INTERFACIAL EFFECTS IN THE RECOVERY
OF RESIDUAL OIL BY DISPLACEMENT:
STUDIES AT NORTHWESTERN UNIVERSITY

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OBJECTIVE A: EFFECT OF SURFACE VISCOSITIES

Our long term objective is to quantify the relative effects upon displacement of interfacial tension, the interfacial viscosities, wettability, and contact angle hysteresis.

(i) displacement in a single pore

Our short term objective is to determine the effects of the interfacial viscosities during the displacement of a gas by a liquid in a straight capillary tube. We have outlined two methods of obtaining this solution.

The first method involves an iterative solution of an integral equation, which was explained in our last annual report. We are now satisfied with the accuracy with which we can predict velocity gradients using this technique to describe Poiseuille flow. We are beginning our next test problem: displacement by a solid piston (or equivalently, flow in the entrance of a tube beginning with a uniform velocity distribution).

The alternative method of solution employs newly developed bounding principles which allow us to compute upper and lower bounds for the rate of dissipation of energy within the system. The rate of energy dissipation is easily related to the pressure drop over the system and the speed of displacement of the phase interface. We expect to begin a problem using this method of attack in January 1978.

(ii) multiphase microemulsion displacement of residual oil

Healy et al. (1976) suggest a criterion for the optimal composition of a microemulsion to be used in the displacement of residual oil. Their choice is supported by a limited experimental study (Healy and Reed 1977). In a paper

that we have recently prepared

"Multiphase Microemulsion Displacement of Residual Oil",
J.C. Slattery and C.Y. Lin, currently being reviewed for
publication

we propose a mechanism by which a microemulsion may displace residual oil.
This mechanism supports the Healy et al. (1976) criterion for optimal composition.

The predicted effects of the surface viscosities during a multiphase microemulsion displacement are similar to those to be expected in a single phase microemulsion displacement (Slattery 1974).

(iii) interfacial effects in the displacement of residual oil by foam

In a paper recently prepared for publication

"Interfacial Effects in the Displacement of Residual Oil by Foam",
J.C. Slattery, currently being reviewed for publication

a qualitative theory is developed to explain the roles of surface tension and the two surface viscosities in the displacement of foams through porous media. There is a critical value of the surface tension above which a foam cannot be displaced. The displacement efficiency of a foam can be raised by increasing the surface tension to only slightly less than its critical value, by increasing the viscosity of the aqueous surfactant solution from which the foam is formed, and by increasing the surface viscosities. The predictions of the effects of the surface viscosities are in agreement with available experimental data (Kanda and Schechter 1976).

OBJECTIVE B: MEASUREMENT OF SURFACE VISCOSITIES

Our primary objective here is to begin measuring the oil-water interfacial shear viscosity as a function of salt and surfactant concentrations in the aqueous phase, of equivalent alkane carbon number for the organic phase, and of interfacial tension.

(i) deep channel surface viscometer

At least initially, we will use the experiment with the deep channel surface viscometer suggested by Hegde (1971) and recently demonstrated as feasible by Deemer (1976).

We have recently placed the order for some of the optical equipment required to improve the deep channel surface viscometer.

(ii) spinning drop surface viscometer

Let us assume that we start with the spinning drop interfacial tensiometer and impose a small oscillatory perturbation on the angular velocity of the tube. One might visualize measuring either the amplitude of the oscillation of the drop or the phase lag between the oscillation of the tube and the oscillation of the drop. To the extent that these quantities are dependent upon the surface viscosities, their measurement might prove to be the basis for a new technique for measuring the surface viscosities.

We have recently completed (with Dr. Charles Thomas and Dr. P.D. Fleming of Phillips Petroleum Company) an analytic solution for the spinning drop surface viscometer. We are currently considering the feasibility of designing an experiment based upon this solution.

In the process of considering the spinning drop surface viscometer, we have developed an alternative solution for the spinning drop interfacial

tensiometer. This solution, while in agreement with those previously published, is somewhat easier to use by an experimentalist. A paper describing this solution

"Alternative Solution for Spinning Drop Tensiometer",
by J.C. Slattery and J.D. Chen, accepted for publication
in J. Colloid Interface Sci.

has recently been prepared.

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OBJECTIVE C: THE MEASUREMENT OF SMALL INTERFACIAL TENSION BY THE ROD-IN-FREE SURFACE MENISCAL BREAKOFF METHOD

During this quarter (June 1 to August 31, 1977) a theoretical development for mass transfer effects was applied to the meniscal breakoff and spinning drop tensiometer data. It was noted in the previous communication (Quarterly Technical Progress Letter, March 1 to May 31, 1977) that times to achieve steady state values of interfacial tension were very different in the two instruments. The spinning drop (SD) readings for equilibrated Octane/.2% Witco TRS 10-80, 1% NaCl in H_2O appeared to require up to 300 hours for steady state; the meniscal breakoff (MB) data for the same system (obtained from the same batch) reached steady values after 50 hours. The results are shown in Fig. 1.

The theoretical model for mass transfer to the spinning drop involves four major assumptions:

- a) the drop length is large compared to drop radius, with interfacial properties only a function of time:
- b) the relationship between surfactant surface concentration, surfactant bulk concentration, and interfacial tension is given by the Frumkin (or Shishkovskii) equation.
- c) the spinning drop is in quasi-static equilibrium, i.e., interfacial tension is related to interfacial area through the equations governing the steady-state spinning drop:
- d) the mass transfer is controlled by interfacial factors; bulk diffusion is neglected.

The above considerations enable the formulation of a differential equation relating interfacial tension to time. If interfacial area is assumed constant one can also obtain interfacial tension versus time for the constant area case.

After optimally choosing two parameters related to surface mass transfer a curve of IFT vs. time for the spinning drop data is shown on Fig. 1. Using the same mass transfer parameters the meniscal breakoff data may be compared with the theory for constant area IFT vs. time (dotted curve, Fig. 1).

These results are encouraging in-so-far as they do predict the much longer times to steady-state for the spinning drop as compared with the meniscal breakoff. Furthermore, a similar treatment for the sessile drop appears to give the same type of IFT vs. time behavior as the spinning drop; calculations show almost identical results. This may contribute to an explanation of why comparisons between spinning drop and sessile drop experiments show reasonable agreement.

We are now engaged in experiments needed to give the above outlined theory further support. If successful, one must reconsider spinning drop data in the light of required long equilibration times; the meniscal breakoff method would then be recommended as one that can give steady-state data in a much shorter time.

Figure 2 shows the same data as on Fig. 1, but with a greatly expanded time scale. It can be seen that one might conclude the spinning drop experiment after 24 hours; but that would miss the apparent order of magnitude decrease over the next 300 hours.

Fig. 1 Interfacial tension vs. time for equilibrated Octane/.2% Witco TRS 10-80, 1% NaCl in H_2O . The solid curve is a theoretical result that includes mass transfer to the spinning drop; the dotted curve is for the same interfacial mass transfer parameters, but constant interfacial area.

Fig. 2 Early time interfacial tension vs. time for the same data as in Fig. 1.