# TECHNIQUES FOR RELATIVE PERMEABILITY CALCULATIONS : A CLOSER LOOK

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## Introduction

Relative permeability is one of the key factors in Reservoir Engineering calculations to simulate multiphase behaviour in porous media. In the laboratory, relative permeabilities are computed from two different experiments: the Steady State (SS) experiment and the UnSteady State (USS) experiment. This paper deals with USS experiments interpretation.

The analytical interpretation of such experiments allows a quick calculation of the relative permeability but: it focuses on the saturation range swept after breakthrough; the capillary pressure effects are usually neglected[1]. Nordtvedt[2] showed how hazardous such an assumption can be.

The introduction of simulation and inversion tools has made it possible to include the capillary pressure effects in the relative permeability computation. Besides, in situ saturation measurements provide alternative data for a better interpretation[3].

This study aims at: evaluating the added value of the numerical interpretation and studying the impact of the in situ saturation data inclusion in the inversion data set.

## Toolkit for our inversion study

### Methodology

The main idea was to synthesise laboratory type data with known relative permeability and capillary pressure properties and to perform an inversion calculation on two data sets: one with and one without in situ saturation data. Results of the inversion were then utilised to simulate the experiment again. Both the results of the inversion and the results of the simulation were finally compared through different criteria.

The simulated experiment is a water injection at a constant rate in an oil saturated core sample in the presence of irreducible water saturation.

### Initial data set

Core sample data are summarised in Table 1:

| Length [cm] | 7 | Permeability [mD] | 35 |
|---|---|---|---|
| N grid blocks | 140 | Initial water saturation [frac.PV] | 0.20 |
| Area [cm$^2$] | 11.3 | Core orientation | Vertical |
| Porosity [frac.] | 0.24 | Flow orientation | Bottom to top |
| Compressibility [KPa$^{-1}$] | $10^{-8}$ | | |

*Table 1: Core sample data*

Two fluids velocities were tested: 10 and 0.3 meter/day.

The fluids densities were kept constant. The oil viscosity only was changed and thus the viscosity ratio. Table 2 summarises these data.

The SCAL data were designed in order to simulate two water wet situations, one with low and one with high capillarity, and one oil wet situation were simulated. The relative permeability curves are Corey type curves. Table 3 summarises their end points and exponents. The capillary pressure curves were derived from the simulated porous media structure and its porosity and permeability and wettability characteristics.

|  | Water | Oil |
|---|---|---|
| Density [kg/m$^3$] | 1090 | 840 |
| Viscosity [$10^{-3}$ Pa.s] | 1 | 5 or 0.3 |

*Table 2: Fluids data*

|  | Water wet | Oil wet |
|---|---|---|
| Krw end point | 0.3 | 0.82 |
| Krw exponent | 1.5 | 3 |
| Kro end point | 0.9 | 0.5 |
| Kro exponent | 3 | 1.5 |

*Table 3: Relative permeability data*

**Validation criteria for the inversion process**

- Accurate reproduction of the breakthrough time and of the cumulative oil production and pressure drop after and before the breakthrough by the post-inversion simulation.
- Relative permeability and capillary pressure curves similar to the initial ones in the range of saturation investigated.
- Accurate reproduction of the water saturation and water pressure profiles by the post-inversion simulation. This criterion ensures the realisation of the first one and is even more severe because it considers what is happening inside the sample.

## Impact study on the inversion process

Five parameters were selected as likely to impact the inversion quality: the inversion technique (JBN[1], numerical) the content of the input (with or without in situ saturation observations), the experimental parameters (SCAL data set, fluids velocity, viscosity ratio), the model initialisation and the solution curves representation (spline curves in our case).

The last two points were not studied in the frame of this work but identified as valuable sources of improvement for the inversion quality. The first three points are developed below.

### Impact of the inversion method

Our conclusion is that, the numerical inversion technique gives better results than the JBN technique. This fact is already very well documented[2,4].

### Impact of the input content

Figure 1 shows how, on the same water wet case, the introduction of saturation profiles in the inversion data set improves the match on the saturation profiles and the accuracy of the water relative permeability computation. However, the results of the inversion do not perfectly match the input relative permeability data. Please note that in the 2 cases, the match on the cumulative oil production and on the pressure drop was perfect.

The conclusion is that saturation profiles are very valuable for improving the numerical inversion results. However, the simulator seems to need more information to compute relative permeability and capillary pressure that simulate the initial water pressure profiles.
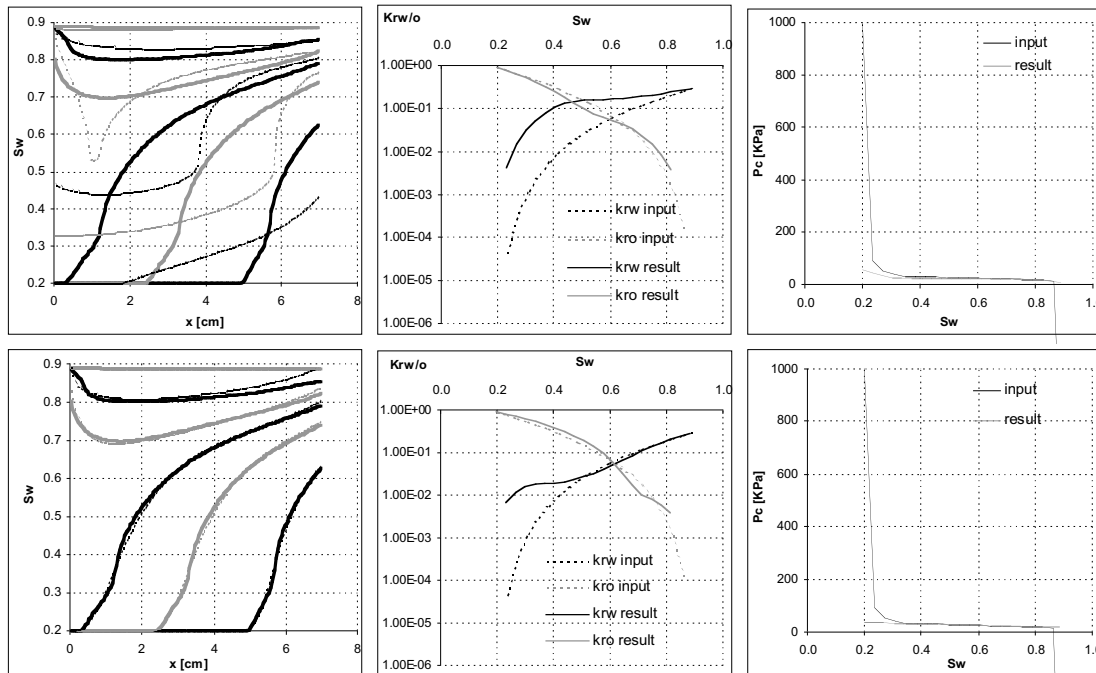
*Figure 1: Impact of the saturation profiles on the inversion (cont. bold line: initial; dotted thin line: Num)*
*Top: without; bottom: with saturation data in the inversion input data set. Low velocity; low viscosity ratio case.*

## Impact of the experimental data

SCAL data

Whatever the technique utilised for the inversion, the water wet case with low capillarity is the most favourable.

The inversion on the Oil wet cases would have been much more accurate if multiple increasing rates displacement experiments were set up instead of single rate experiments. Multiple rate experiments allow investigating a broader saturation range (lower *Sor*) and different equilibrium conditions (i.e. different *Sw(Pc)* values).

Fluids velocity

The inversion results are more accurate with high fluids velocity experiments than with low fluids velocity experiments if the capillary pressure is not independently measured.

Impact of the viscosity ratio

A high viscosity ratio should be preferred in Water wet situations and a low viscosity ratio should be preferred in Oil wet situations. This conclusion only applies if the capillary pressure is not independently measured or in the absence of alternative source of pressure information.

## Water relative permeability at low water saturation: general remark and consequences

In Water wet cases, the inversion results that are the most inaccurate are the capillary pressure and the water relative permeability at "low" water saturation values. Figure 2 compares the inversion results in two Water wet situations with low capillarity, one at high and one at low fluids average velocity.

The curves presented here are the velocity curves of each saturation element ($dx/dt|S_w$ ). They are computed from the relative permeability curves for a specific average fluids velocity (30 cm/day). The straight line crossing the curves is the shock front velocity. Its intercept with the velocity curve is the top front saturation.
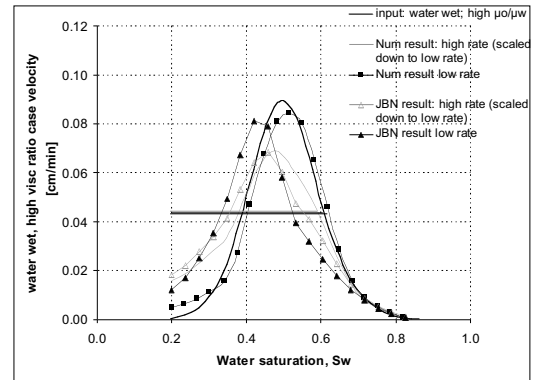


Figure 2: Saturation velocity curve

Obviously neither the shock front velocity nor the top front saturation do differ too much from one numerical inversion case to the other. For comparison purposes, please note that the JBN interpretation results in a top front saturation underestimation despite its good match on the front displacement velocity.

## Conclusions

The main conclusions are:
1. Numerical inversion techniques should be preferred to the JBN analytical technique.
2. In situ saturation measurements are very valuable for computing the relative permeability. However, in situ saturation data are not enough to ensure a unique and accurate solution if capillary pressure is unknown. The input of an independently measured capillary pressure is necessary to achieve this goal. If such data are not available, the overall inversion quality is better for high displacement velocity experiments.
3. The largest inaccuracy concerns capillary pressure, and the water relative permeability at low water saturation. Its consequences are negligible with numerical inversion.

Some parameters such as the capillary pressure initialisation and the solution curves spline model were not investigated in this study but identified as valuable sources of improvement for the inversion quality.

Finally, this paper only deals with the interpretation of experiments on homogeneous samples. If heterogeneous samples were concerned, numerical simulation would be the only tool available for interpreting the experiments.

## References
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