Injection of cold CO_2 in to depleted gas fields

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Summary

Offshore depleted gas fields are the primary near-term option for storage of CO_2 and emissions reduction from industry in The Netherlands [1]. Injection of CO_2 in such fields often leads to significant differences in temperature between the injected CO_2 and the reservoir. A low pressure in the reservoir due to depletion leads to decompression and cooling of the CO_2. The safe and efficient injection and storage of cold CO_2 requires simulation of pressure and temperature in the pipelines, wells and reservoir. The reservoir is generally represented in a simplified way in pipeline and well models via multi-dimensional tables. A sensitivity analysis of CO_2 injection in a realistic dynamic reservoir model shows that the injection of cold CO_2 below the critical pressure, fluid properties are highly variable and such tables are too limited.

Statement of the problem

Captured CO_2 is transported by a high-pressure pipeline to an offshore depleted gas reservoir at depths of about 3500m at temperatures (T) of about 126°C. Initial pressure (P) of the order of 37MPa is reduced to around 1.5MPa or lower. When injection temperature and reservoir pressure are below the liquid-vapor phase line, CO_2 properties (density and viscosity) will be highly variable around the well. Possibly, hydrate formation and fracturing due to thermal stresses will need managing. The bottom-hole P and T during injection depend on the conditions in the transport pipeline (pressure, temperature, CO_2 composition), the flow rate down the well, as well as on properties of the storage reservoir and the conditions in the reservoir near the well [2][3][4][5].

The design of a CO_2 transport and storage concept requires extensive modeling and reservoir simulation including the flow in the well and pipeline. Typically in hydrocarbon production scenarios, the reservoir is represented by multi-dimensional tables of Inflow Performance Relationships (IPRs). However, for CO_2 injection into depleted gas fields, the temperature is an additional parameter that increases the dimensionality of IPR tables. Furthermore, creating a set of IPRs with the highly variable properties of CO_2 is not trivial. Here, we investigate how injectivity responds to different temperature and injection rates.

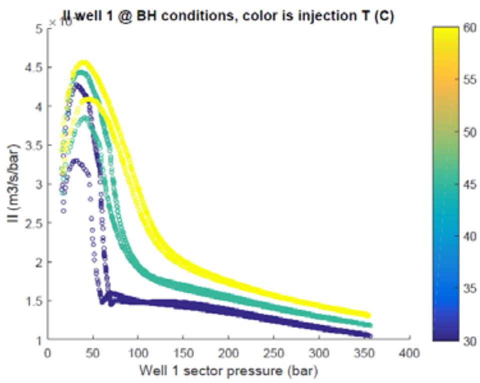
Methodology and Simulation Design

Dynamic modelling of the injectivity of CO_2 is conducted with a realistic reservoir model characteristic of Dutch offshore depleted gas fields in the North Sea. The reservoir is a tilted fault block with moderately-sized aquifer, temperature of ~126 °C and abandonment pressure ~15 bar. The field is first produced and then filled with CO_2 through three near-vertical wells. The simulation couples heat and fluid flow and includes Joule-Thomson cooling and evaporation of formation water. The numerical burden is made manageable with a few simplifications of negligible impact on the results. Although the depletion phase is simulated for natural gas, before the start of the CO_2 injection, the remaining in-situ gas is changed to CO_2, i.e. the initial reservoir is filled with CO_2 instead of natural gas. To improve stability of the simulations, some CH_4 and water (3%) were added to the injection stream.

CO_2 dissolution, salt precipitation, chemical reactions, hydrate formation, non-Darcy flow and mechanical effects are ignored in this study. Sensitivity analyses examine the effects of near-wellbore grid size, different temperatures (15-75°C) and injection rates (2-20kg/s).

Results, Observations, Conclusions

The Joule-Thompson (JT) cooling and water vaporization are strong for small grid sizes. At larger grid sizes, the pressure increases substantially before the temperature is low enough to induce a strong JT effect. The volumetric well Injectivity Index (II) displays the impact of temperature (indicated by color 30, 45 and 60°) at injection rates of 10 and 20 kg/s.



Overall the results show that if reservoir pressure and temperature are comfortably above the phase-line, injection can be represented using 4-dimensional IPR curves depending on reservoir and well pressure and temperature. However for lower temperature and pressure, such tables become unfeasible due to the high variability in CO_2 properties. Since a full coupling of a multi-well model with well and pipeline models is currently not available and would be extremely demanding of simulation effort and CPU time, a smarter solution needs to be developed. In the next step, we plan to replace the IPR tables with machine learning techniques. This will also allow to include the well interference in well-reservoir coupling.

Novel/Additive Information

Previous models studying the behavior of cold CO_2 injection near the critical point were mostly single well models [e.g. 6]. The main reason for using a multi-well model is to incorporate interference between wells and the influence of reservoir architecture (faults and permeability heterogeneity).

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