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# Enhancement of Steam Phase Relative Permeability Due to Phase Transformation Effects in Porous Media

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An experimental study of two-phase concurrent flow of steam and water conducted (Verma et al., 1985) and a set of relative permeability curves was obtained. These curves were compared with semi-empirical results (Brooks and Corey, 1964) and experimental results obtained by other investigators (Johnson et al., 1959, and Osoba et al., 1951) for two-phase, two-component flow (oil/gas; gas/water; gas/oil). It was found that while the wetting phase relative permeabilities were in good agreement, the relative permeability for the steam phase was considerably higher than the relative permeabilities of the non-wetting phase (oil in oil/water and non-condensing gas in gas/oil or gas/water) in two-component systems (Figs. 1 and 2). This enhancement of steam relative permeability is attributed to phase transformation effects at the pore level in flow channels.

There are two separate mechanisms by which phase transformation affected relative permeability curves (1) phase transformation in converging-diverging flow channels with hydrophilic walls can cause an enhancement of steam phase relative permeability; and (2) phase transformation along the interface of a stagnant phase and the phase flowing around it controls the irreducible phase saturation of the stagnant phase (Verma, 1986).

A pore level model was considered to study the first mechanism. In this model a pore space, shown in Figure 3, is idealized as a torroidal flow channel (Fig. 4) with a throat radius $r_t$ and pore body radius $r_b$. Flow of steam and water through the throat portion of a pore was modeled using the MULKOM simulator (Pruess, 1983). The results indicate that when steam encounters a pore throat of a highly constricted flow channel (i.e., $\frac{r_t}{r_b} << 1$) in high conductivity solid, a fraction of the flowing steam condenses upstream from the constriction, depositing its latent heat of condensation. This heat is conducted through the solid grains around the pore throat, and evaporation takes place downstream. Therefore, for a given bulk flow quality, a smaller fraction of steam actually flows through the throat segments. Since steam has much higher kinematic viscosity than liquid water, and since the throat segments are the primary contributors to the overall flow resistance in the flow channels, the phase transformation effects reduce the overall resistance to steam flow along channels with varying cross sections. This pore-level effect manifests itself as relative permeability enhancement on a macroscopic level. However, our numerical studies indicate that for typical pores found in sandstone this effect is negligible.

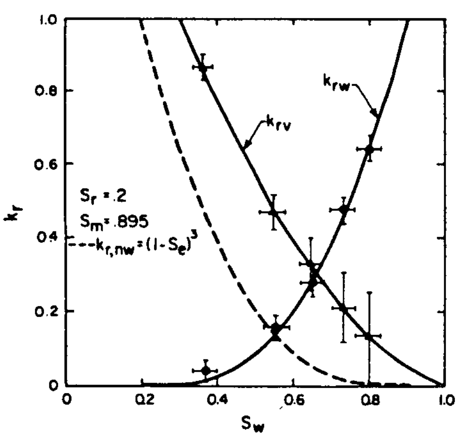


Figure 1. Relative permeability curves. Data points indicate the experimental results; the solid lines indicate the best fit. The broken curve is the relative permeability of the nonwetting phase according to the data of Brooks and Corey (1964).

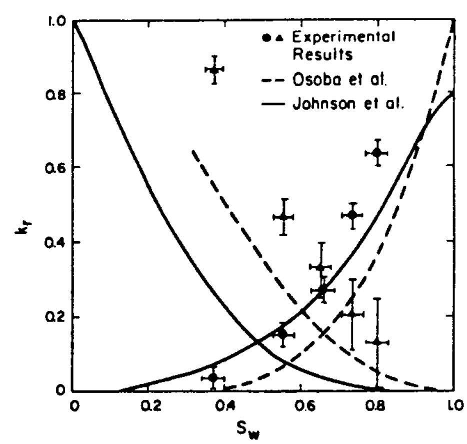


Figure 2. Comparison of our experimental results with those of Johnson et al. (1959) for oil-water and Osaba et al. (1951) for oil-gas. The wetting phase relative permeabilities compare well, but the steam phase relative permeabilities are higher than nonwetting phase relative permeabilities obtained by other investigators.

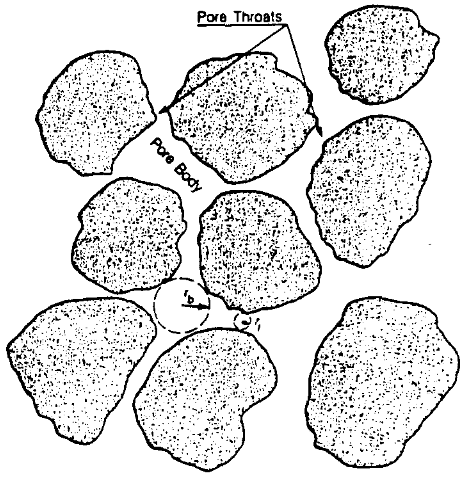


Figure 3. Schematic of pore space showing pore bodies and the throats connecting them.

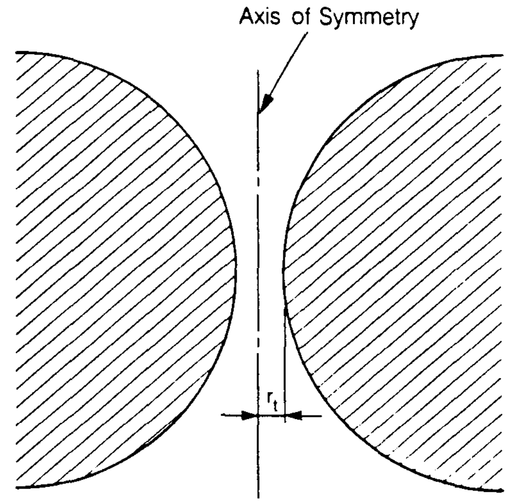


Figure 4. Idealized representation of a pore throat as a torroidal flow channel.

The second effect was studied by applying thermodynamic stability criteria to stagnant phases in pore space. Our study indicates that: (1) irreducible phase saturation for the steam phase will be negligible small when the liquid phase is flowing in the direction of lower thermodynamic pressure and temperature; and (2) irreducible phase saturation for the liquid phase will generally be negligible when steam is flowing in the direction of lower thermodynamic pressure and higher temperature. Detailed derivation of these results is given in a forthcoming report (Verma, 1986).

We conclude that the enhancement of steam relative permeability observed in our experiment is due to a reduction in irreducible steam phase saturation in comparison to the irreducible phase saturations for the non-wetting phase in the oil-water and oil-gas experiments with which we have compared our results.

## References

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