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A Methodology for Assessing and Improving the Capacity of CO2 Injection in Saline Aquifers

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Abstract

Carbon capture and storage (CCS) is recognized as one of the key strategies to mitigate greenhouse gas emissions and tackle climate change. In CCS, carbon dioxide (CO2) is captured from industrial processes, compressed, and injected into geological formations, such as saline aquifers, for long-term storage. However, the success of CCS depends on the capacity of geological formations to store CO2 safely and securely. As saline aquifers form one of the potential known geological storage, evaluating the capacity reliably early in time is valuable. This paper presents a methodology for assessing the CO2 capacity using a material balance approach and comparing the results with dynamic simulation in order to define if an early reliable estimation is possible.

The methodology includes four main steps: (1) data collection and analysis, (2) reservoir characterization understanding, (3) modelling and simulation, and (4) sensitivity analysis and optimization.

The first step involves collecting and analysing data on the reservoir and injection operations, such as geological and hydrogeological parameters, reservoir pressure, and injection rate. The second step focuses on characterizing the saline aquifer using geological data. The third step involves developing a material balance model to simulate the injection and storage of CO2 in the aquifer, then compared to the dynamic simulation. The fourth step involves performing sensitivity analysis and optimization to evaluate the impact of different parameters on CO2 storage capacity, including operating condition, injection pressure and rate, then the optimum strategy for improving the injection efficiency can be identified.

The proposed methodology was applied, and the results showed that the material balance model could help to predict the behaviour of CO2 storage capacity at an early stage with reasonable and acceptable accuracy. Sensitivity analysis on reservoir permeability, injection rate, and reservoir pressure has been conducted and the results are discussed in this paper. The optimization analysis identified that increasing the injection rate and maintaining high reservoir pressure could significantly improve CO2 storage capacity.

In conclusion, the proposed methodology provides a comprehensive and systematic approach for assessing the capacity of CO2 in saline aquifers at an early stage as well as the potential solutions to improve the capacity.

Methodology

Data Collection and Analysis

Data collection in a Carbon Capture and Storage (CCS) project for saline aquifers is a critical phase that lays the foundation for the entire project's success. It involves gathering extensive and varied information, including geological, geophysical, and petrophysical data, to understand the aquifer's characteristics and behaviour thoroughly. This phase requires the use of sophisticated tools and technologies such as seismic surveys, well logging, and core sampling to obtain accurate and detailed data. Ensuring the personnel are skilled in these technologies and adhering to established protocols is crucial to collecting reliable and comprehensive data. Regular calibration and maintenance of the equipment used also enhance the data's precision.

The collected data undergoes rigorous analysis to model the saline aquifer and simulate the CO_2 injection process. Material Balance Simulation models are employed to analyse the data and generate insights into the aquifer's suitability for CO_2 storage, including its capacity, injectivity, and containment security. The analysis includes an assessment of the aquifer's porosity, permeability, and caprock integrity. Geomechanical analysis helps in understanding the stress fields and the potential for fault reactivation or induced seismicity due to CO_2 injection. This phase demands collaboration among multidisciplinary teams, including geologists, reservoir engineers, and data analysts, to ensure comprehensive and accurate analysis.

Reservoir Characterization for CO_2 Injection in Saline Aquifers

Reservoir characterization is a critical step in evaluating the suitability of saline aquifers for carbon dioxide (CO2) injection and long-term storage, a process known as geological carbon sequestration. Comprehensive characterization of the aquifer, including its geological, geophysical, geochemical, and hydrogeological aspects, is essential to ensure the efficiency and safety of CO2 storage projects.

Geological Characterization. A thorough geological assessment is paramount. This involves analysing the structural and stratigraphic setting of the saline aquifer, ensuring it possesses a suitable cap rock or seal to prevent CO2 escape. The study of rock properties such as porosity, permeability, and mineral composition is essential to assess the aquifer's storage capacity and injectivity. Additionally, understanding the geological history and tectonics helps in identifying potential risks associated with fault and fracture networks that may compromise the storage integrity.

Geophysical Characterization. Geophysical techniques, such as seismic, gravity, and magnetic surveys, are employed to obtain subsurface images and information on reservoir architecture and properties. Seismic reflection data is particularly valuable as it provides detailed structural and stratigraphic information necessary for constructing reservoir models. These models aid in identifying sweet spots for CO2 injection and predicting the plume migration within the aquifer.

Geochemical Characterization. A comprehensive geochemical evaluation is critical to understanding the interactions between injected CO2, formation water, and reservoir rocks. This evaluation involves assessing the mineralogy, total dissolved solids, pH, and other parameters of the aquifer to predict potential geochemical reactions. Understanding these reactions is vital for evaluating the long-term stability and capacity of the reservoir for CO2 storage, as well as mitigating any adverse reactions that could compromise the reservoir's integrity.

Material Balance Model and Dynamic Simulation Model

A comprehensive material balance simulation model was meticulously developed and calibrated for the express purpose of projecting the upper limits of carbon dioxide (CO2) sequestration capacity within a designated subsurface containment reservoir. To ensure accurate and meaningful results from this material balance model, fundamental inputs were sourced from a dynamic reservoir simulation constructed specifically for this initiative. This dynamic model provided invaluable insights into the storage potential of the reservoir, particularly concerning its intricate characteristics. Critical parameters extracted from the dynamic model encompassed data obtained from specialized core analysis procedures, phase behaviour studies represented by pressure-volume-temperature (PVT) correlations, porosity measurements, and determinations of the possible aquifer's dimensional characteristics. Figures 1 and 2 show information extracted from the dynamic model.

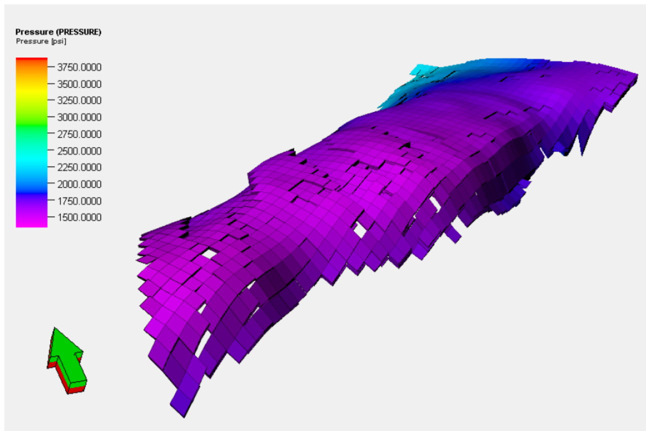

Figure 1—3D pressure array in Dynamic model

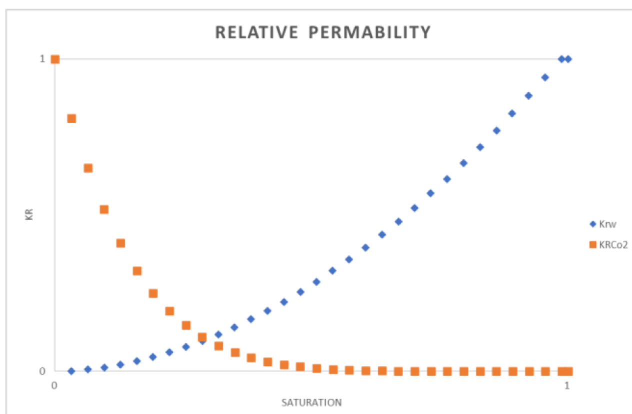

Figure 2—Relative permeability used for Dynamic Simulation and Material Balance

Utilizing the comprehensive data derived from the dynamic model, a multitude of critical technical parameters were meticulously established. These include relative permeability, which sheds light on the flow characteristics of multiple fluids within the reservoir. Another pivotal factor considered was the Pressure-Volume-Temperature (PVT) information, instrumental in understanding the fluid properties under varying reservoir conditions. Additionally, porosity, a key determinant of the reservoir's storage potential, was assessed to gain insight into the pore spaces available for fluid storage. The temperature of the reservoir was another crucial input, as it plays a significant role in influencing the behaviour and movement of reservoir fluids. Similarly, the reservoir pressure, indicative of the potential drive mechanisms and overall reservoir performance, was taken into account. All these input parameters collectively facilitated a more accurate prediction of the reservoir's storage capacity. To provide a visual representation of the foundational data, Figure 3 presents the material balance input parameters, offering a clear overview of the factors considered in the assessment.

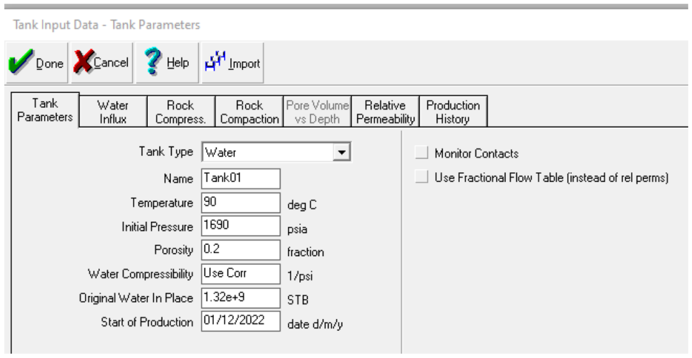

Figure 3—Material Balance input data.

It is important to highlight that the material balance model cannot model CO2 solubility in brine during simulations.

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Comparison between Dynamic model and Material Balance

In the process of evaluating the efficiency and accuracy of the two modelling methods, the CO2 injection profile, characterized by its temporal variation and accompanying pressure fluctuations, was meticulously incorporated as primary input parameters into the constructed material balance model. This deliberate integration aimed to facilitate the extrapolation of anticipated pressure responses and cumulative CO2 deposition patterns, which are distinctly illustrated in Figures 4 and 5.

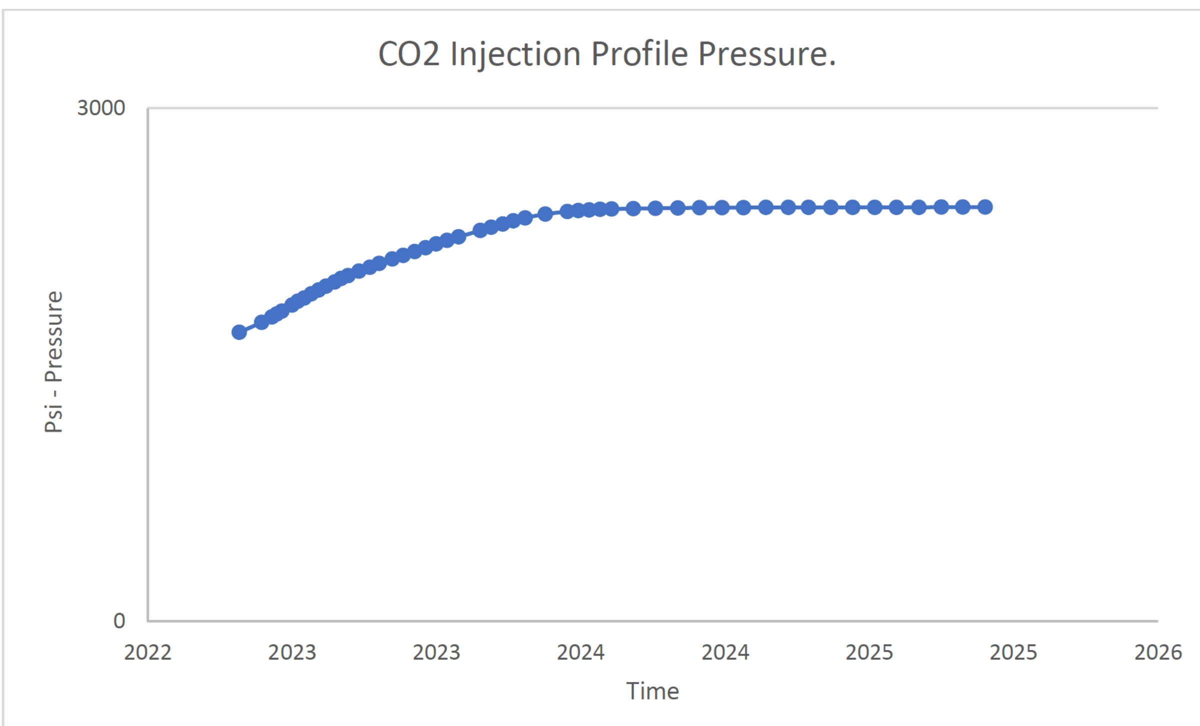

Figure 4—Dynamic pressure respond

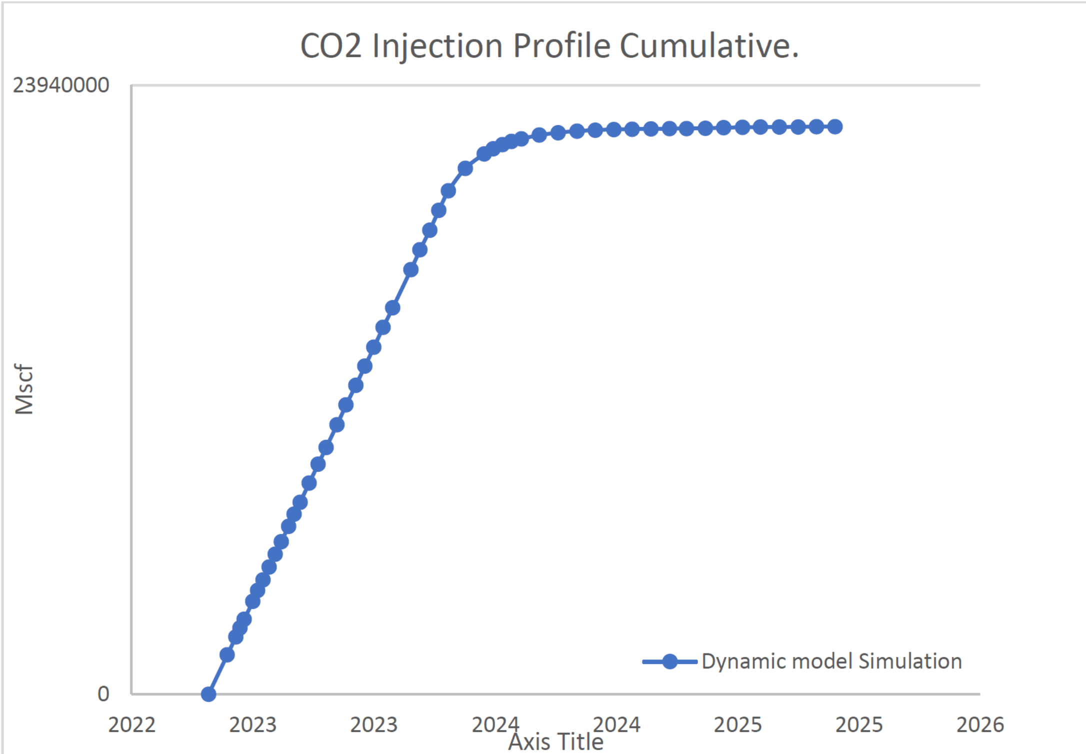

Figure 5—CO_2 Cumulative preduct by Dynamic model.

The aforementioned data, once assimilated into the Material Balance model, served a dual purpose. First, it was used to validate the model's functionality and reliability. Second, it sought to determine the extent to which the pressure response derived from the material balance model could align or deviate from the predictions generated by its counterpart, the dynamic simulation model.

Upon rigorous analysis, when juxtaposing the outcomes from the material balance model against the dynamic simulation model, certain disparities became evident. Specifically, the material balance model indicated a pressure variation of approximately 5% from the dynamic model's projections. Moreover, there was a discernible difference in the order of 7% with respect to the cumulative CO2 volume when benchmarked against the predictions from the dynamic model.

Comprehensive Sensitivity Analysis and Optimization Procedures

To fully comprehend the intricacies of CO2 storage potential within subsurface formations, it is imperative to systematically execute sensitivity analysis and optimization. This involves critically assessing the influence of various parameters on the CO2 storage capacity. Noteworthy among these parameters are the prevailing operating conditions, injection pressures, and respective injection rates. Delving deep into these factors aids in delineating the upper boundaries of pressure that the reservoir can sustain during CO2 injection phases. Such boundaries are not mere approximations; they must be rigorously derived from detailed geomechanical analyses, which take into account the reservoir's structural integrity and mechanical behaviour under stress.

Once these pressure limits and associated constraints are accurately established, it paves the way for strategizing ways to enhance injection efficiency. By examining the interplay of these parameters within the system dynamics, one can pinpoint the optimal operational strategies that not only maximize storage but also help to understand risk during CO_2 injections. Such optimization will prove invaluable in making informed decisions regarding sustainable CO2 sequestration.

Figure 6 and 7 shows sensitivities performed on CO_2 injection rate to comprehend the answer of pressure how faster pressure can build up and what will be the possible variability on stored volume.

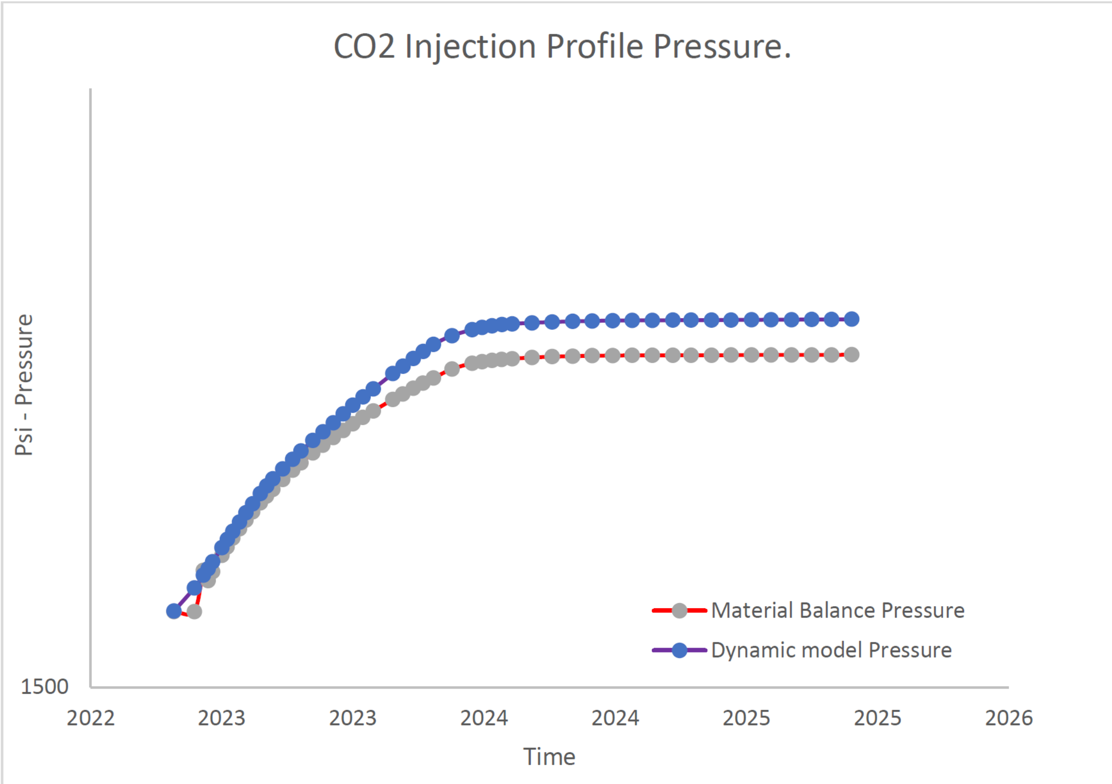

Figure 6—Material Balance and dynamic model comparison (pressure)

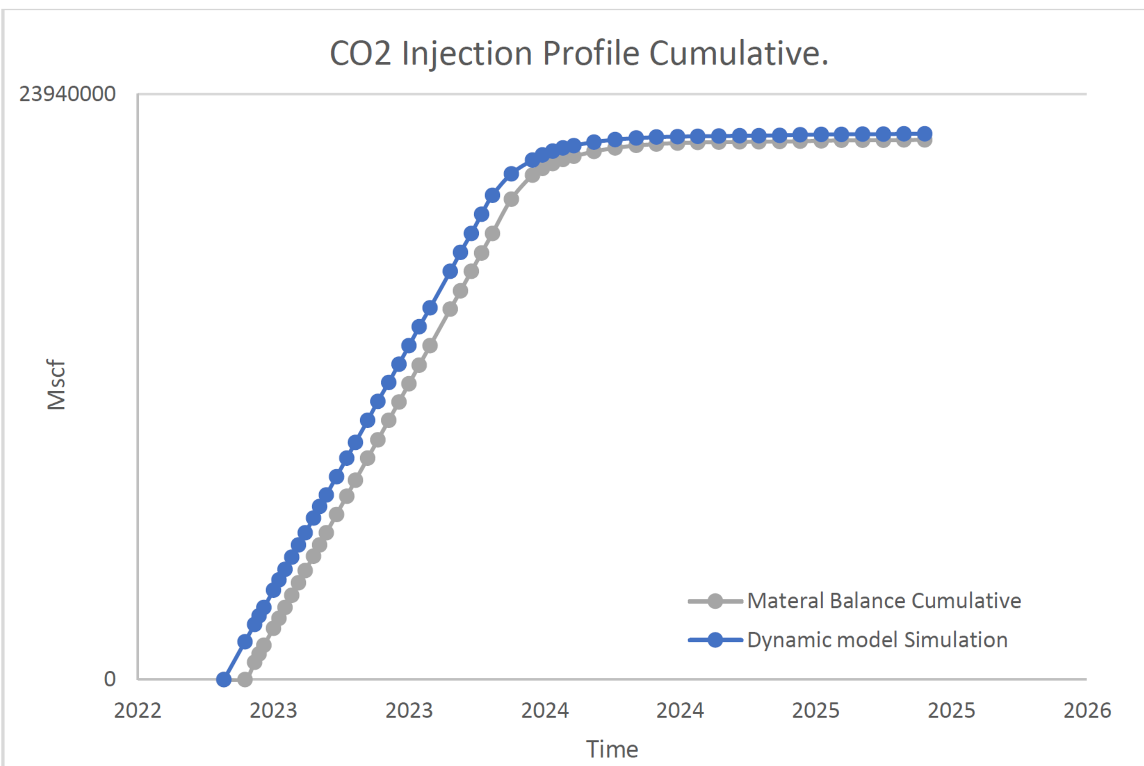

Figure 7—Material Balance and dynamic model comparison (CO_2 Cumulative injection)

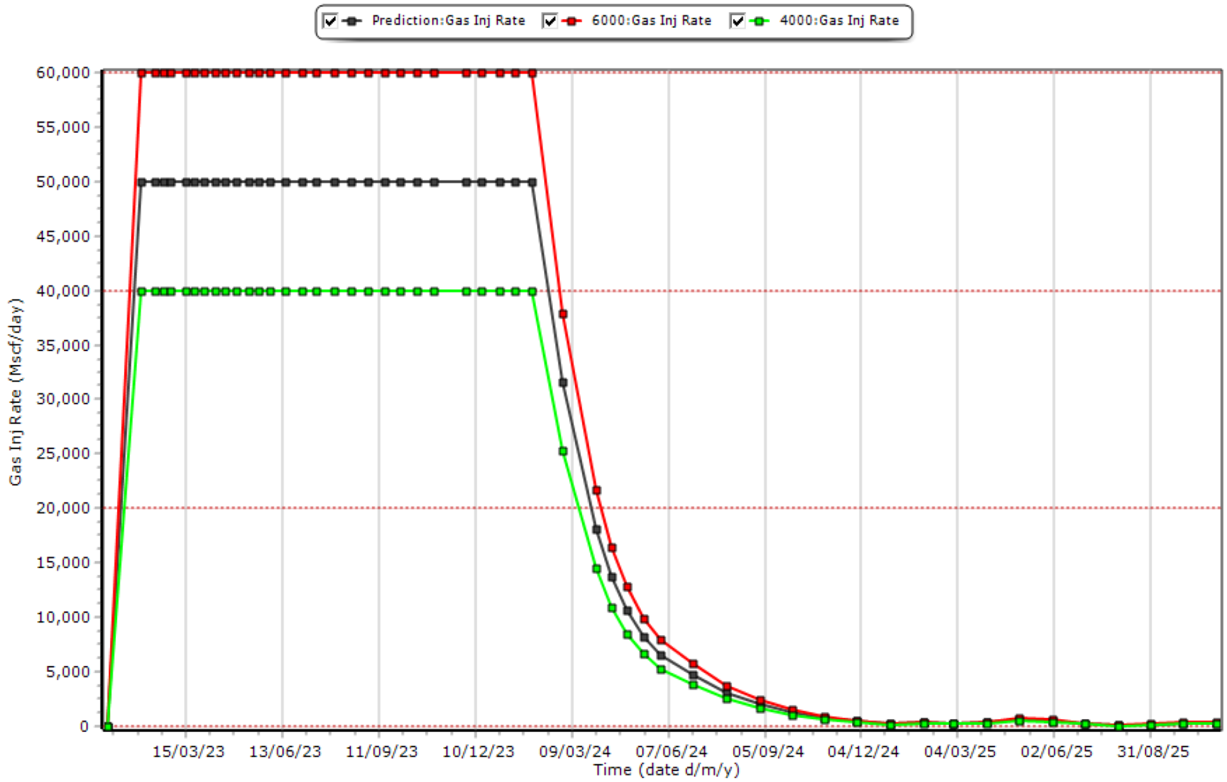

Figure 8—prediction analysis with diferent injection rate.

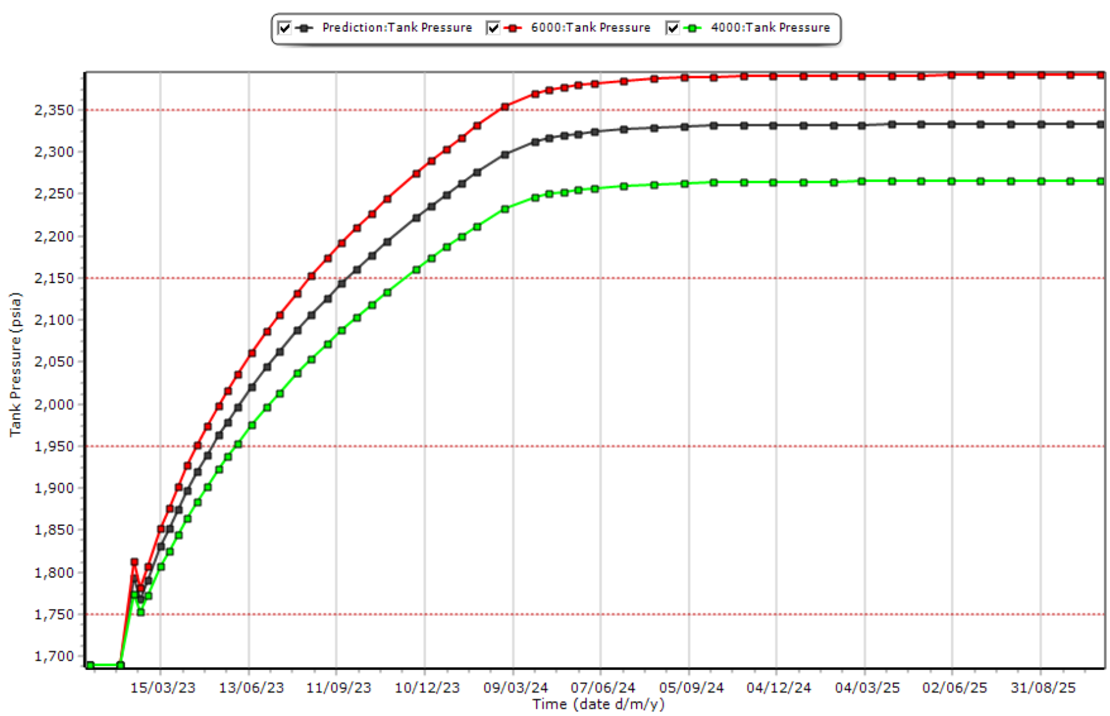

Figure 9—pressure respond with prediction analsis with diferent injection rate.

Conclusion

The rigorous comparison between the Dynamic model and the Material Balance model revealed disparities in their respective predictions. While both models provided valuable insights into CO2 storage dynamics, the material balance model exhibited an approximate pressure deviation of 5% and a 7% variation in cumulative CO2 volume relative to the dynamic model's projections.

The Material Balance model, fed with precise CO2 injection profiles and pressure data, not only authenticated its operational capability but also gauged its relative alignment or divergence from the dynamic simulation model's outputs. This comparative approach underscores the importance of utilizing multiple modelling methodologies to ensure robustness in predictions.

Sensitivity analysis and optimization procedures are indispensable tools in understanding the complexities of CO2 storage within subsurface reservoirs. By evaluating parameters such as operating conditions, injection pressures, and rates, one can ascertain the upper-pressure boundaries sustainable by the reservoir during injection phases.

The pressure boundaries of the reservoir are not arbitrary but are established through detailed geomechanical evaluations. These analyses ensure that the reservoir's mechanical stability and structural integrity remain uncompromised during CO2 injections.

Once the aforementioned boundaries are defined, it becomes feasible to devise strategies that optimize injection efficiency while concurrently safeguarding against potential risks associated with CO2 sequestration.

As showcased in Figures 6 and 7, the sensitivities performed on CO2 injection rates elucidate how rapidly pressure can accumulate within the reservoir. Additionally, they provide insights into potential variability in stored CO2 volume, aiding in more precise decision-making processes for future storage initiatives.

In essence, the combination of rigorous modelling, detailed sensitivity analyses, and geomechanical evaluations offers a comprehensive framework for safe, efficient, and sustainable CO2 sequestration.

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