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Optimizing Geothermal and CO_2 Sequestration Systems at Scale: A High-Performance Computing Approach to Decision-Based Modeling

Abdulrahman AlManea[1]

[1]Saudi Aramco

Abstract

Geothermal energy and CO_2 sequestration are critical components of a sustainable energy future, offering the potential to reduce greenhouse gas emissions while meeting growing energy demands. However, the development and optimization of these systems require advanced modeling capabilities to handle the inherent uncertainty in subsurface conditions and the vast number of parameters that must be optimized to ensure efficient and sustainable operation. Decision-Based Modeling (DBM) is crucial for evaluating multiple scenarios and identifying optimal strategies, but its computational demands create a bottleneck for large-scale projects.

To address these challenges, we present an advanced computational framework that leverages high-performance computing (HPC) to enhance the efficiency and scalability of decision-based modeling for geothermal and CO_2 sequestration systems. Central to this framework is the development of a highly scalable, massively parallel subsurface simulator capable of handling the computational intensity of modeling billions of cells. This simulator is designed to capture the intricate physics of CO_2 plume migration, heat extraction, and fluid flow dynamics across vast geothermal fields, thereby overcoming the computational challenges associated with large-scale numerical models. This cutting-edge modeling capability is augmented with innovative optimization strategies, designed for handling the complexities of geothermal and CO_2 sequestration systems. An example of these innovative strategies is the Multi-Scale Inline Simultaneous Optimization (MSISO), which is a novel process that integrates real-time simulation feedback with geothermal field management, enabling dynamic adjustment of injection and production parameters to maximize energy output and CO_2 sequestration efficiency in CO_2-Plume Geothermal (CPG) systems. This multi-scale approach considers various scales of the system, from local to global, ensuring a comprehensive understanding of the system's behavior. The inline and simultaneous nature of MSISO allows for real-time optimization, streamlining the decision-making process and enhancing the system's performance.

The integration of MSISO within our framework offers significant benefits, enhancing efficiency and reducing costs through real-time optimization and efficient resource use. This synergy improves decision-making for large-scale geothermal and CO_2 sequestration projects, where simulation results show increased energy extraction efficiency and extended reservoir longevity, delaying thermal breakthrough by up to five years through optimized operation strategies. These results highlight the transformative potential of such advanced computational methods in addressing the challenges in geothermal and CO_2 sequestration projects, enabling sustainable and efficient energy solutions through the power of HPC.