RELATIVE PERMEABILITIES AND RHEOLOGY OF POLYMERS IN SANDSTONE CORES

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INTRODUCTION

This work is a part of a research project performed in the years 1993-1996 by three project partners and supported by the European Community [2]. Its main objective is the quantification of additional oil recovery by polymer flooding in heterogeneous reservoirs.

The relative permeabilities of kerosene/artificial brine and kerosene/xanthan solution in Bentheimer and Berea sandstone have been investigated at different temperatures according to the Penn. State technique.

In situ rheology of xanthan has been studied in terms of aqueous phase mobility with and without oil content in Berea and Bentheimer sandstones cores. The influence of temperature and xanthan concentration on the viscosity yield curves (rheometer) and apparent viscosity yield curves (pore space) have been investigated and correlated.

1 RELATIVE PERMEABILITY MEASUREMENTS

Comparison of the relative permeabilities before and after polymer contact for Bentheimer sandstone show a minor permeability reduction to brine, see Figure 1. The relative permeability reduction to brine shows a minor but relevant temperature dependence. The reduction decreases with increasing temperature. The influence of polymer treatment on the relative permeabilities to oil is found to be negligible in the whole temperature range.

In case of Berea sandstone the relative permeability reduction to brine after polymer contact is more pronounced than in case of Bentheimer sandstone. Contrary to Bentheimer sandstone the k_{ro}-values are reduced by polymer treatment, see Figure 2. This different behavior of the relative permeabilities to oil could arise from a different wettability behavior of both sandstones.

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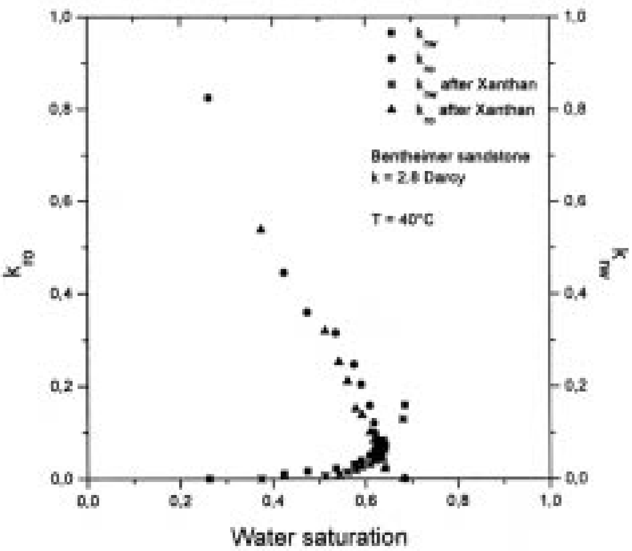

Figure 1

Relative permeabilities of artificial brine/kerosene before and after polymer contact at 40°C for Bentheimer sandstone.

This assumption seems to be supported by the finding that with increasing temperature the relative permeability reduction to oil decreases and can be neglected at 70°C, see Figure 3.

A striking feature of Berea sandstone is the extremely high relative permeability to oil at connate water saturation S_{wi} before xanthan treatment.

2 RHEOLOGICAL BEHAVIOR OF XANTHAN

The rheological behavior of xanthan is described by a modified Carreau equation comprising shear rate dependent correction parameters, P(1) and P(2), for the zero-shear-rate viscosity (η_0) and the relaxation time (Θ).

$$\eta = \frac{\eta_0 - P(1)*\dot{\gamma}}{\left\{1 + \dot{\gamma}^2 * \left[\frac{P(2)}{\dot{\gamma}} + \Theta\right]^2\right\}^{((1-n)/2)}}$$

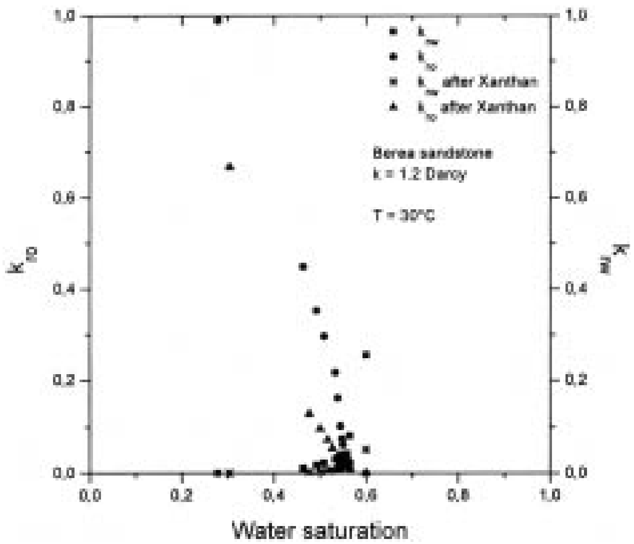

Figure 2

Relative permeabilities of artificial brine/kerosene before and after polymer contact at 30°C for Berea sandstone.

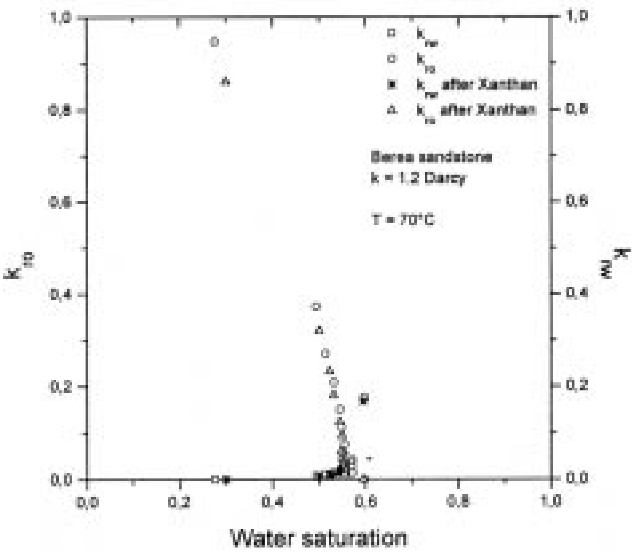

Figure 3

Relative permeabilities of brine/kerosene before and after polymer contact at 70°C for Berea sandstone.

In case of the *in situ* rheological behavior, the wall shear rate is calculated using an equation given by Chauveteau [1].

Contrary to the rota-viscometer measurements no well-defined Newtonian plateau could be observed. For Berea sandstone, however, the transition zone between the Newtonian and power-law regime, could be determined.

The power-law index, determined from the yield curves of the apparent viscosity of xanthan at different concentrations, is plotted in Figure 4 for different temperatures. Within the limits of the experimental error a linear dependence on the xanthan concentration is found.

A comparison of the power-law index obtained from the rheological behavior in sandstones and that determined by rota-viscometer measurements is given in Figure 5 as a function of polymer concentration. A similar concentration dependence was observed by Sorbie and Huang [3]. The power-law index observed seems to increase with increasing permeability and shows the highest values in the rheometric measurements. This behavior could be attributed to the different influence of the shear rate profile on the macromolecule conformation in the pore space and in the rota-viscometer and hence on the form of the yield curve.

The behavior of the Carreau parameters n, η_0 and Θ as a function of temperature and concentration is similar to that found by rota-viscometer measurements.

The residual oil exerts no specific influence on the *in situ* rheological behavior of xanthan going beyond the reduction of the pore space available.

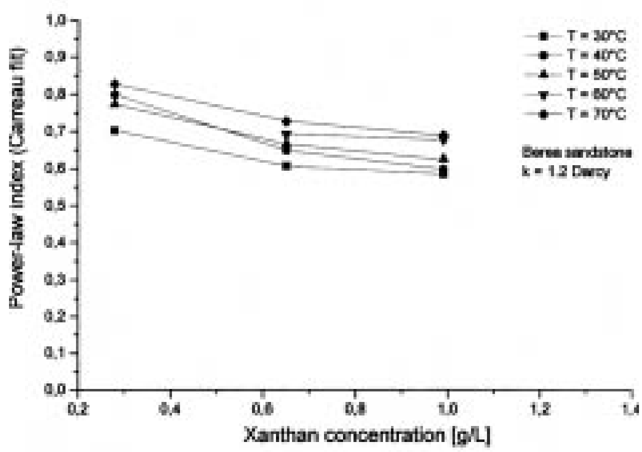

Figure 4

Power-law index as a function of xanthan concentration at different temperatures for Berea sandstone.

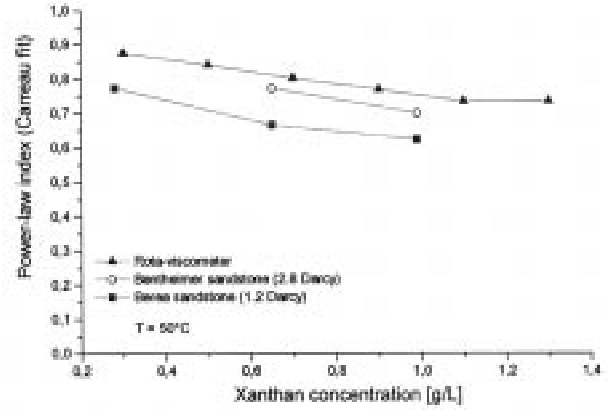

Figure 5

Power-law index as a function of xanthan concentration at 50°C.

CONCLUSIONS

A slight permeability reduction to brine after polymer contact was found for both sandstones investigated. The reduction of the relative permeability to oil by polymer treatment depends on the sandstone properties as well as on the temperature.

The best fit of the yield curves of the rheometric and the *in situ* rheological measurements is found by including correction terms accounting for a weak dependence of the Carreau parameters η_0 and Θ on the shear rate. The rheological parameters of xanthan in porous medium increase with increasing permeability.

NOMENCLATURE

k	:	permeability
k_{ro}	:	relative permeability to oil
k_{rw}	:	relative permeability to water
n	:	power-law index
P(1), P(2)	:	correction factors (modified Carreau equation)
S_{wi}	:	irreducible water saturation
$\dot{\gamma}$	:	shear rate
η	:	viscosity
η_0	:	zero-shear rate viscosity
Θ	:	relaxation time

REFERENCES

1 Chauveteau G., (1982), Rodlike polymer solution flow through fine pores: Influence of pore size on rheological behavior. *Journal of Rheology*, **26**, 2, pp. 111-142.

2 Kessel D., I. Swaid and K. Wilke (1996), Quantification of additional oil recovery by polymer flooding in heterogeneous reservoirs. *Final Report* JOU II-CT92-0242, pp. 5-35, August 1996.

3 Sorbie K.S. and Y. Huang (1991), Rheological and transport effects in the flow of low-concentration xanthan solution through porous media. *J. Colloid Interface Sci.*, 145, pp. 74-89.

Final manuscript received in January 1997