The Role of Hysteretic Two-Phase Flow Processes During Capillary Leakage

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Present-day hydrocarbon migration simulators treat capillary leakage as a symmetric process, that is initiation and end of leakage occur at the same hydrocarbon column height and the relationship between column height and leakage rate (or effective permeability to the leaking phase) is the same during drainage and imbibition. In exploration terms, drainage corresponds to both trap fill and establishment of leakage pathways through capillary seals while imbibition corresponds to both trap emptying and successive closure of leakage pathways. However, two-phase and three-phase fluid flow in porous media is hysteretic.

Hydrocarbon pressure in a trap has to overcome a critical pressure, the breakthrough pressure Pbr, to initiate capillary leakage. Experiments in a glass bead trap model show that a different critical pressure, the snap-off pressure Psn, exists at which leakage will stop. Results from the trap model experiment yield values of approximately 0.35 for the ratio Psn/ Pbr. This indicates that traps which undergo capillary leakage will retain hydrocarbon columns of approximately 35% of the breakthrough column height if the seal remains water-wet during leakage.

For identical hydrocarbon column heights, effective permeability to oil or gas (and thus leakage rates) will be higher during imbibition than during drainage. This impacts on the steady-state hydrocarbon column height for a given inflow rate. Application of available capillary pressure data for seal material while neglecting hysteretic processes results in predictions with too high leakage rates and too low estimates of the possible static and dynamic hydrocarbon column height in a trap. This work was carried out at SINTEF Petroleum Research, Trondheim, Norway.