
● Short Communication

ESTIMATION OF POROUS MEDIA FLOW FUNCTIONS USING NMR IMAGING DATA

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Nuclear magnetic resonance (NMR) imaging data measured during two-phase displacement experiments on porous rock core samples are used in an inverse problem methodology to estimate the two-phase flow functions relative permeability and capillary pressure. Nuclear magnetic resonance imaging data contain valuable information about variation of fluid states within the core sample and are therefore important for accurate estimation of these properties. A precise agreement between measured data, which also includes pressure drop across the core samples, and the data simulated by using the estimated flow functions is found, indicating accurate flow function estimates. © 1998 Elsevier Science Inc.

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INTRODUCTION

Relative permeability and capillary pressure functions, commonly referred to as flow functions, are basic properties used to describe the flow of multiple fluid phases through porous media. The flow functions are essentially defined in a mathematical model for multiphase flow through porous media and have to be determined from data measured during flowing experiments on core samples by solving an appropriate inverse problem. This is a particularly challenging problem because the flow functions are functions of one of the state variables (saturation) and the mathematical model for multiphase flow through porous media is typically composed of coupled partial differential equations.

The accuracy with which the flow functions can be estimated is limited by experimental design, which includes the manner in which the experiment is conducted, the data to be measured, and the accuracy of measurements. Previously, data measured outside the sample, such as production and pressure drop, were the only data used in estimation of flow functions. Recent attempts at improving the experimental design were directed toward stepping up injection rates to increase the pressure information (Urkedal, H.; Ebeltoft, E.; Nordtvedt, J.E.;

Watson, A.T. A new design of steady-state type experiments for simultaneous estimation of two-phase flow functions, manuscript in review.). Modern imaging methods provide a means to measure fluid saturations throughout the sample. This can provide significant information regarding fluid states within the sample so that flow functions can be accurately resolved. Previous attempts at including saturation data within the estimation^{1,2} (Ref. 2 used x-ray computed tomography scanning and Ref. 3 used γ -ray attenuation) have not achieved good agreement between the measured data and the corresponding data simulated using estimated flow functions and, thus, the methodology has not been validated.

In this paper, we use saturation data measured using nuclear magnetic resonance (NMR) imaging data in estimation of two-phase flow functions. A two-phase displacement experiment is conducted on a Texas Cream limestone sample. Saturation profiles are measured using NMR imaging.^{3,4} The generalized, regression-based approach⁵ is used for estimating the flow functions. We report a fairly precise agreement between measured and simulated data, thus validating the estimation methodology.

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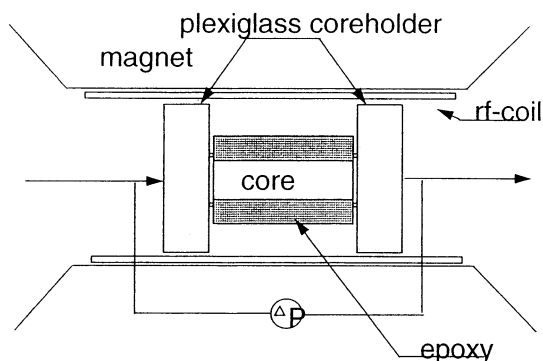


Fig. 1. Schematic of the experimental setup.

Table 1. Core and fluid properties for the primary drainage experiment

Water viscosity (cP)	1.26
Oil viscosity (cP)	3.34
Core length (cm)	4.9
Core diameter (cm)	2.5
Porosity (%)	26.6
Absolute permeability (mD)	10.2
Initial water saturation	1.0
Injection rates (cc/min):	
Water	0.0
Oil	0.05

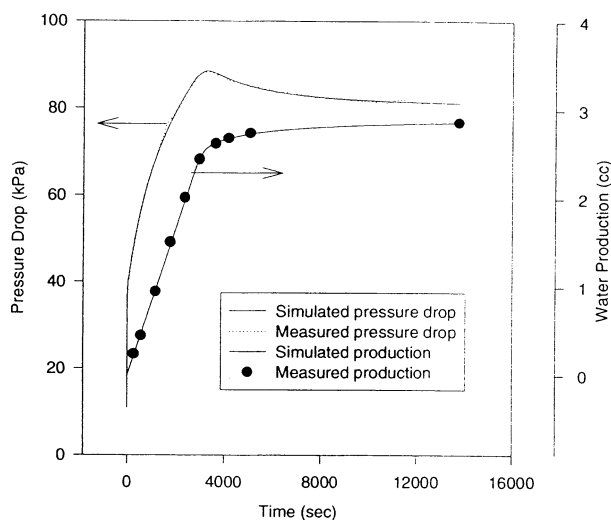


Fig. 2. Measured and simulated pressure drop and production.

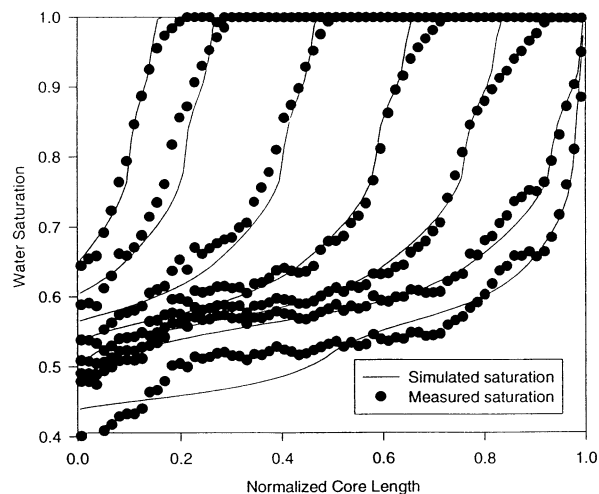


Fig. 3. Measured and simulated water saturation profiles at various times.

EXPERIMENTAL DETAILS AND RESULTS

Cylindrical samples were laterally sealed using epoxy (Stycast 2651) and mounted in plexiglass coreholders with O-rings to conduct the displacement experiments. The schematic of the apparatus is shown in Fig. 1. All NMR measurements were conducted with a GE 2-Tesla CSI-II imager/spectrometer with 31-cm magnet bore and equipped with a 20 G/cm shielded gradient coil and a birdcage radiofrequency coil. Hexadecane was used as the oleic phase and deuterium oxide (D_2O) was used as the aqueous phase. Protons are imaged so that only the oil phase is observed.

The data measured during the experiment included the

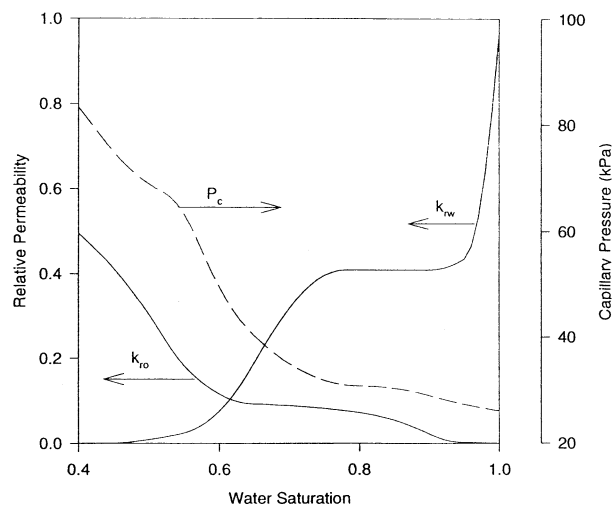


Fig. 4. Estimated flow functions.

pressure drop across the sample and oil-saturation profiles. The water production was calculated by material balance about the initial state. The details of the rock sample properties and the displacement process are tabulated in Table 1.

Figures 2 and 3 show the measured and simulated data. It can be noted that a saturation of 0.4 is reached at the end of the displacement and, therefore, the flow functions can be reliably estimated only for the water saturation range 0.4–1.0. The estimated flow functions are shown in Fig. 4. It can be seen that the agreement between measured and simulated data is quite good, indicating that the flow-function estimates are consistent with the measured data.

REFERENCES

1. Mejia, G.M.; Mohanty, K.K.; Watson, A.T. Use of in-situ saturation data in estimation of two-phase flow functions in porous media. *J. Petroleum Sci. Eng.* 12:233–241; 1995.
2. Chardaire-Riviere, C.; Chavent, G.; Jaffre, J.; Liu, J.; Bourbiaux, B.J. Simultaneous estimation of relative permeability and capillary pressure. *SPE Form. Eval.* 7:283–289; 1992.
3. Chen, S.; Qin, F.; Watson, A.T. Determination of fluid saturations during multiphase flow experiments using NMR imaging techniques. *AIChE J.* 40:1238–1247; 1994.
4. Kulkarni, R.N.; Watson, A.T. Robust technique for quantification of NMR imaging data. *AIChE J.* 43:2137–2140; 1997.
5. Watson, A.T.; Richmond, P.C.; Kerig, P.D.; Tao, T.M. A regression based method for estimating relative permeabilities from displacement experiments. *SPE Res. Eng.* 3:953–958; 1988.