operation of these storages is characterized by comparatively low reservoir pressure change amplitude related to the average cycle value. It is in these UGS that we can expect the major effect from partial replacement of cushion natural methane gas by carbon dioxide.

Aims and methods

The concept of development of a combined cushion gas volume in the porous formation of underground storage became the basis for substantiating the selection of potential locations for partial replacement of cushion natural methane gas by carbon dioxide.

The targeted geological model of potential UGS sites has been generated.

Mathematical and gas dynamic models of mixing gases of different composition in porous formations of UGS were generated – the lateral diffusion model on the basis of two-layer geometrical reservoir model and 3D gas-dynamic filtration-diffusion reservoir model.

Using these models numerical experiments on filtration and convective-diffusion mixing of natural methane and injected carbon dioxide in a porous formation with partial replacement of cushion gas volume in a UGS facility were carried out.

Technical forecast calculations of carbon dioxide spreading in the porous formation and of parameters of partial displacement of cushion natural gas volume by carbon dioxide were made.

Results

The UGS where these works are carried out was constructed in a depleted gas field and has two domes: the first, basic that was used for UGS and second that was a unified gas deposit together with the first dome at the development stage. At present there is also gas-hydrodynamic connection between the domes.

2 main options of daily productivity and injected carbon dioxide volume were considered.

The first option is CO_2 injection in the amount of 1 MCM/day, the second – 2 MCM/day. This volume is enough to replace over 2 BCM of cushion methane for 5,5 years in the first option and over 4 BCM in the second one. The share of natural methane gas replacement by carbon dioxide for two options will amount to: in the methane gas volume in the second dome -about 22% and 45% respectively and in design cushion gas volume in UGS on the whole – about 2,8% and 5,6%.

Three options of injection well spacing in the second dome, including existing and potential new wells, were considered. The first option is using 15 existing wells located in the central top part of the dome, second option – two row location of 15 new injection wells in the eastern periphery of the dome along GWC boundary, third option – location of 15 new injection wells in its north-eastern part.

Performed calculations show that it is possible to partly replace the cushion natural methane gas volume by carbon dioxide without its breakthrough to production wells of the first dome for all considered options. At the same time in case of longer periods and greater volumes of carbon dioxide injection, such breakthroughs are possible primarily for options where injection wells are located in the centre and in the north-east.

On the other hand, the use eastern and north-eastern locations for carbon dioxide injection requires drilling of not less than 15 new injection wells.

The comparative analysis of considered carbon dioxide locations and injection rate and volumes within 2 MCM/day and 4 MCM/day respectively has shown that the injection into the central top part of the second dome should be recommended. This option includes carbon dioxide injection using 15 existing wells.

Proposals for the system of selective (through the section) and areal regulation of carbon dioxide injection into formation have been developed.

The studies of the impact of second dome penetration intervals in injection wells have shown that in case of injection into the near-top part of reservoir (20 meters) and the lower part of gas saturated layer of reservoir (20 meters) different penetration intervals do not have a significant impact on methane gas replacement by carbon dioxide.

Therefore, selective (through the section) regulation of carbon dioxide injection into formation will be conditioned by actual injection capacity of different reservoir intervals in each injection well.

To reduce the risk of untimely breakthrough of injected carbon dioxide to production wells of the first dome, the areal regulation of pilot injection is recommended. This means regulating the sequence of hooking up injection wells recommended from existing ones in the option of their central top location from south-east to north-west.

It is recommended to use nearest observation wells for monitoring of injected carbon dioxide flow in the second dome in the direction of first dome production wells. It is recommended to use existing observation wells to control the injected carbon dioxide flow in the second dome.

Conclusions

We have studied options with various location of CO_2 injection wells, various intervals of gas saturated layer penetration and by 2 times different carbon dioxide injection rate and volume and can make the following conclusions:

1) In studied geological reservoir conditions the gas saturated layer penetration interval does not have a significant impact on methane gas displacement by carbon dioxide. Carbon dioxide is mainly spreading in the gas saturated layer and displaces methane. The areal location of injection wells that inject carbon dioxide has a much greater impact on the efficiency of cushion volume replacement by CO_2 compared to penetration intervals.

2) According to the calculation results, the row-type location of injection wells on the second dome along the eastern part of GWC boundary is preferable compared to well location in the centre or in a separate section of the deposit. Near-GWC boundary injection of carbon dioxide allows to maximum efficiently displace methane to the first dome of UGS and minimizes the risk of CO_2 breakthrough to production wells.

3) The volume of injected carbon dioxide is linearly proportional to CO_2 spreading front, which indicates that it is necessary to take into account the reservoir pore volume and planned injection schedule in each individual case when calculating volume of injected gas. Carbon dioxide spreading parameters are different for every underground gas storages, they depend on geological conditions, chemical content of rock and reservoir fluids.

4) The received results allow to make a conclusion that it is potentially possibly to partially replace the cushion natural gas volume by carbon dioxide.

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