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**DROP-DROP COALESCENCE: THE EFFECT OF TEMPERATURE AND
EQUILIBRATION TIME ON WILMINGTON CRUDE OIL IN A WEAKLY ALKALINE BRINE**

Topical Report

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DROP-DROP COALESCENCE: THE EFFECT OF TEMPERATURE AND EQUILIBRATION TIME ON WILMINGTON CRUDE OIL IN A WEAKLY ALKALINE BRINE

By Deborah A. Peru^{*} and Shawn D. Thornton^{**}

ABSTRACT

Coalescence data were obtained for Wilmington crude oil droplets in sodium bicarbonate brine using a vertically inclined spinning drop tensiometer. The effect of temperature and aging on drop-drop coalescence was evaluated. In most cases, film drainage is considered to be the rate-limiting process prior to coalescence.

Results indicate that coalescence time is dependent on temperature, being long at low temperature and short at high temperatures. Aging of the oil drops in alkaline brine appeared to decrease coalescence time although the effect was more noticeable at high temperature. Natural surfactants produced from the reaction of bicarbonate brine with strong acids in Wilmington crude oil appeared to inhibit drop-drop coalescence probably due to a surfactant concentration gradient which was providing resistance to flow at the interface. The period of time that interfacial tension remained at a dynamic minimum was directly related to coalescence time.

A spinning drop tensiometer was found to be useful in obtaining drop-drop coalescence data. The apparatus is simple to operate and could be used in laboratory optimization of the mechanisms of oil mobilization and oil bank formation.

INTRODUCTION

For a chemical enhanced oil recovery (EOR) process to remove oil droplets that tend to adhere to the surfaces of subterranean formations, the chemical must be able to overcome capillary forces. A chemical that lowers interfacial tension (IFT) is likely to facilitate the removal of oil from a solid surface. Although the mobilization step is important, it is not sufficient for efficient EOR. A chemical system must also promote the reconnection of oil droplets to form an oil bank that must then propagate through the

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reservoir and effectively reconnect additional oil ganglia along its path. Without the formation and propagation of an intact oil bank, mobilized oil ganglia will eventually break up and become retrapped within the porous media.

Drop-drop coalescence is the fundamental phenomenon that must occur for an oil bank to form. Much research has been performed to identify the factors that stabilize emulsions.¹⁻⁹ Generally, systems with ultralow IFT tend to form more stable emulsions. However, systems with ultralow IFT do not always recover large amounts of residual oil in linear-flow, oil-displacement tests. It has been reported that surfactant systems that obtained the highest oil recovery efficiencies were those that were the least stable; that is, systems having minimum interfacial viscosity (IFV) and fast rates of coalescence, whereas systems that had lower oil recoveries had higher IFV and slower rates of coalescence.¹ Further research showed that no relationship existed between IFT and interfacial viscosity and/or coalescence for the surfactant/crude oil systems studied.¹⁻³ This indicates that both IFT and IFV are important and yet separate interfacial properties which should be determined and optimized during chemical evaluation procedures.

The coalescence process has several stages. First, the drops approach one another by means of gravitational force, mechanical force, and/or centrifugal and electrical forces. Secondly, a thin layer of continuous film is formed between the approaching drops. With time, the film drains producing a thinner and thinner layer between the oil drops. Finally, a critical thickness of thin film (from 500 Å to 1,000 Å) is reached where thermal disturbances of molecules cause a sudden rupture of the thin film and the two drops coalesce. In most cases, film drainage is considered to be the rate-limiting step for the coalescence process.^{4-5,7}

Many factors interfere with film drainage and thus prevent coalescence of oil droplets; some of them are as follows:

1. **Physical factors** -- The viscosity of the bulk phase can slow film drainage by preventing the thin layer of liquid between oil drops from draining thereby decreasing the rate of coalescence. Differences in density between the oil and brine phases can cause buoyancy effects, whereby large buoyant or coalescing forces (F) increase the rate of coalescence. Large oil drops have a larger buoyant force than smaller oil drops and therefore would promote faster coalescence. High temperature and temperature gradients may

promote more rapid film drainage by changing the concentration of stabilizing agent over the surface of the drops.

2. **Electrical factors** -- Emulsions can be stabilized by repulsive charges on the surfaces of the dispersed phase. Oil drops with anionic surfactants at the interface have a net negative charge on the drop which tend to repel one another thus preventing coalescence.³ The presence of an expanded electrical double layer or high interfacial charge density inhibit coalescence.^{3,5,7}

3. **Interfacial properties** -- Drainage of liquid film between oil drops is greatly impaired when minute quantities of surfactant or impurities are present at the interface.^{7,9} During the film drainage process, surfactant molecules are carried out toward the bulk aqueous phase. Owing to the non-uniform distribution of surfactant at the interface, IFT gradients arise that tend to inhibit liquid film drainage. The magnitude of the interfacial shear and dilational components of viscosity are inversely related to coalescence time. Measurements have established that film drainage is principally controlled by surface dilational viscosity.¹² Dilational viscosity is the component of surface viscosity that opposes a change in the area of a surface element.

These examples are by no means all of the factors that affect coalescence but merely represent some of the factors inhibiting coalescence.

In this report, we present the results of simple drop-drop coalescence tests using a spinning drop tensiometer to obtain coalescence times of Wilmington crude oil droplets in a weakly alkaline brine containing sodium bicarbonate and sodium chloride. The experimental results presented in this report include the effect of temperature, and aging on the coalescence time of two oil drops.

EXPERIMENTAL METHODS

The inclined (7° angle) spinning drop method developed by Flumerfelt et al.⁴ for low tension systems is used at a 90° angle in this work to study oil drop lifetimes of a system with higher IFT. Figure 1a illustrates schematically the coalescence cell used in this study. Two drops of Wilmington crude oil (average 1mm diameter) are injected with a fine bore glass syringe into a capillary tube containing the more dense aqueous phase.

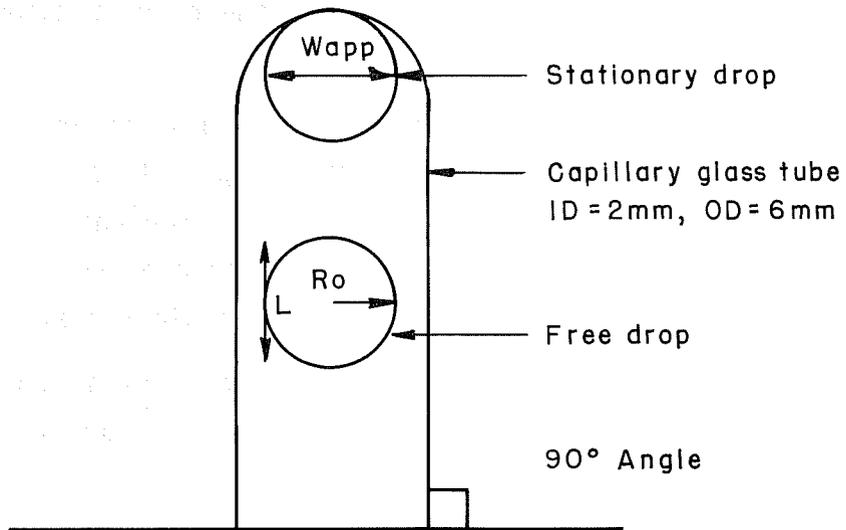


FIGURE 1a. - Geometry of the drop-drop coalescence experiment using the spinning drop tensiometer.

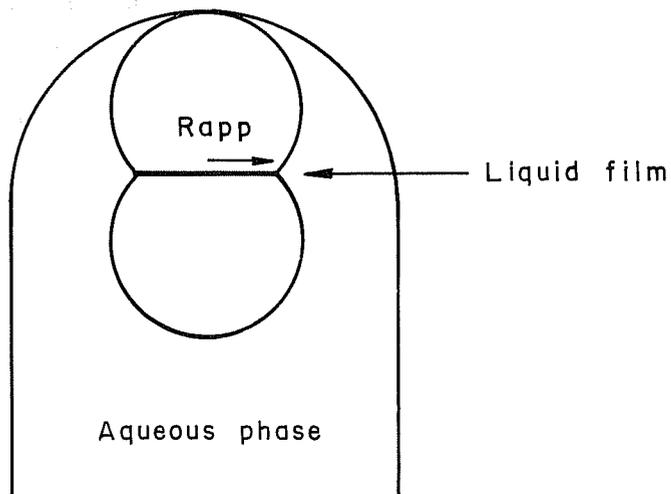


FIGURE 1b. - Illustration of contact radius and the thin liquid film preventing coalescence of oil droplets. Contact area = $\pi (R_{\max})^2$.

The tube is then sealed and placed into the temperature-controlled spinning drop tensiometer and aged (equilibrated) at 40 rev/sec.

During the 8-minute or 1-hour aging period, the apparatus is maintained in a horizontal position so that lengths (L) and widths (W_{app}) of the stationary and the free drops can be measured. The width (W_{app}) and contact radius (R_{app}) are measured from outside the capillary tube with a cathetometer attached to a low-power, traveling microscope. An optical magnification factor is required to compensate for the cylindrical lens effect of the tube. This can easily be corrected since the magnification factor of a drop centered in a perfectly cylindrical tube is equal to the refractive index of the denser phase in the spinning tube.¹⁰ The real image measurement of W (and R) are both found by [$X_{app}/1.335 = X$] for a 1-percent sodium salt brine. No correction is needed for length measurements.

After a specified aging period, the instrument is rotated 90°, and the two oil droplets are allowed to float to the top of the capillary tube under the action of buoyancy. The time for drop-drop coalescence to occur starts when the free drop contacts the stationary drop. The force driving coalescence is the buoyant force on the free drop i.e.,

$$F = \Delta\rho g V \sin \phi \quad (1)$$

where $\Delta\rho$, is the density difference between the continuous and drop phases; g , is the acceleration due to gravity (980 cm/s^2); V , is the free drop volume; and ϕ , is the inclination angle. The free drop volume is obtained from measurements of the free drop length L and width W and use of equation 2 for spheres

$$V = \frac{4}{3} \pi \left(\frac{L}{2}\right)^3 \quad (2)$$

or equation 3 for drops with length > width.

$$V = \pi\left(\frac{W}{2}\right)^2 (L-W) + \frac{4}{3} \pi \left(\frac{W}{2}\right)^3 \quad (3)$$

The average pressure in the film resulting from the free drop force is most easily derived for a completely mobile interface. It may be determined simply by dividing the buoyant force by the maximum contact area:

$$P_f = \frac{F}{\pi (R_{\max})^2} \quad (4)$$

where R_{\max} is the maximum contact radius and the value of π (pi) = 3.1416. Contact radius (R) is defined as the radius of the circle shared by the two oil droplets, as shown in figure 1b. An average of six contact radius measurements were made for each trial from which the maximum contact radius measured was used. The magnitude of film pressure (P_f) when calculated using equation 4 is correct although the precision of the values may vary. This is because equation 4 assumes that there is little pressure drop within the film which is not the case for real systems.

During the course of an experiment, there is a noticeable enlargement in the contact area up to a maximum value followed by a steady decline. This is attributed to the dynamic behavior in IFT which is characteristic of alkaline reagents reacting with acidic crude oils.^{2, 13-14} Actual IFT values can be calculated with the use of equation 5:

$$R = \left(\frac{FR_0}{3 \pi \sigma} \right)^{\frac{1}{2}} \quad (5)$$

where R_0 is the free drop radius, and σ is the interfacial tension. In this study, equation 5 was rearranged to solve for IFT. The kinetics of variation of IFT between two oil droplets in alkaline systems can be indirectly studied by using the cathetometer and measuring contact radius during the time prior to the coalescence event.

The weakly alkaline brine used in this study contained 1.2 percent Tronacarb™ (NaHCO_3) and 0.17 percent NaCl dissolved in boiled and cooled distilled-deionized water, pH = 9. Upon injection of two oil drops into a filled capillary tube, the bicarbonate solution reacts with some of the stronger acids in Wilmington crude oil (acid number 2.1 mg KOH/g oil sample) to produce natural surfactants that have been found to lower IFT.¹¹ Coalescence time depends mostly on the total concentration of these natural surfactants at the interface, their solubility in the oil and water phases, and the rate at which they equilibrate with the oil and brine phases. Note

that differences in drop size for both the free and stationary drop lead to the partitioning of varying amounts of natural surfactant at the oil-water interface. For this reason, it was occasionally observed that coalescence times for systems with seemingly identical film pressure were not reproducible.

A 1-percent NaCl solution (equivalent in sodium ions with the above bicarbonate brine) was made from boiled and cooled distilled-deionized water and was used in several attempts to obtain coalescence data at pH 7. Because of the strong tendency for Wilmington crude oil to wet glass at pH 7, only one data point was obtained in the NaCl brine.

The densities of Wilmington crude oil and bicarbonate brine at 25°, 50°, and 70° C are listed in table 1.

RESULTS

Dependence of t_c on P_f

One of the factors that affects drop-drop coalescence is the force pushing against the interface. The size of the free drop, and the difference in density between the oil and water phase determine the force that a drop exerts on the interface.

Tables 2 and 3 give coalescence times (t_c) at three temperatures for systems aged for 8 minutes and 1 hour, respectively. The buoyant force F , maximum contact radius R_{max} , film pressure P_f (film stress), and the quantity $t_c F / \pi R^2$, which is the product of (coalescence time and coalescence stress) are

TABLE 1. - Densities of oil and brine at various temperatures

Temperature, °C	Brine ρ , g/cm ³	Oil ρ , g/cm ³	$\Delta \rho$, g/cm ³
25	1.0080	0.9429	0.0651
50	0.9987	0.9252	0.0735
70	0.9879	0.9116	0.0763

TABLE 2. - Data obtained for systems aged 8 minutes

System	¹ F, dyne	² R, cm	³ P _f , dyne/cm ²	⁴ t _C , min	⁵ $\frac{t_C F}{\pi R^2}$, poise
A ⁶ 25° C	9.43 X 10 ⁻³	0.0161	11.60	200	10 ^{5.14}
	2.43 X 10 ⁻²	0.0273	10.39	563	10 ^{5.54}
	5.12 X 10 ⁻²	0.0402	10.07	111	10 ^{4.83}
	3.98 X 10 ⁻³	0.0113	9.84	123	10 ^{4.86}
	2.85 X 10 ⁻²	0.0311	9.35	416	10 ^{5.37}
	3.44 X 10 ⁻²	0.0342	9.34	590	10 ^{5.52}
	1.49 X 10 ⁻²	0.0230	8.97	352	10 ^{5.28}
	3.26 X 10 ⁻²	0.0345	8.70	356	10 ^{5.27}
				Avg. = 10 ^{5.23±0.27}	
B ⁶ 50° C	1.29 X 10 ⁻³	0.0045	20.40	5.6	10 ^{3.84}
	1.42 X 10 ⁻²	0.0169	15.84	33	10 ^{4.50}
	4.43 X 10 ⁻²	0.0328	13.10	67	10 ^{4.72}
	3.48 X 10 ⁻²	0.0309	11.61	57	10 ^{4.60}
	3.58 X 10 ⁻²	0.0320	11.12	98	10 ^{4.82}
					Avg. = 10 ^{4.50±0.39}
C ⁷ 50° C	3.45 X 10 ⁻²			0.2	
D ⁶ 70° C	7.96 X 10 ⁻³	0.0109	21.17	5.5	10 ^{3.84}
	6.73 X 10 ⁻²	0.0306	16.47	17.0	10 ^{4.22}
	6.04 X 10 ⁻³	0.0115	14.43	5.8	10 ^{3.70}
	2.68 X 10 ⁻²	0.0244	14.29	9.5	10 ^{3.91}
	2.69 X 10 ⁻²	0.0262	12.45	12.4	10 ^{3.97}
	2.05 X 10 ⁻²	0.0231	12.22	12.0	10 ^{3.94}
	3.32 X 10 ⁻²	0.0310	10.99	22.0	10 ^{4.16}
	1.94 X 10 ⁻²	0.0251	9.76	14.0	10 ^{3.91}
				Avg. = 10 ^{3.96±0.17}	

¹F = coalescing force

²R = maximum contact radius

³P_f = film pressure

⁴t_C = film drainage time (coalescence time)

⁵ $\frac{t_C F}{\pi R^2}$ = product of (coalescence time and coalescence stress)

⁶ = 1.2% NaHCO₃ + 0.17% NaCl brine

⁷ = 1.0% NaCl brine

TABLE 3. - Data obtained for systems aged 1 hour

System	¹ F, dyne	² R, cm	³ P _f , dyne/cm ²	⁴ t _C , min	$\frac{{}^5t_C F}{\pi R^2}$, poise
E ⁶ 25° C	6.79 X 10 ⁻³	0.0081	33.14	18	10 ^{4.55}
	9.33 X 10 ⁻³	0.0138	15.54	42	10 ^{4.59}
	2.65 X 10 ⁻²	0.0286	10.34	72	10 ^{4.65}
	2.24 X 10 ⁻²	0.0260	10.55	430	10 ^{5.43}
	1.47 X 10 ⁻²	0.0218	9.90	446	10 ^{5.42}
	2.47 X 10 ⁻²	0.0314	7.95	637	10 ^{5.48}
F ⁶ 50° C	2.82 X 10 ⁻²	0.0098	94.09	0.93	10 ^{3.72}
	8.48 X 10 ⁻³	0.0062	69.81	1.1	10 ^{3.66}
	1.81 X 10 ⁻²	0.0097	61.30	2.1	10 ^{3.89}
	1.67 X 10 ⁻²	0.0103	49.93	2.0	10 ^{3.78}
	3.65 X 10 ⁻²	0.0182	35.23	16	10 ^{4.53}
	3.62 X 10 ⁻²	0.0218	24.32	4.4	10 ^{3.81}
	8.70 X 10 ⁻²	0.0381	19.10	10	10 ^{4.06}
					Avg. = 10 ^{3.92±0.30}
G ⁶ 70° C	1.30 X 10 ⁻²	0.0057	128.12	0.8	10 ^{3.79}
	4.53 X 10 ⁻²	0.0130	85.39	0.85	10 ^{3.64}
	2.41 X 10 ⁻²	0.0106	69.01	0.72	10 ^{3.47}
	4.32 X 10 ⁻²	0.0152	59.73	0.78	10 ^{3.45}
	4.44 X 10 ⁻²	0.0192	38.14	1.0	10 ^{3.36}
					Avg. = 10 ^{3.54±0.17}

¹F = coalescing force
²R = maximum contact radius
³P_f = film pressure
⁴t_C = film drainage time (coalescence time)

$\frac{{}^5t_C F}{\pi R^2}$ = product of (coalescence time and coalescence stress)

⁶ = 1.2% NaHCO₃ + 0.17% NaCl

calculated. The quantity $t_C F / \pi R^2$ is less sensitive to the magnitude of the contact radius than the quantity $t_C F$. Comparison of these values ranks each set of conditions according to its effect on drop-drop coalescence. Systems that coalesce rapidly have the smallest values of $t_C F / \pi R^2$, and systems that coalesce slowly have the largest $t_C F / \pi R^2$ values. The average values of

$t_c F / \pi R^2$ in column 5 of tables 2 and 3 clearly indicates that coalescence of oil drops is sensitive to both temperature and aging although the effect of aging was more pronounced at elevated temperatures. This is discussed more fully in the following section.

Figure 2 shows the experimental relationship between film pressure (P_f) and film drainage time (t_c) for all the data obtained in this study. In general, when the pressure on the film is large, drop-drop coalescence time is short, and when the pressure on the film is small, drop-drop coalescence time is long. The inverse relationship between drop-drop coalescence time and film pressure is consistent with results obtained by other researchers.⁹

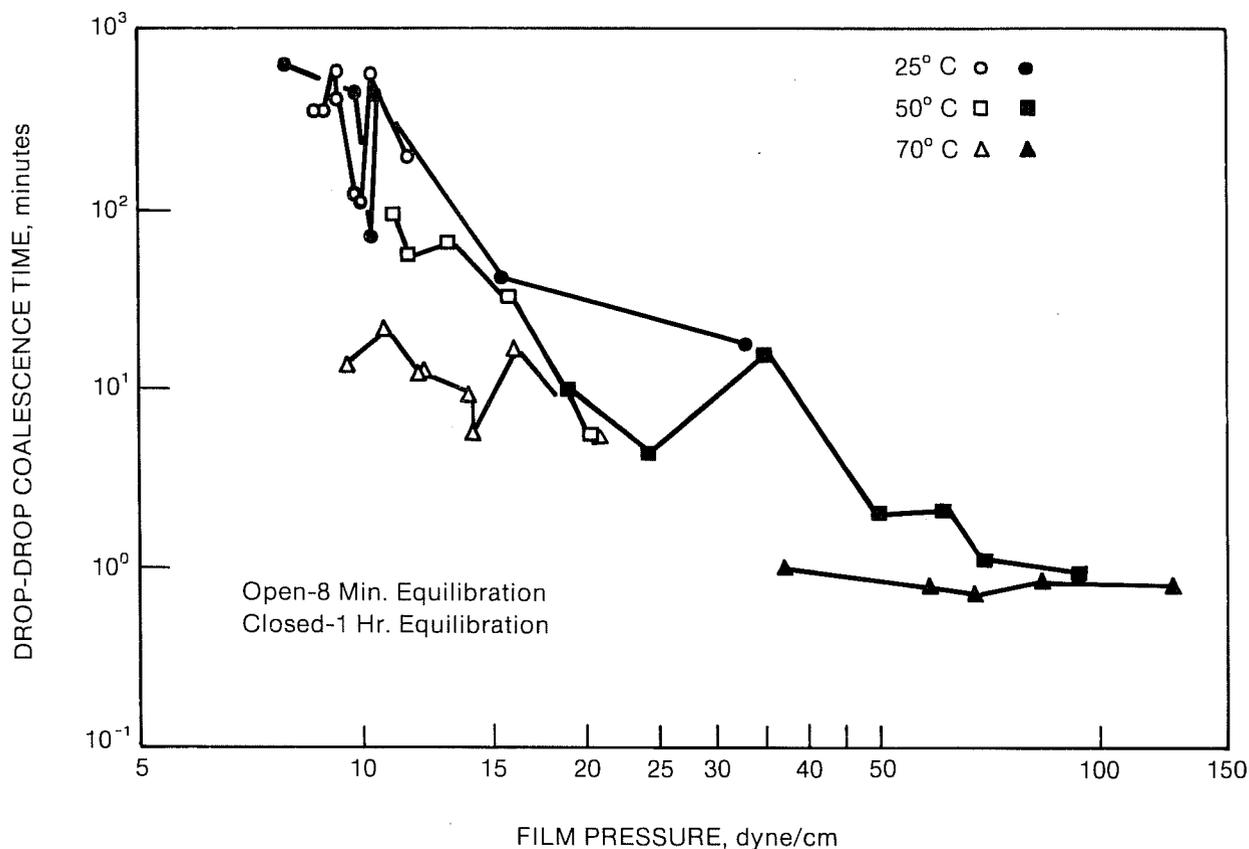


FIGURE 2. - Dependence of drop-drop coalescence time t_c on film pressure P_f (film stress). Drop-drop coalescence time t_c is shown to be inversely related to film pressure.

The Effect of Temperature and Equilibration

The hydrodynamic film drainage model that is applied in this study was developed by Barber and Hartland.^{1,2} Using this theory, Flumerfelt et al.⁵ were able to obtain the interfacial shear (ϵ) and dilational (k') components of viscosity by measuring the coalescence time between droplets of surfactant microemulsions at various salinities. In this study, this same method is used to determine and compare the relative mobility of the acidic crude oil/bicarbonate brine interface at three temperatures and after two different equilibration periods.

Upon integration of the Barber-Hartland film drainage rate equation, the following relation among the coalescence time t_c , the applied force F , the effective contact radius R , the bulk phase viscosity of the film μ , the critical collapse distance δ_c , and the combination $\eta = k' + \epsilon$, is obtained:

$$t_c = \left(\frac{\pi\eta}{3\mu F}\right)^2 [x^2 - 4 \ln I_0(x)] \quad (6)$$

where $x = (6\mu R^2/\delta_c\eta)^{1/2}$ and I_0 is the modified Bessel function of zero order.

In this study, the two limiting cases of equation 6 are the guidelines for comparing interfacial mobility. When interfacial resistance to drainage is small, equation 7 becomes the limiting case for mobile interfaces and t_c is inversely related to film pressure P_f and the critical collapse distance δ_c , and directly related to η :

$$t_c = \frac{2\pi R^2 \eta}{F \delta_c} \quad (7)$$

where $\pi R^2/F = 1/P_f$. A mobile interface is usually caused by systems having low interfacial viscosity. For completely rigid interfaces, equation 6 takes the form:

$$t_c = \frac{3\pi \mu R^4}{4F \delta_c^2} \quad (8)$$

which states that t_c is inversely related to P_f and δ_c^2 , and directly related to R^2 and μ . A rigid interface is usually caused by systems having high interfacial viscosity. The dependence of t_c on R varies between these limits, and is second order for the most mobile interface and fourth order for the

most rigid interface. Most systems will fall between these two limiting cases, but the ability to describe interfacial mobility will also depend on how well the Barber-Hartland theory applies to our system.

When the logarithm of $t_c F$ is plotted versus the logarithm of R , the slope for the limiting case for mobile interfaces (equation 7) is equal to 2, and the slope for the limiting case for rigid interfaces (equation 8) is equal to 4.

Figure 3 shows the log-log plot of $t_c F$ versus R for systems aged 8 minutes. The slopes of these lines suggest that temperature had little effect on the mobility of the interface after the oil drops were aged only 8 minutes. The results in figure 4 indicate that after 1 hour of aging, temperature had a much greater effect on drop-drop coalescence time. It is reasonable that at high temperature and after long aging periods, the interface becomes less rigid due to the desorption of surfactants from the

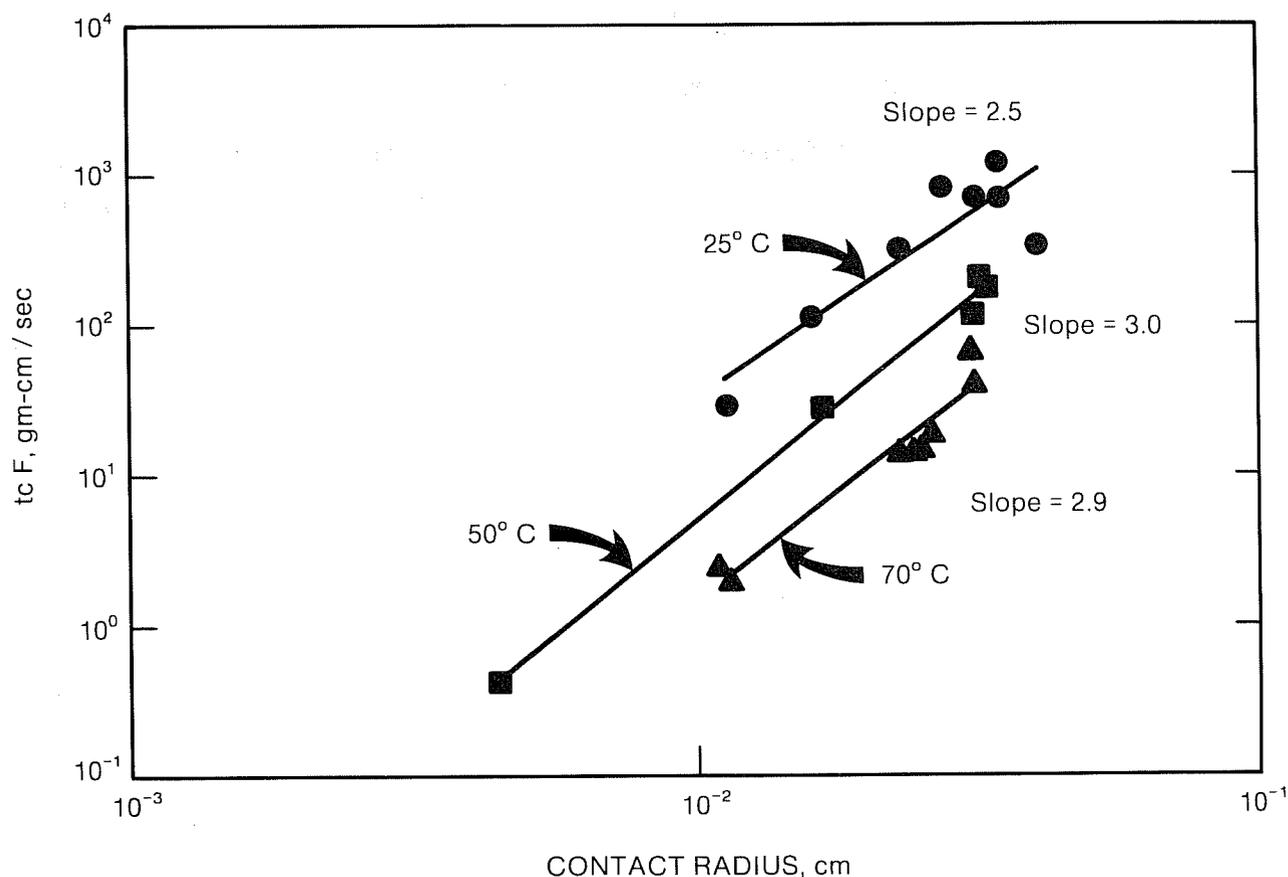


FIGURE 3. - Dependence of $t_c F$ on R_{max} for systems aged 8 minutes. The slopes of the $\log t_c F$ versus $\log R_{max}$ plots are given.

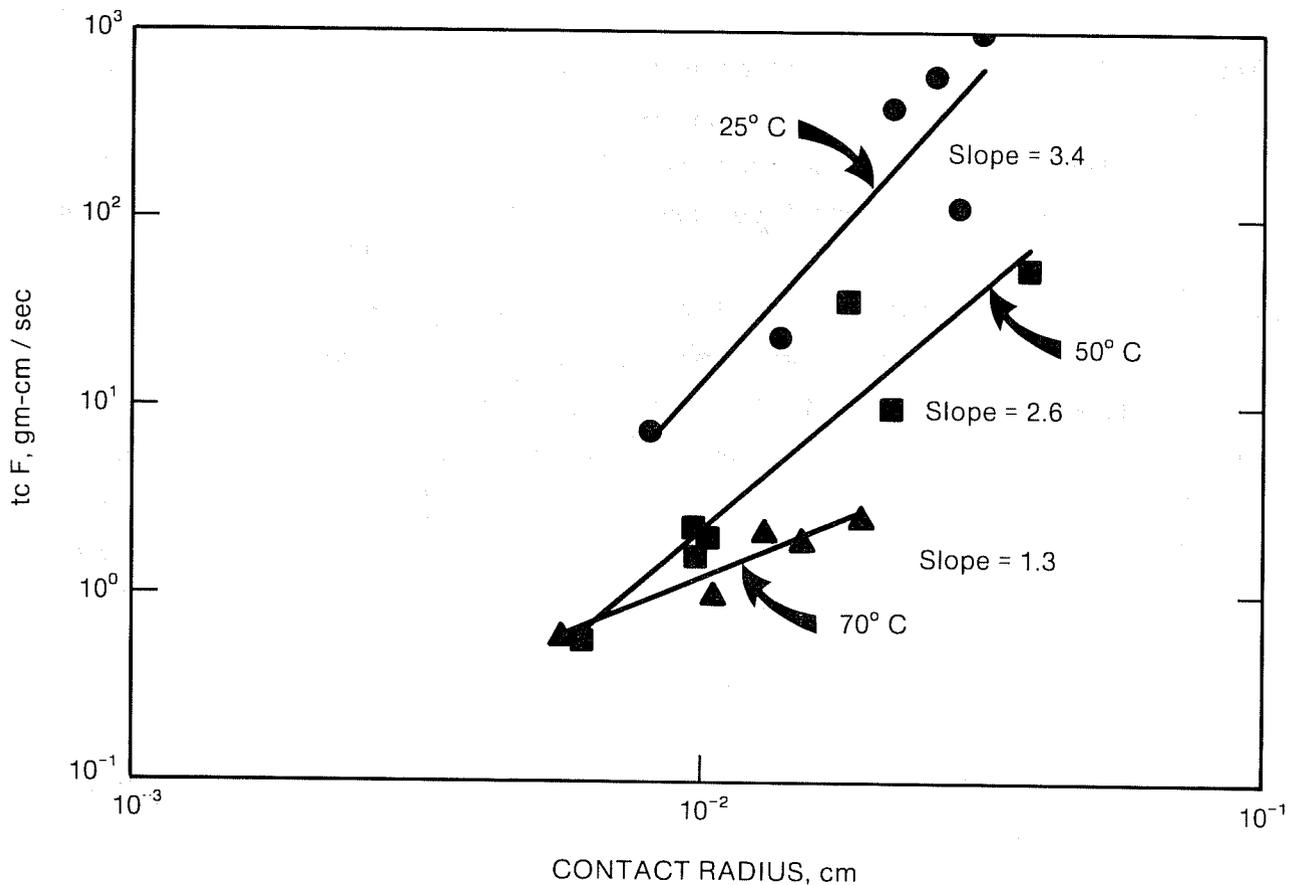


FIGURE 4. - Dependence of $t_c F$ on R_{max} for systems aged 1 hour. The slopes of the $\log t_c F$ versus $\log R_{\text{max}}$ plots are given.

interface.^{2,13} Hence, systems at 50° and 70° C that are aged for 1 hour are more likely to behave as the limiting case for mobile systems than are the 25° C systems.

In general, the observed behavior at the three temperatures was similar for systems aged either 8 minutes or 1 hour. The fastest coalescence (minimum $t_c F$ values in figures 3 and 4) occurred at 70° C for any given contact radius. Similarly, the slowest coalescence (maximum $t_c F$ values) for systems aged either 8 minutes or 1 hour occurred at 25° C .

Figure 5 shows the effect of temperature and aging on drop-drop coalescence time by plotting the average values of $t_c F / \pi R^2$ versus temperature for each system. Large values of $t_c F / \pi R^2$ represent long coalescence times, whereas small values of $t_c F / \pi R^2$ represent short coalescence times. The effect of aging on coalescence was again more noticeable at elevated temperatures

than at room temperature. This may be because the rate of desorption of the natural surfactants is increased at high temperature. After 1 hour of aging at elevated temperature, most of the natural surfactants may have diffused from the interface into the aqueous or oil phases. A lower concentration of natural surfactant at the interface means that resistance to film drainage was smaller.

In summary, increased temperature and aging of acidic oil drops in alkaline brine resulted in a more mobile interface and shorter coalescence times. This was probably due to the decrease in the interfacial concentration of natural surfactants allowing film drainage to occur more rapidly. The one coalescence time acquired using NaCl brine supports this. At 50° C and after an 8-minute aging period, drop-drop coalescence occurred within 12 seconds. It is assumed that relatively little surfactant was present in this system at pH 7 resulting in a much cleaner interface (free from surfactant molecules) that provided less obstruction to flow.

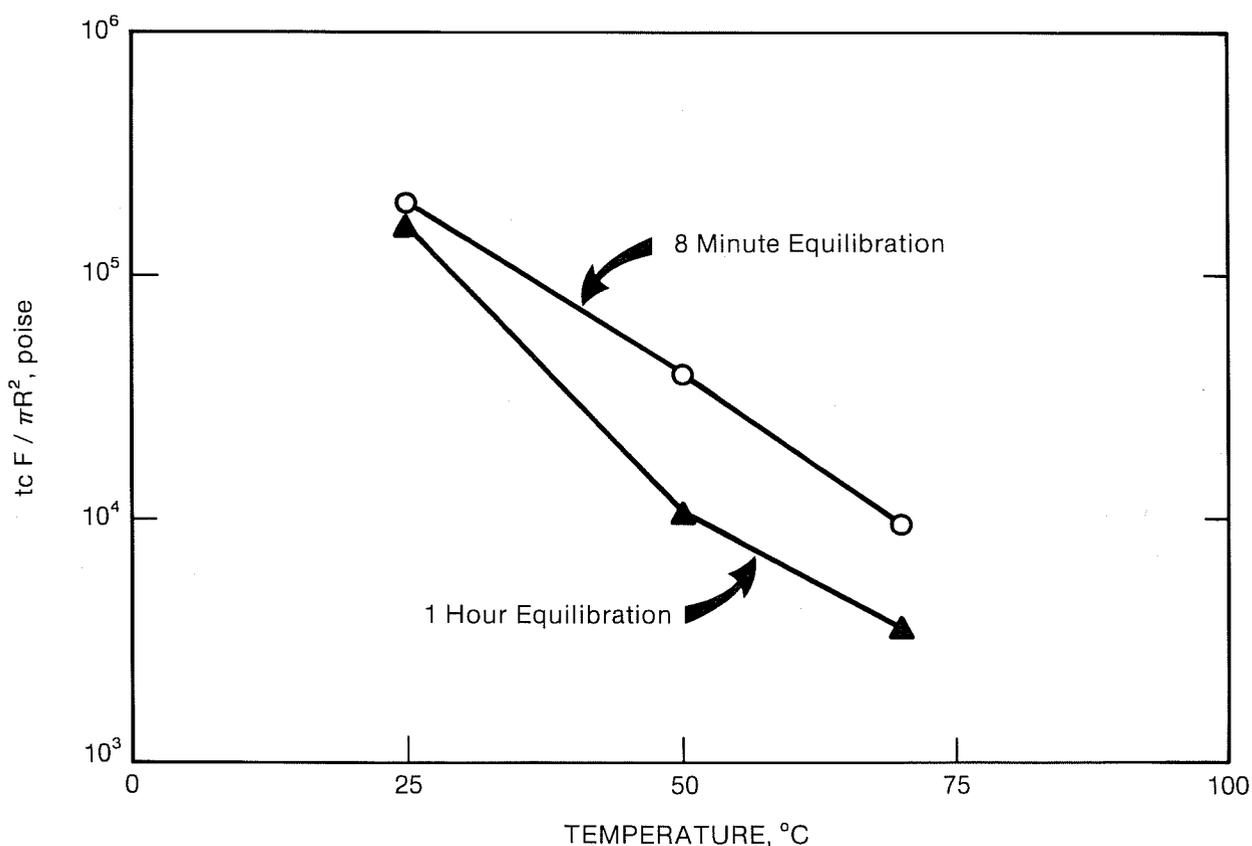


FIGURE 5. - Plot of the average product of (coalescence time and coalescence stress) versus temperature for systems aged either 8 minutes or 1 hour.

Experimental Dependence of Coalescence on Dynamic IFT

It has been reported that coalescence is greatly hindered by an increase in the area of film drainage.⁵ In this study, we found that the contact area between two freshly contacted oil drops steadily increased and that coalescence did not occur until the contact area reached a maximum value followed by a rapid decline.

Equation 5 shows that the IFT is inversely related to the square of contact radius. When IFT is low, the contact radius is very large and when IFT is high, the contact radius is very small. We previously showed that for systems aged 8 minutes at 25°, 50° and 70° C, the relative mobilities (viscous effects) of the interface are similar. Therefore, we can use equation 5 to solve for IFT and relate the dynamic IFT behavior with coalescence.⁵

Figure 6 shows the dynamic IFT behavior for the Wilmington crude oil/sodium bicarbonate system during the time prior to coalescence. The plot shows that the longest dynamic IFT minimum occurred at 25° C which was the

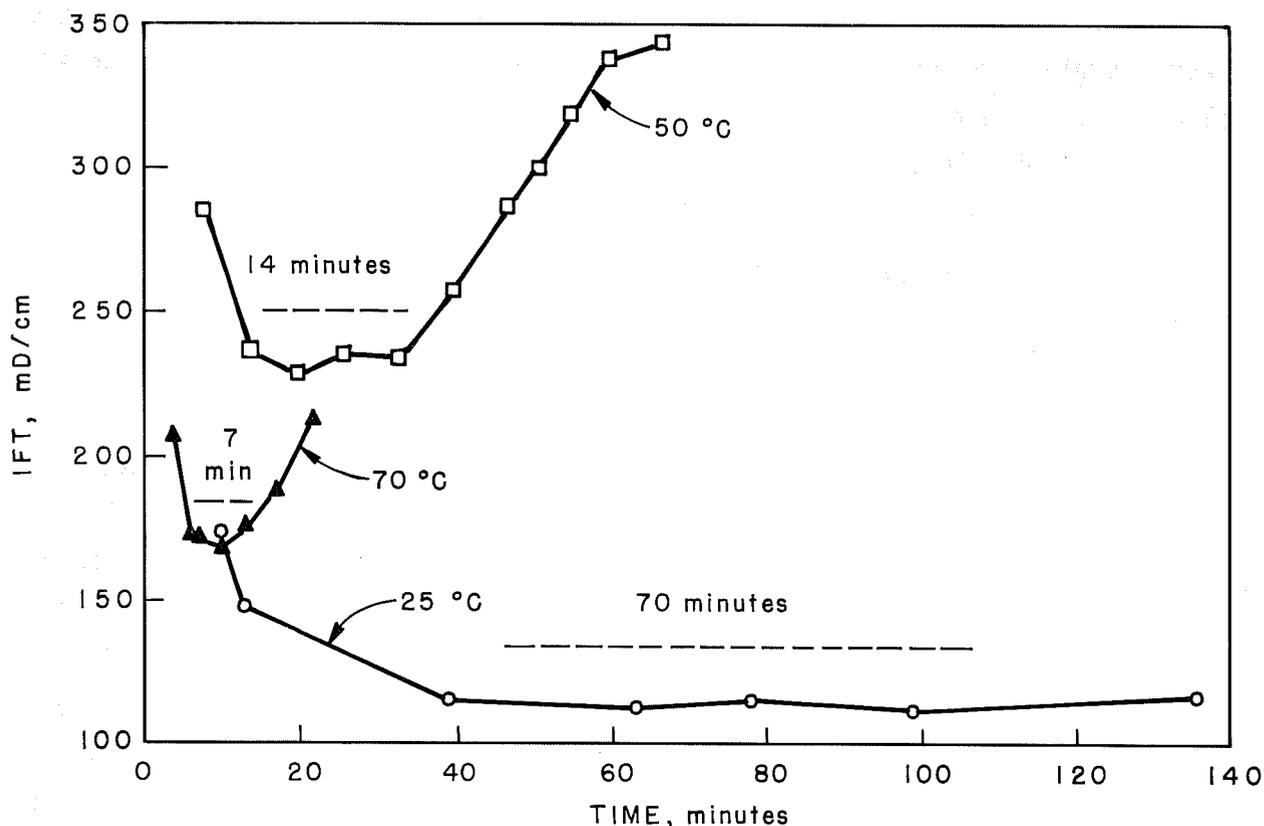


FIGURE 6. - Dynamic IFT behavior at three temperatures for systems with similar R_{max} values. IFT was calculated from equation 5 using experimentally measured values of contact radius.

system that had the longest coalescence times. Because minimum IFT corresponds with a maximum in interfacial surfactant concentration,¹⁴ this suggests that the natural surfactants in this system are emulsion stabilizers.

The plot of dynamic IFT behavior also shows that interfacial tension remained low for 70 minutes at 25° C, 14 minutes at 50° C, and for 7 minutes at 70° C. This indicates that the rate of desorption of natural surfactants from the interface is highly sensitive to temperature. Furthermore, the length of time that the IFT remained low was directly related to the experimentally measured average coalescence time for each system. This indicates that the coalescence of oil drops in alkaline brine depends more on how long the natural surfactants remain at the interface than on the actual value of IFT. These results suggest that interfacial tension does not correlate well with coalescence time, which has also been observed by other researchers.¹⁵⁻¹⁶

DISCUSSION

The main purpose of this work was to determine the effect of temperature and equilibration on the coalescence time of two acidic oil drops in a weakly alkaline brine. Because of the presence of natural surfactants and viscous components in Wilmington crude oil, coalescence will also depend on the concentration of these compounds and how much they impair film drainage.

In this study, the coalescence time of the two Wilmington crude oil drops was much longer in sodium bicarbonate (Tronacarb™) brine compared with the one successful trial in sodium chloride brine. This may be due to the accumulation of natural surfactants at the oil/water interface which slowed the film drainage process. However, it was observed that an increase in temperature or an increase in the age of the two oil drops promoted faster coalescence. This is likely to be due to the desorption of natural surfactants from the interface. The "desorption" theory is consistent with the observed increase in IFT before the coalescence event. No relationship was found between IFT and coalescence for the systems studied. This points out the fact that understanding the relationship among various interfacial properties and their effect on oil mobilization and oil bank formation is critical to the design of an optimized chemical system for enhanced oil recovery.

The significant results of this work are: (1) coalescence of acidic crude oil droplets in sodium bicarbonate brine (pH 9) is extremely sensitive to temperature, particularly after aging; (2) desorption of surfactant molecules from the interface after 1 hour at 70° C was so complete that film drainage occurred with little resistance; and (3) although the importance of oil drop coalescence has been well recognized, the coalescence of oil drops in laboratory evaluation and optimization of chemical EOR systems is usually neglected. The technique described here appears suitable for routine use because it can be conducted on the same spinning drop instrument used to determine IFT. The effects of bulk viscosity, divalent ions, suspended clays, and added surfactant on oil drop coalescence will be determined using this method and qualitatively compared in another Topical Report that will be submitted in August 1987.

EXPERIMENTAL CONCLUSIONS

1. Natural surfactants generated at pH 9 increase the coalescence time of oil drops probably due to a surfactant concentration gradient which provides resistance to flow at the interface. This promotes emulsification.
2. The 7-minute dynamic minimum in IFT at 70° C compared with the 70-minute dynamic minimum at 25° C indicates that temperature increases the rate of desorption of the natural surfactants from the interface. This promotes coalescence.
3. Elevated temperature has little effect on interfacial mobility (interfacial viscosity) when oil drops are aged in alkaline brine for 8 minutes. Conversely, elevated temperature has a significant effect on interfacial mobility when the oil drops are aged for 1 hour.
4. No direct relationship exists between IFT and drop-drop coalescence time for the systems studied.

5. The spinning drop tensiometer used to obtain drop-drop coalescence data appears to be a good technique for routine laboratory evaluation of chemical EOR systems. Relative rates of coalescence can be obtained and compared using this technique.
6. The Barber-Hartland theory used in this study to describe the relative mobility of the Wilmington crude oil/bicarbonate interface appears to be a reasonable model for film drainage when applied to a weakly alkaline EOR process.

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