Introduction

Integrating the subsurface model with the surface network model is essential for maintaining the long-term deliverability of CO_2 to the geological formation. Cross-disciplinary model integration accounts for constraints, such as surface limitations, which might be overlooked if the subsurface model is developed independently. Therefore, a holistic asset modeling approach is necessary to assess the overall geological CO_2 storage performance.

This case study presents the integration of a compositional reservoir model with a wellbore and surface network model using a fully implicit system to evaluate CO_2 sequestration in a deep saline aquifer. Key considerations include storage mechanisms, CO_2 plume migration, and potential leakage pathways into overlying formations. The integrated workflow enables the incorporation of uncertainties across static and dynamic reservoir properties, as well as surface facility and well operational parameters.

Methodology

Figure 1 shows the conceptual design for integrated asset modeling used in the study. The case study is in the Johansen formation, a saline aquifer located offshore of the west coast of Norway. The Johansen formation dataset was developed as part of MatMoRA research project that available online (MatMoRA, 2012). Sector model with heterogeneous rock properties is used. Three different trapping mechanisms are modelled to store the CO_2 which are structural trapping, residual trapping, and dissolution based on study performed by Tewari et al. (2024). The model is calculated using compositional simulation by injecting CO_2 mixed with gas impurities into the permeable layers of the Johansen formation. The model is then fully implicitly integrated with the surface network system which transports the CO_2 via a 60 km pipeline from the onshore power plant source to the storage site, where the main compressor is located, to distribute the CO_2 to the injector wells.

Within the integrated approach to modeling a system "subsurface-well-surface network", a unified PVT fluid model is used for all parts of the system. A well construction is modeled as a continuation of the surface network. The well's performance is constrained by the vertical lift performance curve and a well tubing head is modeled by a joint which connects the well to the surface network. In the connection of an injector, the composition is the same as in the part of the wellbore which the connection belongs to. As a result, the system of equations describing the well state can be replaced with the unified system of surface network equations. The obtained system of equations implicitly connects all blocks with the connections of wells belonging to the surface network.

An integrated surface-to-subsurface network workflow is constructed to investigate the effects of different boundary conditions at the source, compressor design, pipeline diameter, thermal conductivity, fluid components, injection tubing design (inside diameter), sensitivity with respect to CO_2 injectivity, storage capacity, and potential geomechanical risks. The integrated workflow is developed using Python based function. Scenario bases simulation cases were generated Monte Carlo and Latin hypercube designs. This space-filling design method is particularly effective in capturing uncertainty ranges by ensuring optimal spacing and comprehensive parameter coverage. The numerical simulations conducted in this study are highly complex, involving numerous interrelated parameters. Consequently, the primary goal of the designed experiments is to develop an uncertainty model that can reliably predict system behavior within specific parameter ranges. The results of the uncertainty quantification will be presented in this paper. In addition, optimization of the surface and well operational parameters will be also discussed in order to maximize CO_2 storage capacity while maintaining the cap rock integrity.

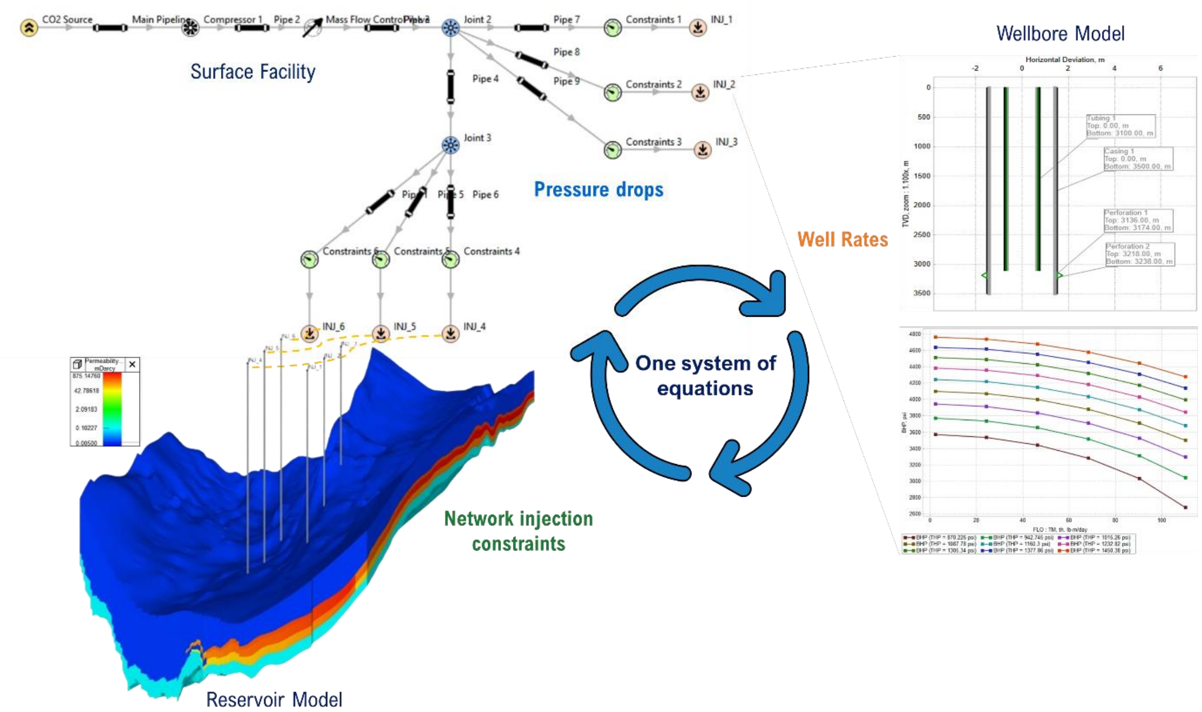

Figure 1 *The scheme of an integrated subsurface-well-surface network model implemented for the Johansen formation*

Results

Based on multi-realization scenarios, some best cases were selected considering the optimum well and surface facility designs to achieve target injection rate with less geomechanical risks. The system could maintain the injection rate for all the wells until at the end of simulation time-step, which means a stable system without any convergence issues. In addition, it also observes that the CO_2 plume migration maintains under the caprock. Therefore, the optimum operational design ensures that the injection target can be achieved while managing caprock integrity.

Conclusions

The integrated model helps describe all technological processes occurring in both the subsurface system and the surface network system, and provides a detailed database of the technological parameters of the system elements. The results of the integrated workflow show that the input parameter distributions and the resulting forecasts helped in making reliable decisions in determining CO_2 injection rates, CO_2 plume distribution with the optimum well and surface facility designs.

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