Impact of Reservoir Properties, Cushion Gas Type, and Well Configuration on Performance of Hydrogen Storage in Gas Fields

David Nagy[2], Agha Baghirov[2], Rifaat Al Mjeni[1], Rouhi Farajzadeh[1,2]

[1]Shell
[2]TU Delft

Abstract

The objectives of the energy transition are combatting climate change and reducing the dependency on fossil fuels. While renewable sources like solar and wind have a lower CO2 intensity, their intermittency poses challenges. Underground hydrogen storage has the potential to address the intermittency challenge by converting renewable electricity to hydrogen and storing the hydrogen in a subsurface reservoir for later usage. This study investigates the impact of different rock-fluid properties on the fate of the stored hydrogen. The results are used to establish screening criteria for the optimal design of the hydrogen storage in gas fields. The methodology defines the reservoir model, outlines the modelling steps and describes the calculations for the purity, recovery, exergy efficiency, and eventual CO2 intensity of the back-produced electricity. The investigated parameters include different cushion gases (hydrogen, methane, CO2 and nitrogen), permeability characteristics, well configurations, dispersion and injection cycles.

It is found that use of hydrogen as cushion gas is the most expensive and energy-intensive option due to cost of hydrogen production This case gives the highest produced hydrogen purity among other cushion gases considered. For the case of CO2 cushion gas, negative CO2 emissions occur and the purity is notably high, with a small mixing zone between hydrogen and methane at the top of the reservoir.

We also find that numerical dispersion has a large impact on the purity and recovery. Physical dispersion is not a major concern because the impact on the purity and recovery is smaller compared to numerical dispersion and the purity and recovery of the simulations are high, even when considering the high combined dispersion value of the numerical and physical dispersion.

Various cases with average permeability and different horizontal to vertical permeability ratios demonstrate negligible differences in hydrogen recovery rates. The Kv/Kh ratio has minimal impact on the size and position of the mixing zone. A larger average permeability results in a smaller mixing zone between hydrogen and methane, which leads to a slightly higher purity and exergy efficiency.

It is also observed that vertical wells exhibit a larger hydrogen-methane mixing zone, resulting in lower purity and recovery, affecting the economics and exergetic efficiency of the process. A longer injection cycle leads to a larger hydrogen-methane mixing zone, which leads to a significantly lower purity. The larger energy requirement for separating and re-injecting methane and lower recovery results in lower cash flows, lower exergy efficiency and higher CO2 emissions. However, it is possible to vary the injection cycle within certain limits to accommodate supply and demand variations while meeting purity requirements.

In conclusion, this research addresses the technical viability of Underground Hydrogen Storage (UHS) in gas fields by conducting a sensitivity analysis of various parameters impacting the purity, recovery, exergy efficiency, CO_2 intensity and economics. Notably, the impact of heterogeneity on the purity is minimal when the permeability is high and horizontal wells give a higher purity and recovery compared to vertical wells. The optimal setup for Underground Hydrogen Storage in a gas field is simultaneous injection of hydrogen from horizontal wells at the top and CO_2 from horizontal wells at the bottom.