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A NOVEL APPROACH TO MODELING UNSTABLE EOR DISPLACEMENTS

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OBJECTIVES

This research is aimed at developing a methodology for predicting the performance of unstable displacements in heterogeneous porous media. A performance prediction approach that integrates numerical modeling with laboratory experiments will be developed.

Flow visualization experiments will be performed on laboratory corefloods using X-ray computed tomography (CT) and other imaging technologies to map the insitu fluid saturations in time and space. A systematic procedure will be developed to replicate the experimental image data with high-resolution numerical models of the displacements.

SUMMARY OF TECHNICAL PROGRESS

An initial attempt was made to simulate an unstable CT experiment using an in-house numerical reservoir simulator. The experiment was an unstable immiscible waterflood of a heavy oil in a strongly water-wet sandpack. The pertinent data for the experiment, which were presented in a previous report, are shown in Table 1 (Peters, 1991).

The simulation was performed with a 2-D finite difference model developed in-house (Khataniar, 1991). Instead of matching the recovery curve from the experiment as is traditionally done in the literature, we focused on matching the saturation profiles and the CT image data in order to replicate the displacement process within the porous medium. Where possible, the average properties of the numerical model were the same as in the experiment. These include the oil-water viscosity ratio, the absolute permeability and the porosity of the medium. The adjustable parameters in the model were the degree of heterogeneity of the porous medium and the relative permeability curves. A random permeability field was used to simulate the sandpack. The degree of heterogeneity was characterized by the Dykstra-Parsons coefficient of the permeability field. The degree of heterogeneity and the relative permeability curves were adjusted systematically to match the saturation profiles inside the core.

Results and Discussion

Figure 1 compares the simulated and experimental saturation profiles in a simulated porous medium with a Dykstra-Parsons coefficient of 0.576. Plotted on the figure are the normalized water saturation profiles defined as

$$S_n = \frac{S_w - S_{wi}}{1 - S_{wi}} \tag{1}$$

Several observations can be made. The overall agreement between the simulated and the experimental saturation profiles was good. Not only were the saturation profiles in good agreement, the breakthrough time also was correctly predicted. However, the agreement in the saturation profiles was better before breakthrough than after breakthrough. After breakthrough, the simulated saturations were somewhat higher than the experimental saturations.

Figure 2 compares the simulated and experimental recovery curves. As with the saturation profiles, it shows better agreement before breakthrough than after breakthrough. However, the deviation between the two curves after breakthrough was less than 4%, which indicates good agreement between the simulation and the experiment. It may be observed that after breakthrough, the simulated and experimental recovery curves were essentially parallel, with the simulation predicting a higher recovery curve than the experiment. The fact that the slopes of the recovery curves were the same indicates that the essence of the unstable displacement process was successfully captured in the simulation. Additional fine-tuning of the model parameters would further improve the agreement.

Figure 3 shows the relative permeability curves used to obtain the above results. The shape of the curves are in agreement with those typically associated with strongly water-wet media. These curves are modelled by the following equations:

$$K_{rw} = K_{rw}\left[\frac{S_w - S_{wi}}{1 - S_{wi} - S_{or}}\right]^n \tag{2}$$

$$K_{ro} = K_{or}\left[\frac{1 - S_w - S_{wi}}{1 - S_{wi} - S_{or}}\right]^m \tag{3}$$

with $S_{wi} = 0.15$, $S_{or} = 0.20$, $K_{wr} = 0.8$, $K_{or} = 0.9$, $n = 0.49$ and $m = 3.5$.

Figures 4 and 5 show the experimental and simulated saturation images at two time steps. A qualitative comparison of the saturation images shows how the simulation may be improved. First, the displacement front in the simulation is more irregular than in the experiment. This defect can be corrected by reducing the variability in the permeability field and by including capillary pressure in the simulation. These changes will tend to smooth and spread the simulated front in a manner similar to the experiment.

The images also show that the inlet boundary conditions for the simulation and the experiment were different. The initial radial ingress of the injected water in the experimental image reflects the point source nature of the experimental inlet boundary condition. In the simulation, however, the injection fluid was distributed over the entire inlet face of the porous medium. Thus, CT images of the displacement can reveal the source of the discrepancies between the simulated and experimental results. They also are helpful in pointing the way to how the simulation may be improved.

Concluding Remarks

The above results show that an unstable immiscible displacement can be simulated successfully by use of the appropriate relative permeability curves and by including heterogeneity in the model. The results also demonstrate that CT imaging experiments can be extremely useful in guiding the development of numerical models for predicting the performance of unstable displacements.

Nomenclature

K_{ro} = Relative permeability to oil
K_{rw} = Relative permeability to water
K_{or} = End-point relative permeability to oil
K_{rw} = End-point relative permeability to water
m = Relative permeability exponent for oil
n = Relative permeability exponent for water
S_n = Normalized water saturation
S_{or} = Residual oil saturation
S_w = Water saturation
S_{wi} = Connate water saturation

REFERENCE

1. Khataniar, S.: A Numerical Study of the Performance of Unstable Displacements in Heterogeneous Media, PhD Dissertation, The University of Texas, August 1991.
2. Peters, E.J.: "A Novel Approach to Modeling Unstable EOR Displacements," DOE Quarterly Report, January - March, 1991.

TABLE 1

EXPERIMENTAL CONDITIONS

Type of Displacement:	Immiscible
Porous Medium:	
Type:	Unconsolidated Sandpack
Length:	54.5 cm
Diameter:	4.8 cm
Absolute Permeability:	9.3 darcies
Porosity:	30.8%
Initial Water Saturation	15.0%
Fluids:	
Displacing Fluid:	Distilled Water + 10% $BaCl_2$
Density of Displacing Fluid:	1.088 g/cm^3
Viscosity of Displacing fluid:	1.14 mPa.s
Displaced Fluid:	Mineral Oil
Density of Displaced Fluid:	0.960 g/cm^3
Viscosity of Displaced Fluid:	103.4 mPa.s
Viscosity Ratio:	91
Interfacial Tension:	26.7 dyne/cm
Darcy Velocity:	8.5×10^{-5} m/s
Stability Number:	271
Gravity Number:	8987
Breakthrough Recovery:	32.9%

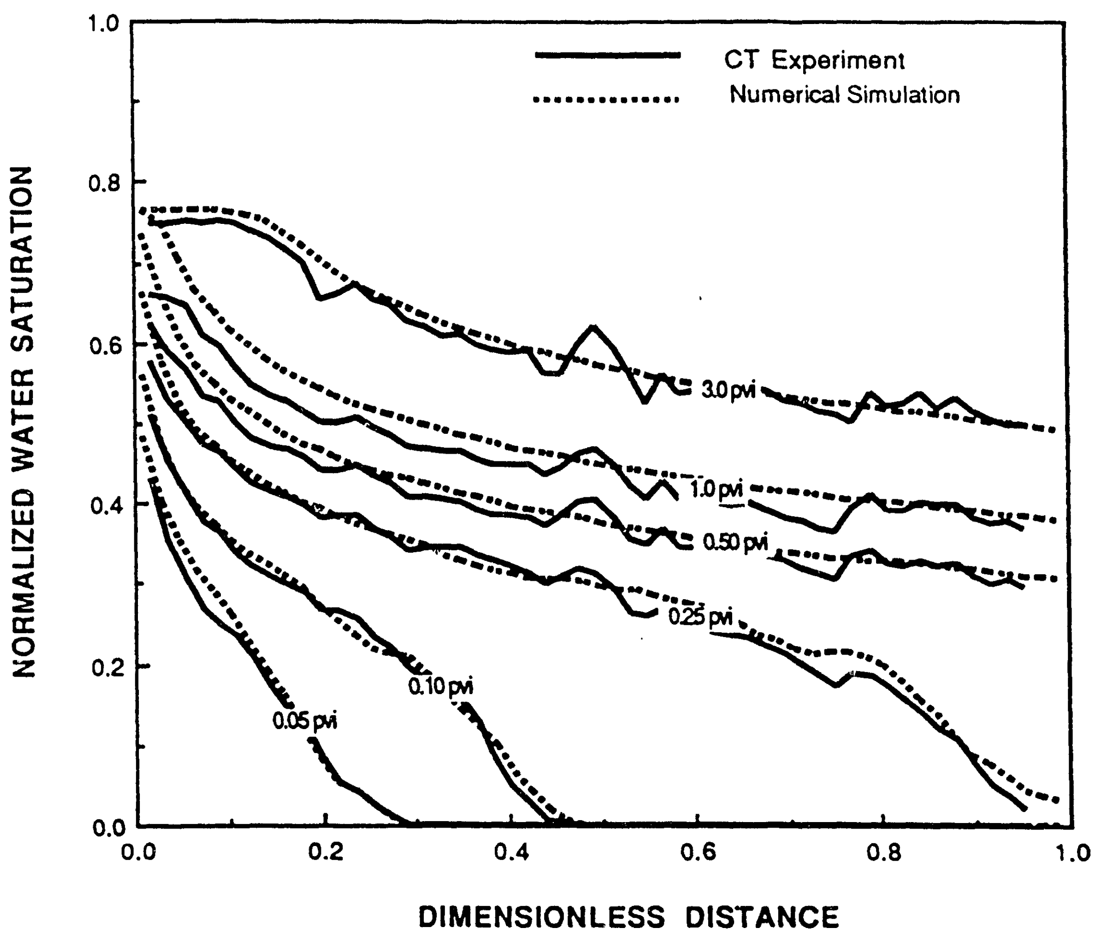


Figure 1 - A Comparison of the Saturation Profiles

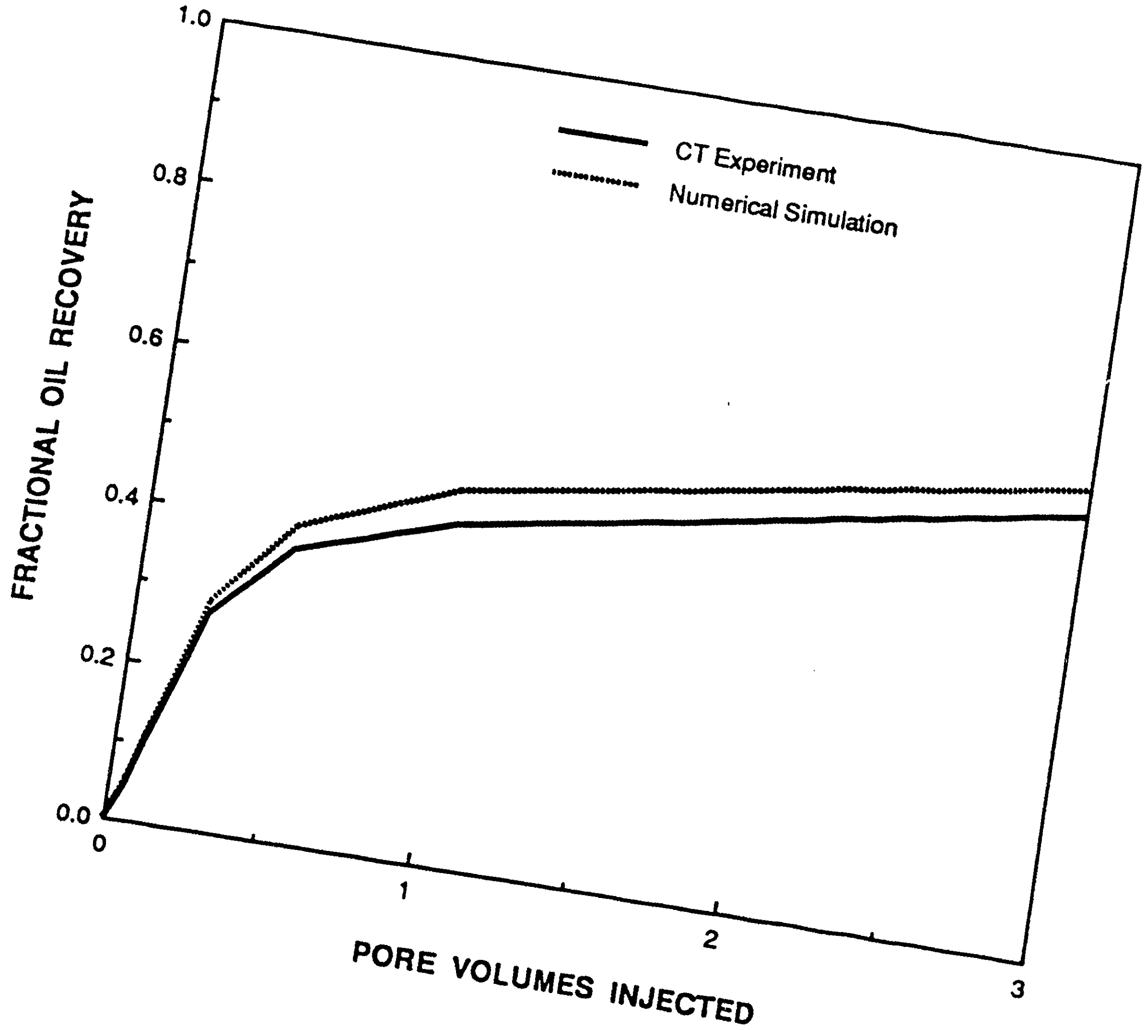


Figure 2 - A Comparison of the Recovery Curves

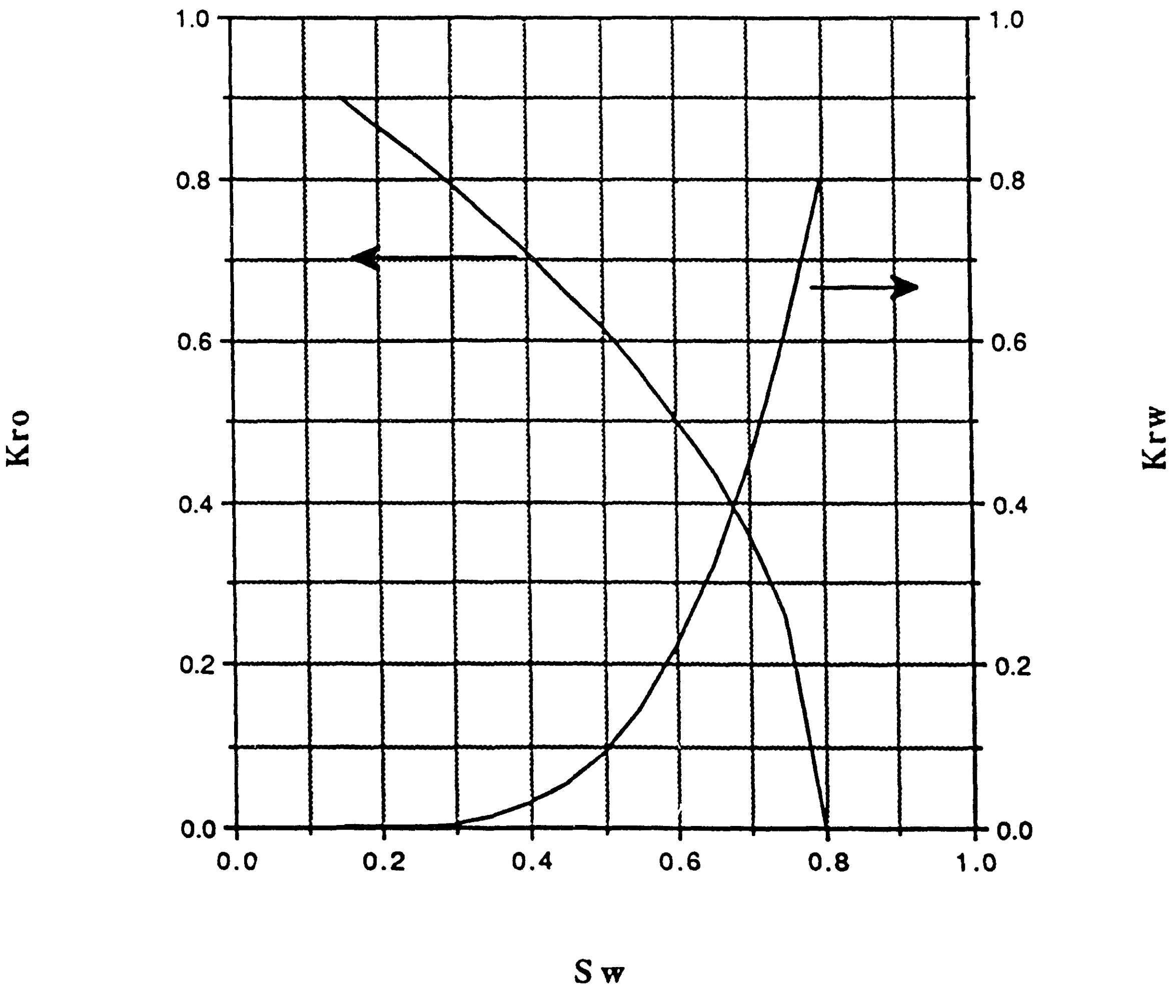
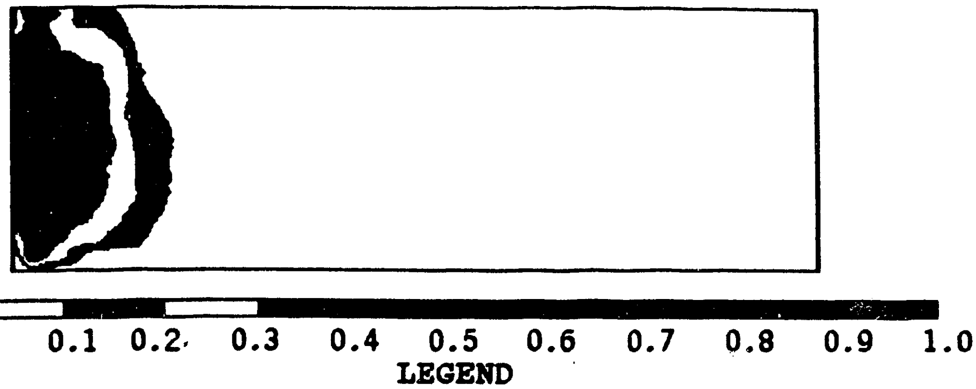
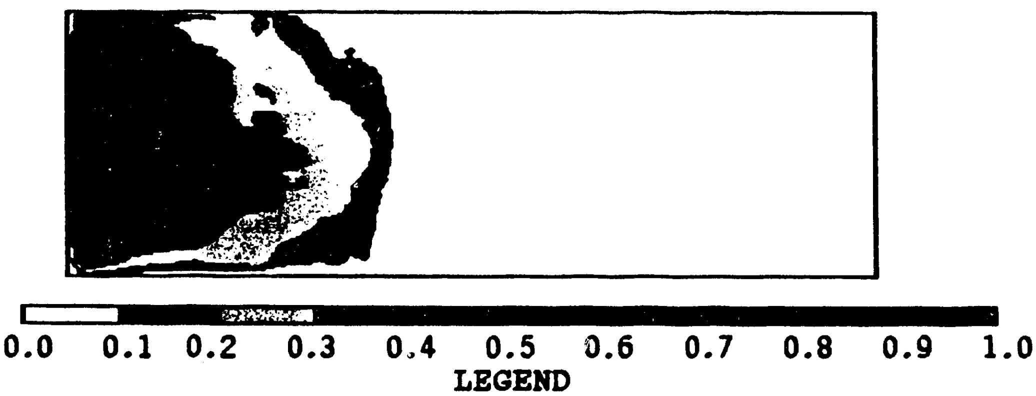


Figure 3 - Relative Permeability Curves

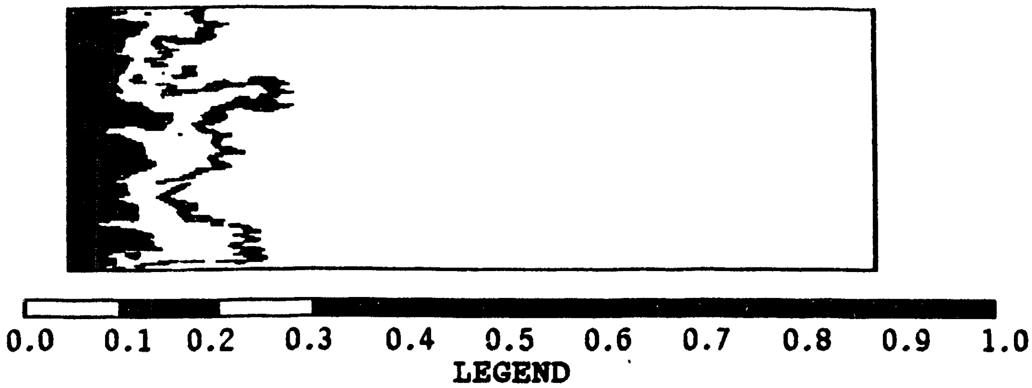


Experimental Water Saturation map at 0.05 PV Injected for Immiscible Displacement at Viscosity Ratio = 91.0 with Swi = 0.15

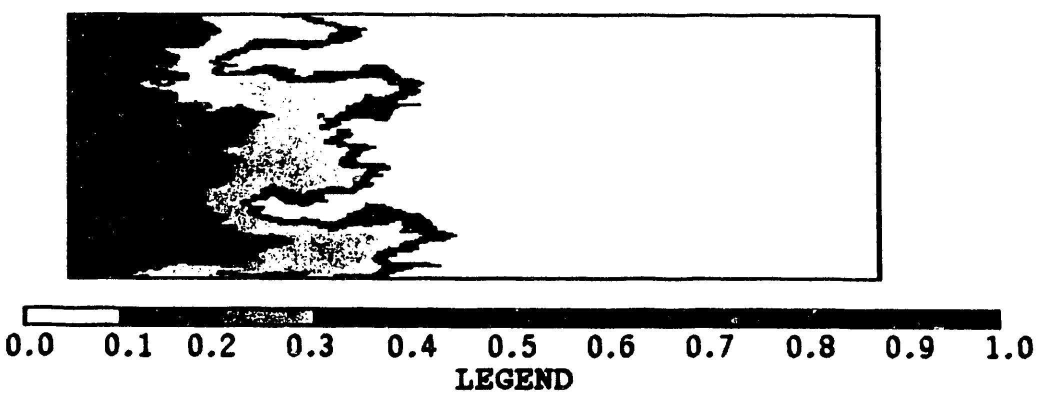


Experimental Water Saturation map at 0.10 PV Injected for Immiscible Displacement at Viscosity Ratio = 91.0 with Swi = 0.15

Figure 4 - Saturation Images from CT Experiment



Water Saturation map at 0.05 PV Injected for Immiscible Displacement at Viscosity Ratio = 91 With Swi = 0.15



Water Saturation map at 0.10 PV Injected for Immiscible Displacement at Viscosity Ratio = 91 With Swi = 0.15

Figure 5 - Saturation Images from Numerical Simulation

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