**Dynamic Flow Simulation of CO\(_2\) Injection at a Geological Sequestration Site**

**Challenge**
Predict dynamic flow behavior of the CO\(_2\) injection process, from the compressor to the reservoir, and identify conditions that could lead to operations outside normal safety and system design limits. Temperature effects were particularly significant for this above-ground pipeline configuration.

**Solution**
A transient thermo-hydraulic model of the existing surface and subsurface equipment was developed and used to perform dynamic simulations (predict transient pressures, temperatures, and fluid flow) to better understand the operational conditions of the CO\(_2\) injection.

**Results**
Simulating the operating scenarios helped define the operating limits to increase safety and efficiency. Model predictions, obtained with the OLGA* dynamic multiphase flow simulator, have been validated and show good agreement with initial operational data from the CO\(_2\) injection.

**Overview of the Illinois Basin – Decatur Project**
The Midwest Geological Sequestration Consortium (MGSC), led by the Illinois State Geological Survey, together with Archer Daniels Midland Company (ADM) and Schlumberger Carbon Services, is currently injecting carbon dioxide (CO\(_2\)) at the Illinois Basin – Decatur Project (IBDP), one of the first million-tonne demonstrations of carbon sequestration in the U.S. The CO\(_2\), captured from the fermentation process used to produce ethanol at an ADM corn processing complex, is compressed into a dense liquid, and injected into the Mt. Simon Sandstone, more than a mile beneath the surface at Decatur, Illinois.

**Need for Transient Analysis of CO\(_2\) Injection in Carbon Capture and Sequestration Projects**
Accurate fluid-flow transient analysis is essential in carbon capture and sequestration (CCS) projects to better understand the injection process, ensure safe and efficient system performance, and to help project analysts visualize the dynamics of multi-phase CO\(_2\) flow. Thorough transient analysis can provide more accurate operational predictions, important target formation simulations for storage, and reduce costly unstable performance conditions.

Prediction of transient phenomena during CO\(_2\) injection is more challenging than modeling traditional oil and gas fluids because the CO\(_2\) may be prone to rapid and frequent phase changes en route from the source to the target injection formation – especially in the case of this above-ground pipeline at a location subject to severe ambient temperature variations.

Fig. 1 – The initially uninsulated above ground CO\(_2\) delivery pipeline (shown on the white elevated pipe rack) connecting to the injection wellhead on the left.
Application of Transient Analysis at the Illinois Basin – Decatur Project

The properties of the injected CO\(_2\) are very sensitive to pressure and temperature conditions, so accurate predictions rely on a sound and comprehensive model with accurate data inputs and the use of dynamic modeling for all transient phenomena. To better understand the injection process at the IBDP, a thermo-hydraulic model was employed to perform simulations of the CO\(_2\) injection operations. The study, performed by the Schlumberger Flow Assurance Group who specialize in modeling multiphase fluid flow in non-steady state conditions, used both steady-state and transient analyses to predict pressures, temperatures, and fluid flow in the modeled scenarios.

Key modeling events included initial startup, shutdown, emergency shutdown, and restarts. The model incorporated the detailed surface pipeline topography and wellbore configuration including the casing and tubing layers and surrounding rocks to capture the hydraulic and thermal dynamics. Multiple variables were input to account for ranges of conditions exceeding normal operating parameters (including pipeline breach), and environmental conditions such as extreme air temperature and wind speed.

As a direct result of the transient analyses at IBDP, the model yielded important issues related to the segregation of gas and liquid phase CO\(_2\) during shut-in and potential “slugging” which could occur during restart. The results of the transient analyses also indicated potential operational risks resulting in suggestions for the modification of the pipeline and optimization of the operational procedures to increase both safety and efficiency.

Model Validation

The simulation used at the IBDP was benchmarked with the first set of available injection data after initial startup. Key operating limits – including fracturing pressure, wellhead temperature, and injection pressure – were examined during the operating scenarios. Despite uncertainties in the data upon which the model was based (notably injectivity), a good match of the predicted and measured wellhead temperature was observed. The variation of wind speed (high to low), ambient temperature changes at the wellhead, and injection rate were closely aligned with the simulation results.

Key Findings

- The model was validated against initial data from the field and found to match well.
- Simulated operating scenarios gave a much improved understanding of the transient thermo-hydraulic behavior of the injection process and helped define the operating limits.
- Extreme cold temperatures could have a negative impact on operation of the system and necessitate an increase in compressor discharge temperature or insulation of the pipe.
- With the good match between the measured data and simulation results, previous designs and conclusions were confirmed, and confidence was gained for employing transient analysis for this and future CCS projects.