The Dynamic Interplay of Oil Charge, Basin Dynamics, Caprock Leakage and Gas Generating Biodegradation Produces Heavy and Super-heavy Oil Fields: Examples from Western Canada

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Summary

Worldwide, giant heavy and super heavy oil (bitumen) resources are found near surface (< 1 km depth) in reservoirs that have experienced reservoir temperatures less than 80°C since filling. Heavy oil and bitumen resources develop by extensive in-reservoir oil biodegradation resulting in a wide range of oil properties reflecting a complex interplay of oil charge rate and composition, biodegradation in oil-water transition zones, geologically controlled in-reservoir diffusive mixing and biogenic gas leakage and/or removal over geological time. We show how varying molecular compositions across these reservoirs can be used to identify reservoir compartmentalization and optimize horizontal well placement to maximize production rates and cumulative recovery.

Worldwide, observed compositional and viscosity gradients are maintained by mixing fresh oil charge near the top of reservoirs and heavy oils derived from biodegradation near the base of the reservoirs at rates comparable to the charge rates of oil fields. These compositional variations can be used to assess well placements and reservoir compartmentalization. Across the Alberta oil sands, elevated CO_2, high CH_4 and low C_2+ gas contents, steep oil compositional and viscosity gradients, high aqueous bicarbonate concentrations and isotopic values in equilibrium with enriched $\delta^{13}C_{CO2}$ gas signatures are indicative of persistence of active biodegradation to the present. The dominant reaction pathway of subsurface hydrocarbon biodegradation is methanogenic alkane degradation by CO_2 reduction, which produces large volumes of isotopically light methane and heavy CO_2 in solution gas (up to 6 times reservoir volumes). This generated biogenic gas should have displaced oils from the traps; however, thin or absent gas caps in shallow heavy oil reservoirs and degraded oil in many oilfield caprocks suggest seal leakage is common.

The paucity of large gas caps, evidence of methane-rich and sometimes oil charged cap rocks, anomalously high formation water alkalinity and enriched aqueous $\delta^{13}C_{carbonate}$ values in shallow Alberta biodegraded oil reservoirs point to leaky reservoir top seals and dissolution of biogenic CO_2 into the water phase. Indeed we consider top seal leakage of biogenic gas is required to produce heavy oil and super heavy oil fields to maintain active biodegradation at the oil-water contact by transport of nutrients through the water phase. This would otherwise be curtailed by petroleum completely filling the reservoir to the underseal. The abundance of heavy oil and super heavy oil in shallow reservoirs reflects leaky reservoir seals at these depths and systematic removal of large volumes of gas generated by petroleum biodegradation and sometimes spill of oil.

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