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## Characteristics and New Scaling for Forced Imbibition Based on Low-Field Nuclear Magnetic Resonance Measurements

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Hydraulic fracturing is an effective method to improve oil recovery by injecting massive fracturing fluid to create complex fracture networks. After that, the well is commonly shut down for a period to promote water uptake and appropriate shut-time is of vital importance. One effective way to predict shut-in time is to combine experimental results of spontaneous imbibition (SI) and dimensionless time model. But the physical simulation of SI is commonly performed at atmospheric pressure and the characteristics of imbibition considering the effect of confining pressure (named as forced imbibition, FI) is often neglected. In this study, pore size distribution in tight core samples was firstly obtained in combination of high pressure mercury intrusion (HPMI) measurements and low-field nuclear magnetic (LF-NMR) measurements and oil distribution in tight core samples was discussed correspondingly. And then experiments of SI and FI were performed in a sealed and pressurized system and oil recovery was measured using a LF-NMR system. Finally, a new scaling law for FI was proposed to predict shut-in time in field scale.

The results showed that 95.94% - 98.12% of the oil was distributed in nano-pores ( $0.1 \text{ ms} < T_2 < 100 \text{ ms}$ ) of core samples, and the average amount of oil in nano-micro-pores, nano-meso-pores and nano-macro-pores were 34.04%, 40.15% and 22.75%, respectively. Ultimate oil recovery of core samples were 22.41%, 44.41%, 57.27%, 61.84% and 62.82%, respectively, as confining pressure increased from 0 psi to 2175 psi. The improved oil recovery of FI was mainly associated with the drop of effective pore radius as a function of confining pressure. Finally, a new scaling law for FI was proposed to calculate shut-in time in field scale by combining experimental results of FI, Mason's dimensionless time (tD) model and Leverett's capillary model.

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