C00-0019-4

Need to RDA-427

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

Quarterly Technical Progress Letter

for Period September 1, 1975 -
November 30, 1975

J.C. Slattery (Department of Chemical Engineering)
and A.A. Kovitz (Department of Mechanical Engineering and
Astronautical Sciences)
Northwestern University
Evanston, Illinois 60201

MASTER

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

December 1975

Prepared For

THE U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
UNDER CONTRACT NO. E(34-1)-0019

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

During this first twelve month period, there are two objectives for this project. We will discuss our progress towards each of these objectives separately.

Objective A: Further Analysis of the Displacement of Oil by Water in
Porous Media

Our initial goal is to determine for a single irregular pore partially filled with residual oil, the critical value of the pressure drop across the pore, below which the residual oil will not be displaced but will instead assume a static configuration. During this third quarter, we have completed the programming required for the necessary numerical computations.

Our approach is to calculate the pressure difference across the oil drop as it assumes a continuous sequence of static configurations in the sinusoidal pore. As we described in the last quarterly report, the dimensionless pressure difference $\frac{\Delta Pa}{2\gamma}$ rises and falls as a function of the axial position of the drop in the tube. We suggested how the occurrence of these maxima and minima in $\frac{\Delta Pa}{2\gamma}$ could be interpreted in terms of the Haines jumps experienced by an oil drop as it moves through an irregular tube.

We did not describe completely in the last report another phenomena that we shall refer to as "popping". Some oil globules, either because of their size or because of the magnitudes of their advancing and receding contact angles, can not assume a static configuration at every position in the irregular tube. At some point in a slow (quasi-static) displacement of the drop through an irregular tube, the drop would appear to "pop" from one position to another, because intermediate static configurations fail to exist. Two examples of popping were noted in the second quarterly report: in the displacement of a small oil globule through an oil-wet pore (Figure 5) and in the displacement

of a small oil globule through a water-wet pore (Figure 8). In these cases, the computation of $\frac{\Delta P_a}{2\gamma}$ as a function of axial position (as in Figure 3 of the second quarterly report) must be terminated as soon as the popping occurs.

In other cases, the popping occurs between one axial position of the drop and another; in a plot of $\frac{\Delta P_a}{2\gamma}$ as a function of axial position, there is a discontinuous gap. In most cases, no popping of any character occurs. For example, no popping occurs in the computation to which Figure 3 of the second quarterly report refers.

This popping phenomena should be distinguished from the Haines jumps described above. In some cases, the popping of a drop may initiate a Haines jump, but the fundamental phenomena seem quite different.

Because of this popping phenomena, our numerical computations were a little more difficult than originally anticipated.

Although we are still evaluating the results of these computations, we expect to be able to discuss two closely related phenomena.

Given some information regarding the distribution of pore sizes among those pores actually containing residual oil, we can estimate the critical interfacial tension above which one should not expect to be able to recover residual oil. We can also estimate the interfacial tension required to recover a significant portion of the residual oil. In this way, we expect to use our numerical results to form the basis for a correlation of relevant data from the literature. Since displacement studies usually provide minimal information regarding wetting conditions and pore size distributions, we will be limited in how far we can go.

We should also be able to discuss preferable wetting conditions for tertiary oil recovery. We define a water-wet system to be one in which the advancing contact angle (measured through the aqueous phase) is less than 90° ; an oil-wet system

is one in which the advancing contact angle is greater than 90° . Our preliminary conclusion is that water-wet conditions are preferable. As shown in Table 1, the maximum value of $\frac{\Delta P a}{2\gamma}$ appears to be minimized as the advancing contact angle (θ_1 in Figure 1 of the second quarterly report) approaches zero. This assumes that the contact angle hysteresis can be described as Morrow's (1974) Class III behavior. The corresponding value of the interfacial tension, which it would be desirable to maximize, is also shown in Table 1.

Reference

Morrow, N.R., 48th National Colloid Symposium, Austin, Texas, June 24-26 (1974).

Objective B: The Measurement of Small Interfacial Tensions by the Rod-In-Free
Surface Meniscal Breakoff Method

During the last quarter (9/1/75 through 11/30/75) a "Version II" of the meniscal breakoff apparatus has been designed and constructed. Its initial use (with indicated modifications) will form the major effort during the remainder of the current grant period.

A schematic of Version II is shown in the Figure. The primary changes include:

- 1) a removable, reduced size glass specimen tank that can be carefully cleaned;
- 2) the direct translation, via an articulated rod and screw mechanism (micrometer or differential screw together with a piezoelectric crystal). of a floating platform on which the specimen tank is rigidly mounted;
- 3) a flotation liquid (currently glycerol) which will tend to damp out unwanted vibration of the specimen tank;
- 4) the floating specimen tank (in which the interface is located) will enable the interface to be accurately translated parallel to itself.

Movement of the specimen tank with accuracies of the order of 10^{-3} cm will be accomplished with the micrometer. Translations with accuracies in the range of 10^{-5} cm will be achieved with commercially available items such as a differential screw device and piezoelectric crystal translators whose ultimate resolutions are $\sim 10^{-6}$ cm. The interfacial translation is not precisely equal to the translation of the specimen tank due to its finite volume and the volume of the meniscus itself. A correction factor, obtainable from the theoretical calculations for meniscal shape and volume, will be applied where necessary. These calculations have been initiated.

Measurements of the interfacial tension for benzene-water and butyl alcohol-water interfaces will be performed to check out the new instrument. This preliminary work is expected to be completed by the end of the current grant period.

TABLE 1. Dimensionless Pressure Difference Across A Pore
Necessary to Recover A Trapped Oil Globule

$$A/a = 1.5, \quad L/a = 6.0, \quad \text{and } V_{\text{oil}}/a^3 = 80.0$$

Contact Angle Hysteresis: Type III of Morrow (1974)

θ_E^* (degrees)	θ_1^* (degrees)	θ_2^* (degrees)	Maximum $\frac{\Delta P a}{2\gamma}$	$\gamma_{\text{max.}}^{**}$ (dynes/cm)
24	10	1	0.3744	0.0294
30	20	2	0.3856	0.0286
40	40	4	0.4306	0.0256
49	60	7	0.6371	0.0173
59	80	11	0.8696	0.0127
69	100	14	1.1070	0.00995
79	120	21	1.3125	0.00839
89	140	38	1.4364	0.00767
100	160	64	1.4193	0.00776
117	170	90	1.2517	0.00880
137	175	130	0.8532	0.0129
150	178	160	0.5440	0.0202
156	179	170	0.5339	0.0206

* θ_E : Equilibrium contact angle measured through the aqueous phase

θ_1 : Advancing contact angle measured through the aqueous phase

θ_2 : Receding contact angle measured through the aqueous phase

** $\gamma_{\text{max.}}$: Maximum interfacial tension calculated assuming $a = 1.5 \times 10^{-3}$ cm,
 $\Delta P/L = 0.5$ psi/ft, and T (tortuosity) = 12.0

FIGURE

MENISCAL BREAKOFF INSTRUMENT: VERSION II

- a contact circle rod
- b specimen tank
- c floating platform
- d connecting rod
- e flotation liquid
- f compression spring
- g translation screw
- h leveling screws for rod fixture