Impact of Reservoir Dip Angle and Hydrogen Molecular Dispersion on Hydrogen Cycling Storage in Depleted Gas Reservoirs – A Numerical Modelling Study

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1. Background

Large-scale hydrogen storage is important for a full development of hydrogen value chain. Hydrogen storage in depleted natural gas reservoirs provides cost-effective and secure solutions due to their proven seal capacity, available surface facilities, abundant surveillance data and less ambiguous reservoir characterization.

High purity of hydrogen is desirable when extracting hydrogen from storage sites. However, when a depleted gas reservoir is repurposed for hydrogen storage, mixing between hydrogen and other gases in the subsurface makes the extracted hydrogen impure. Here, numerical simulation was conducted to understand the mixing mechanism. The optimum geological settings were also investigated for well placement to improve hydrogen purity whilst extracting hydrogen from storage sites.

2. Simulation Strategy

To understand the evolution of the hydrogen plume migration at reservoir-length and operational-time scale, industry standard compositional reservoir simulator ECLIPSE 300 was used in this study to model the mixing process over time. The mixing is influenced by mobility ratios, density differences, molecular diffusion, and mechanical dispersion. It is worth noting that geochemical, microbial activities together with mechanical dispersion were not considered in this modeling due to the software limitation. Our results therefore would be the upper limit for hydrogen purity prediction for a given geological structure.

3. Numerical Simulation Model

To investigate the mixing processes of gaseous components for underground hydrogen storage in depleted gas reservoirs, two artificial anticline geological structures with different dip angles were built, one with 3 degrees and the other with 15 degrees. Figure 1a and 1b show cross sections for these two different models. The operation well was located at the crest of central reservoir and hydrogen was injected into the top 10 layers.

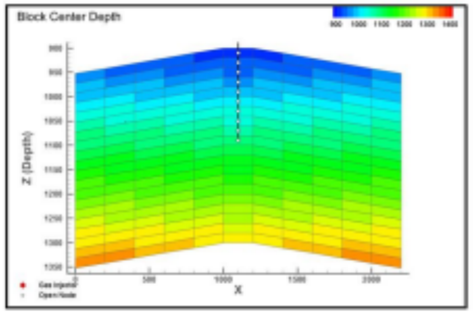

Figure 1a Cross sections for models with a dip angle of 3 degrees

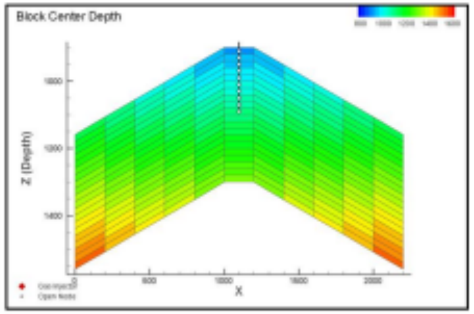

Figure 1b Cross sections for models with a dip angle of 15 degrees

The petrophysical properties (porosity and permeability) are distributed homogeneously. Table 1 shows model properties and hydrogen injection parameters. The fluid in reservoirs consists of two phases (gas and water) with a composition of five components: carbon dioxide (CO2), water (H2O), hydrogen (H2) , methane (CH4), and ethane (C2H6). Their initial mole fraction ratio is 24%, 2%, 0%, 37%, 37% with no hydrogen in the reservoir.

Table 1 Parameters for both simulation models

Quantity	Values
Grid	11 x 5 x 20
Grid block size (m)	200 x 200 x 20
Model size (m)	2200 x 1000 x 400
Wellbore radius (m)	0.15
Depth of crestal reservoir (m)	-900
Model dip angles (degrees)	3 and 15
Formation thickness for each layer (m)	20
Porosity	0.1
Permeability (Darcy)	0.1
Vertical to horizontal permeability ratio	1
Surface measured hydrogen Injection rate (m^3/day)	1×10^6
Surface measured hydrogen production rate (m^3/day)	2×10^6
Initial Reservoir Pressure (Bar)	76.5
Maximum Injection Pressure (Bar)	140
Reservoir Temperature (degree Celsius)	60

In both models the gas-water-contact was set at a depth of 1600 m, which was well below the deepest reservoir in both models. The reservoir was thereby filled with depleted gas and connate water. In this way, gas volume was kept same for both models and the effect of dip angle could not be masked by other factors. Considering no mobile water in the reservoir (only depleted gas and connate water), a pseudo relative permeability and a zero capillary pressure were used. Note that the critical water saturation was set as 20% to make the connate water immobile.

4. Operation Schedule

The implemented hydrogen underground storage scenario included 10 years of annual cyclic operation period with the six months of pure hydrogen injection, three months of idle time and three months of hydrogen production(Figure 2).

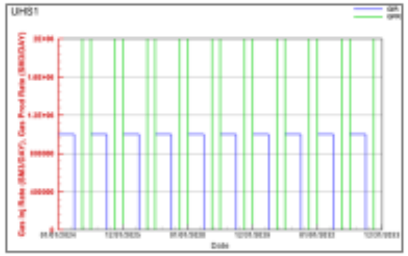

Figure 2 The proposed operation schedule and rate

5. Results and Discussions

Result #1: Hydrogen concentration increases with increasing number of cycles.

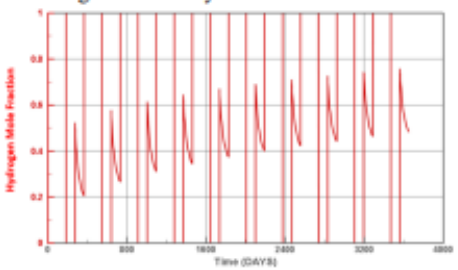

Figure 3 Hydrogen mole fraction at different injection and production cycles

Result #2: Concentration of produced methane gradually decreased with increasing number of cycles.

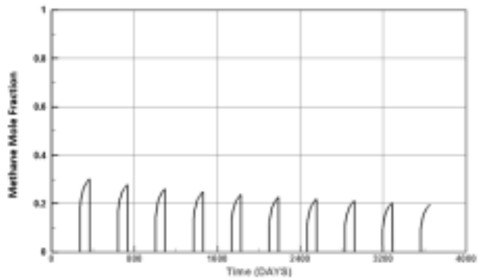

Figure 4 Methane mole fractions at different production cycles

Result #3: Increasing dip angle increases hydrogen production concentration for each production cycle.

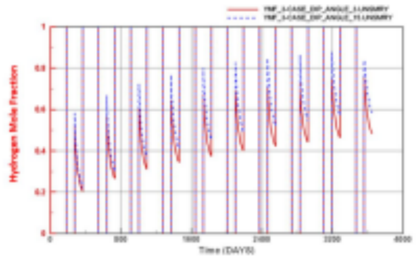

Figure 5 Hydrogen mole fractions for cases with different dip angles

Result #4: Hydrogen dispersion can dilute the hydrogen concentration in the plume, which can be directly seen from 3D numerical model. However, gravity segregation can mitigate the impact of hydrogen dispersion on hydrogen purity in a deep angle reservoir.

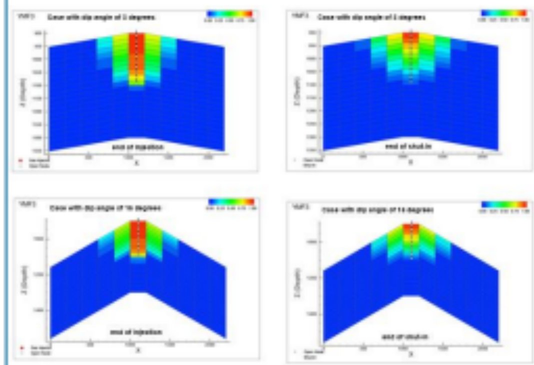

Figure 6 Hydrogen mole fraction distribution for cases with different dip angles

6. Conclusions and Iimplications

1. Gravity segregation and molecular diffusion work together to dominate the mixing process at the idle time. Storing hydrogen in higher dip angle reservoirs could greatly improves hydrogen purity at the upper portion due to stronger gravity segregation.
2. To improve hydrogen production purity, underground hydrogen in depleted gas reservoirs should consider crests of anticlines with a high dip angle as possible.
3. With detailed leakage risk evaluations, the upper portion of the reservoir sealed by faults with a high dip angle is also a good choice for hydrogen storage.

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