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Multi-objective optimization of operation conditions by smart proxy model for geological CO_2 storage design in an over-pressured aquifer in the Ulleung Basin

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A B S T R A C T

This study aims to optimize the geological CO_2 storage (GCS) design in the D structure in the East Sea using a Smart Proxy Model (SPM). Analyzing the geomechanical stability of the overpressured aquifer, it was found that the pore pressure in the fault plane must be maintained below the current pressure value. Assuming that two existing wells were repurposed as an injection well and a relief well, Feature Engineering was adopted to derive new parameters for training the SPM with a reduced number of simulation runs. The optimization was conducted to maximize cumulative CO_2 injection and minimize brine production, considering several design parameters, including pre-relief period, the selection of pre-existing wells, and perforation intervals. The model exhibited high predictive accuracy in blind testing, with higher R^2 than 90%. 14 optimal solutions and the Pareto front were obtained by employing the SPM in the NSGA-II algorithm. As a result, the lowest cumulative CO_2 injection and brine production are 3.89 Mt and 5.12 Mt, respectively, while the largest CO_2 injection and brine production are 33.9 Mt and 59.7 Mt, respectively. In addition, it was found that the optimal perforation intervals strongly depend on both the operation conditions and reservoir characteristics. Therefore, the perforation intervals of the injection and relief wells should be optimized when a relief well design is incorporated into a GCS process. Although this study is specific to the D structure, the proposed ML-based optimization framework incorporating geomechanical risks can be adapted to other geological formations for GCS designs.

1. Introduction

According to the Intergovernmental Panel on Climate Change (IPCC) in 2018, achieving carbon neutrality by 2050 is imperative to limit the global temperature increase to 1.5 °C above pre-industrial levels (IPCC, 2022). The geological carbon storage (GCS) technology has been accepted as a key strategy to meet the goal by capturing CO_2 before it is emitted into the atmosphere by securely storing it in a geological structure. Among potential storage candidates, saline aquifers are particularly attractive due to their extensive geographical distribution and significant storage capacity (Global CCS Institute, 2023; Global institute, 2022). However, field-scale GCS applications targeting saline aquifers have faced practical challenges, including elevated pore pressures, uncertain leakage pathways, and higher capital expenditures.

To establish an optimal GCS design in a saline aquifer, it is crucial to perform geomechanical analysis to investigate the challenges, to provide solutions to prevent those, and to ultimately ensure the long-term reservoir stability. In general, the challenges can be prevented by limiting the injection pressure considering the maximum allowable pressure (Song et al., 2023). For a saline aquifer, which is initially filled with formation brine, operating a relief well can be a great tool to 'relieve' the pore fluid pressure by extracting the brine before or during the GCS process. When the optimization process is performed by the computational simulation, however, it requires massive computing power and time for repeated simulation runs to determine the optimized pre-relief periods, operating conditions, and the well locations.

Artificial intelligence techniques have been increasingly employed to optimize the operational conditions for GCS with proxy models that replicate reservoir simulation outcomes with reasonable accuracy. Musayev et al. developed an artificial neural network (ANN)-based proxy model integrated with a genetic algorithm to optimize the placement of CO_2 injection and brine production wells in the Pohang Basin (Musayev et al., 2023). developed an artificial neural network (ANN)-based proxy model integrated with a genetic algorithm to optimize the placement of CO_2 injection and brine production wells in the Pohang Basin. The proposed approach reduced the number of simulation runs by 80.7% compared to conventional numerical methods, while maintaining high prediction accuracy. Song and Wang proposed an ANN model to optimize the locations and operating conditions of relief wells for CO_2 storage in the Pohang Basin (Song and Wang, 2021). Considering geomechanical stability, the authors proposed a framework evaluating 10-, 20- and 30-year injection scenarios, and identified the

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