Abstract

Reliable tracer-based diagnostics are essential for understanding inter-well connectivity, fluid flow behaviour, reservoir heterogeneity, and well integrity in complex oilfield systems. This thesis presents an integrated experimental, analytical, machine-learning, and numerical framework for chemical and gas tracer applications in enhanced oil recovery (EOR), CO_2 storage monitoring, and high-pressure well integrity assessment.

In the first phase, a novel water-soluble chemical tracer, 4-Nitro-N,N-Diphenylaniline (N-TPA), was synthesised and evaluated against the industry-standard tracer 4-Fluorobenzoic Acid (4-FBA). Purity exceeding 98% was confirmed using nuclear magnetic resonance analysis. UV spectroscopy and HPLC methods were established for ppm-level detection in brine. N-TPA exhibited a distinct retention time (≈15.9 min), well separated from commercial FBA-based tracers (≈1.9-9 min), enabling simultaneous multi-tracer detection without chromatographic overlap. Thermal stability (120-180°C), low adsorption on sandstone (<1%), and core-flooding results demonstrated transport behaviour comparable to 4-FBA, confirming its suitability for inter-well tracer tests. In the second phase, CO_2-soluble perfluorocarbon gas tracers, perfluoromethylcyclohexane and perfluoro-1,3-dimethylcyclohexane, were investigated for CO_2-EOR and geological storage. A flame ionisation detector was introduced as a cost-effective alternative to electron capture detection. Aging experiments at 120°C indicated no tracer degradation, while stable water-wet conditions and minimal tracer-rock interaction were observed. Slim-tube tests yielded a CO_2 minimum miscibility pressure of ≈1,500 psi, supporting sweep efficiency evaluation through breakthrough analysis. In the third phase, annular pressure build-up diagnostics were improved using ML-assisted density prediction and a tracer-based HP/HT dual-cylinder setup validated within ≈10% agreement. Finally, CrunchFlow simulations were performed to analyse advection-dispersion transport and predict tracer breakthrough under heterogeneous conditions. Overall, a comprehensive tracer-based studies was established for reservoir characterisation, EOR optimisation, CO_2 storage surveillance, and HP/HT well integrity assessment.

Keywords: Chemical and Gas tracers, Inter-well tracer tests, Thermal stability, Rock adsorption, CO_2-EOR, CCS monitoring, Machine-learning, APB tracer-based mitigation, advection & dispersion base tracer flow simulation.