# Unsteady State Relative Permeability Curves Derived from Saturation Data Spatially and Temporally Resolved Using Magnetic Resonance Imaging

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**Introduction:** Relative permeability (RP) curves describe the displacement of immiscible fluids in rock samples. These curves, ordinarily time-consuming and difficult to measure, are critical for petroleum reservoir management. They help guide decision-making and permit optimal petroleum recovery. Spatial and temporal measurements of fluid content are essential for investigation of displacement phenomena. Pure phase-encoding with SE-SPI [1] provides spatial and temporal proton density of fluids sufficiently precise to permit evaluation of partial derivatives. This quantitative information can be introduced in governing equations for immiscible displacement of fluids to give important properties: capillary dispersion, $D_c$ and oil fractional flow, $f_o$ [2] which contain RP information.

$$\phi \frac{\partial S_o}{\partial t} + v_t \frac{\partial f_o}{\partial S_o}\frac{\partial S_o}{\partial y} = \frac{\partial}{\partial y}\left(D_c \frac{\partial S_o}{\partial y}\right) \quad \text{Eq. 1}$$

Where $\phi$ is porosity and $v_t$ is total flow rate.

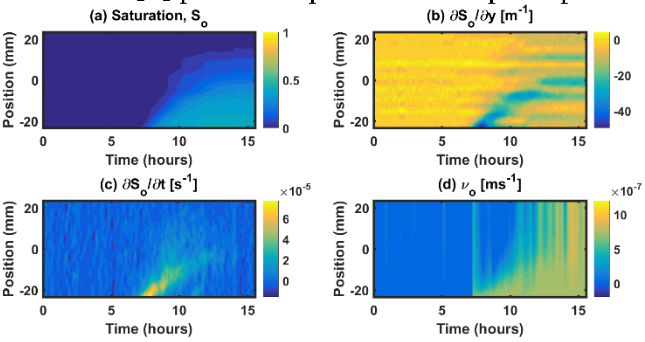


Fig. 1: (a) Oil saturation map and its partial derivatives with respect to (b) position and (c) time. (d) Oil flow rate map for volumetric flow rate, $v_t$ of 0.250 $mm^3/s$.

**Methods:** Displacement of water by oil in Bentheimer sandstones was monitored at 0.2 T with SE-SPI. The MRI profiles were processed to determine RP by: extracting the proton density, converting the data to saturation profiles, $S_o$ (Fig. 1a), calculating saturation partial derivatives (Fig. 1b and 1c), determining flow rate profiles (Fig. 1d), stating all variables as functions of saturation, and finding RP curves by pointwise minimizing the discrepancy of $D_c$ and $f_o$ with the data points. Following this method, capillary dispersion, oil fractional flow, and RPs can be derived versus saturation.

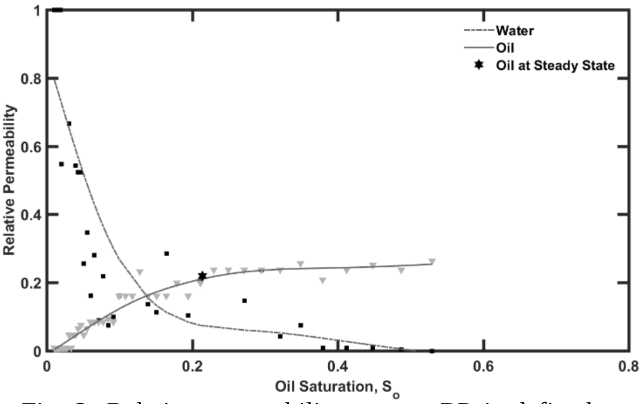


Fig. 2: Relative permeability curves. RP is defined as ratio of effective permeability of a phase in presence of another phase to absolute permeability of the rock.

**Results and Discussion:** The saturation map, Fig. 1a, shows the importance of capillary forces in retention of water in small pores at the end of the core plug. Derivatives, Fig. 1b and 1c show a slanted feature indicating the evolution of the front in time and space. The shape of the propagating front is influenced by capillary forces, whereas, its velocity is influenced by the mobility and RP of the two phases. The RPs are shown in Fig. 2. As oil saturation increases, the water RP decreases from 1 to zero at $S_o = 0.46$ and oil RP increases to a value notably less than 1, indicating the reduction of effective permeability as a result of presence of another phase. A steady state RP measurement at the end of displacement confirms the prediction of RP curves.

**Conclusion:** A method has been derived for calculating RP curves based on evolution of saturation profiles. Such curves are very valuable special core analysis measurements, difficult to measure by conventional methods.

**References:** [1] Petrov, J. Magn. Reason. (2011). [2] Goodfield. SPE. (2001). [3] Bacri, J. Phys. Lett-Paris. (1985).