

Wetting of Low-Energy Surfaces by Nonaqueous Solutions of Dimethylsiloxane-Containing or Fluorocarbon-Containing Surfactants

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February 27, 1969



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ABSTRACT

The wetting of low-energy solid surfaces by nonaqueous solutions has been investigated with solutions of copolymers of dimethylsiloxane-ethylene oxide and solutions of fluorocarbon-containing surfactants. The organic liquids studied were propylene carbonate, bis(2-ethylhexyl)sebacate, isopropylbiphenyl, and a partially chlorinated biphenyl. Surface-tension-vs-concentration isotherms were determined for the surfactants in these liquids. The solid surfaces studied were stearic acid and 11-(perfluorodecyl)undecanoic acid monolayers on stainless steel, polyethylene, and Teflon. In nearly all instances, the surfactants produced a marked improvement in the wetting of the low-energy surfaces by the organic liquids; however, they did not cause spontaneous spreading of the organic liquids on the smooth, solid surfaces, even when the solution surface tensions were depressed below the critical surface tensions of wetting of the solids. The failure of these surfactants to cause spontaneous wetting appears to be related to (a) the adsorption of the surfactant at the organic-solid/air interface and (b) the failure of the surfactants to significantly reduce the organic-solid/organic-liquid interfacial tensions.

PROBLEM STATUS

This is an interim report; work on this problem is continuing.

AUTHORIZATION

NRL Problem C02-10
Project RR 001-01-43-4751

Manuscript submitted September 24, 1968.

WETTING OF LOW-ENERGY SURFACES BY NONAQUEOUS SOLUTIONS OF DIMETHYLSILOXANE-CONTAINING OR FLUOROCARBON-CONTAINING SURFACTANTS

INTRODUCTION

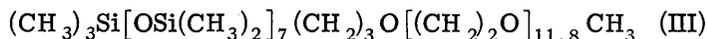
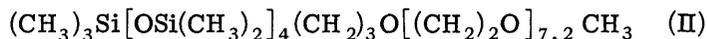
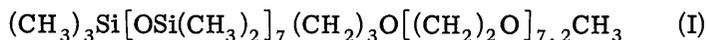
In recent years several new classes of siloxane-containing compounds and fluorocarbon-containing compounds have been shown to be surface active in nonaqueous systems. Blake, Ahlbrecht, and Bryce (1) and Zisman and coworkers (2-6) reported a number of fluorocarbon-containing derivatives that had remarkable surface activity in a variety of organic liquids. Schwartz and Reid (7) and Kanner, Reid, and Petersen (8) found that copolymers of polydimethylsiloxane and polyethylene oxide are effective surface-active agents in polypropylene glycol as well as water.

Because of their surface activity, dimethylsiloxane and fluorocarbon-containing surfactants should act as powerful wetting agents for nonaqueous systems, much as the conventional hydrocarbon surface-active agents act as wetting agents for water (9). The surface tensions of many organic liquids can easily be reduced below the critical surface tension of wetting γ_c of polyethylene ($\gamma_c = 31$ dynes/cm), and with the synthesis of more effective fluorocarbon-containing surface-active agents it should be possible to reduce the surface tensions of organic liquids below the γ_c of Teflon ($\gamma_c = 18.5$ dynes/cm). Thus, the wetting of many low-energy surfaces by organic liquids should be greatly improved by the addition of small amounts of an appropriate additive.

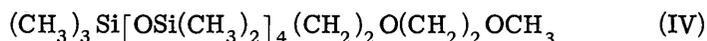
The present investigation was undertaken to determine the extent that certain highly surface-active derivatives will actually reduce the surface tension of propylene carbonate, isopropylbiphenyl, Aroclor 1232 (trichlorobiphenyl), and bis(2-ethylhexyl)sebacate and improve their ability to wet certain low-energy solid surfaces. Wetting data are reported for the nonaqueous solutions on polyethylene, Teflon, and oriented monolayers of stearic and 11-(perfluorodecyl)undecanoic acids adsorbed on stainless steel.

EXPERIMENTAL PROCEDURES AND MATERIALS

The surface-active compounds used in this study were prepared especially for research in surface chemistry. The dimethylsiloxane-ethylene oxide copolymers were kindly furnished by the Silicones Division of the Union Carbide Corporation. The preparation and properties of the copolymers were reported by Kanner, Reid, and Petersen (8). The lengths of the ethylene oxide chains of the



are average values. Chromatographic analysis showed that only



was a relatively pure compound, being better than 99% pure. The higher-molecular-weight copolymers each contained a number of homologs and apparently could not be purified by distillation (8). The two partially fluorinated diesters bis(1H,1H-pentadecafluorooctyl) 4-chlorophthalate and bis(1H,1H-undecafluorohexyl)3-methylglutarate were prepared in this laboratory by O'Rear and Sniegowski. The 1H,1H-pentadecafluorooctanol was obtained from the Minnesota Mining and Manufacturing Company and was redistilled before using. The propylene carbonate ($\gamma_{LV} = 40.6$ dynes/cm) was obtained from Eastman Organic Chemicals, the isopropylbiphenyl ($\gamma_{LV} = 35.2$ dynes/cm) and Aroclor 1232 ($\gamma_{LV} = 41.2$ dynes/cm) were obtained from the Monsanto Chemical Company, and the bis(2-ethylhexyl)-sebacate ($\gamma_{LV} = 31.0$ dynes/cm) was obtained from the Rohm and Haas Company. Aroclor 1232 contained 32 g-mole-% chlorine by weight. Polar contaminants were removed from the organic liquids by percolation through adsorption columns containing activated Florisil. The copolymers were used as received, because percolation through Florisil did not noticeably affect their surface activity.

The surface tensions of the solvents and solutions were determined with a Cenco-duNuoy interfacial tensiometer, using the Harkins and Jordan (10) correction tables. The platinum ring appeared to be completely wetted by the solutions in each case. After allowing at least a 1-hr equilibration time at 25°C, each solution was poured into a clean platinum dish and surface-tension measurements were started immediately. Surface tensions of the pure solvents and the fluorocarbon solutions were reproducible within ± 0.1 dyne/cm and showed no time dependence. However, the surface tensions of solutions of the first three dimethylsiloxane-ethylene oxide copolymers at low concentrations decreased with time, approaching a constant value after several minutes. When the copolymer solutions gave no significant decrease in surface tension over a 5-min period, it was assumed they were near equilibrium and the values were recorded. Variations in length of the ethylene oxide chains in these copolymers may account for the observed drifts in surface tension. Small amounts of the more surface-active homologs may be competing with the less strongly adsorbed molecules for adsorption at the interface. All glassware in these experiments was cleaned in hot 3:1 sulfuric-nitric acid, rinsed profusely with distilled water, and then dried before being used.

Polyethylene disks used in the study were prepared from relatively unbranched, antioxidant-free Super Dylan 6600 received from the Koppers Company in powder form. The preparation of the molded disks and techniques of cleaning the polyethylene surfaces have been described earlier by Bernett and Zisman (9). Specular Teflon surfaces were prepared as described previously (11). Acid cleaning of the Teflon was found to be unnecessary, since washing with Tide solution and rinsing profusely with distilled water effectively cleaned the surfaces. Oriented monolayers of stearic and 11-(perfluorodecyl)undecanoic acids were prepared on smooth stainless-steel disks by retraction from the melt (12). These steel disks (2-cm diameter) were highly polished using standard metallographic procedures, with the final polish being on a grease-free cloth wheel using 0.05- μ alumina. The surfaces were flushed with distilled water and allowed to dry prior to use.

All contact-angle measurements were made with a goniometer telescope (11), using the drop buildup method (13) to give the advancing equilibrium contact angle θ . Even though many of the copolymer solutions showed a decrease in surface tension with time, with only one exception the contact angles showed no time dependence. This exception was copolymer I in propylene carbonate on the 11-(perfluorodecyl)undecanoic acid monolayer, which gave a decrease in θ of up to 10 degrees during the first few minutes. The equilibrium contact angles were quite reproducible, generally varying no more than ± 2 degrees from the mean. All data were taken at $25 \pm 1^\circ\text{C}$.

EXPERIMENTAL RESULTS

The surface-tension-vs-concentration curves for the solutions are given in Fig. 1. In propylene carbonate, the additive bis(1H,1H-pentadecafluorooctyl)4-chlorophthalate and

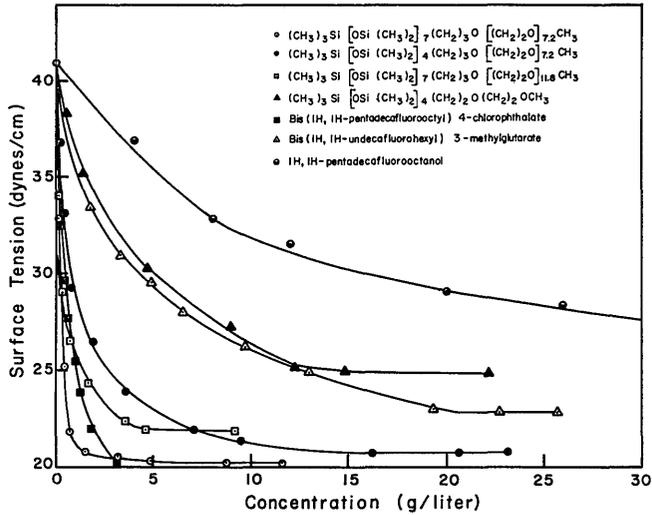


Fig. 1a - Surface-tension-vs-concentration isotherms of surface-active agents in propylene carbonate at 25°C

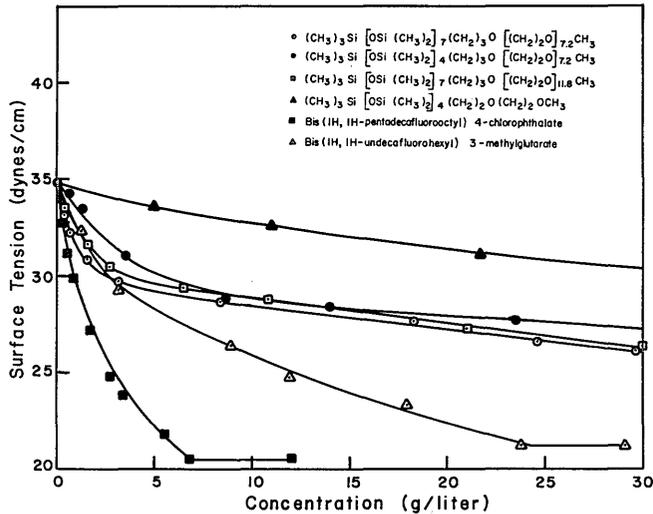


Fig. 1b - Surface-tension-vs-concentration isotherms of surface-active agents in isopropylbi-phenyl at 25°C

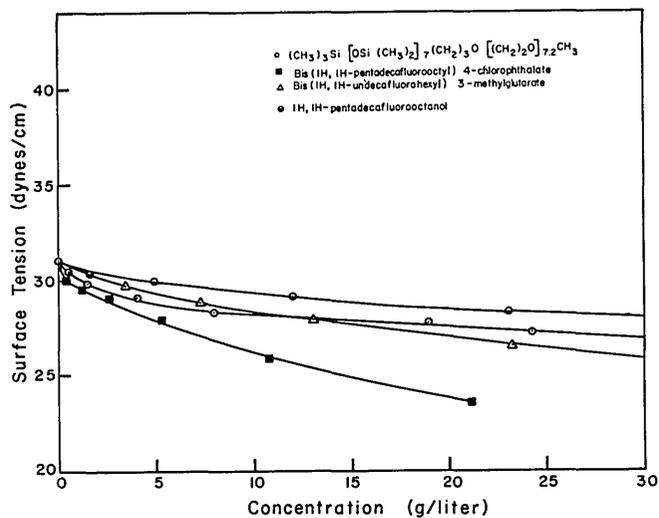


Fig. 1c - Surface-tension-vs-concentration isotherms of surface-active agents in bis(2-ethylhexyl)sebacate at 25°C

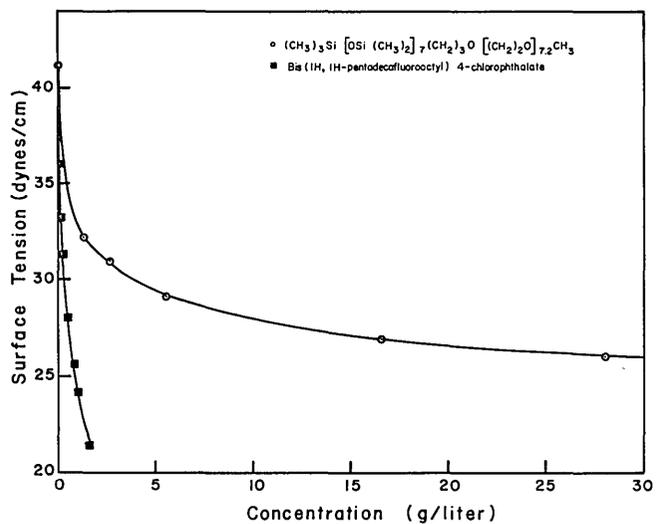


Fig. 1d - Surface-tension-vs-concentration isotherms of surface-active agents in Aroclor 1232 at 25°C

dimethylsiloxane-polyether copolymers I, II, and III showed remarkable surface activity; small concentrations of each reduced the surface tension to very nearly 20 dynes/cm. 1H,1H-pentadecafluorooctanol was considerably less surface active, while bis(1H,1H-undecafluorohexyl)3-methylglutarate and copolymer IV gave intermediate behavior. As expected the diester with the greatest fluorine content was the least soluble and in this case the most surface active.

In the solvents other than propylene carbonate, the dimethylsiloxane-ethylene oxide copolymers were considerably more soluble and less surface active; in fact, they were much less effective in reducing the solvent surface tension than either partially fluorinated diester. In no instance did the dimethylsiloxane-ethylene oxide copolymers reduce the surface tension of these other liquids below 25 dynes/cm. In isopropylbiphenyl, as in propylene carbonate, copolymers I, II, and III showed similar surface activity, with IV being considerably less effective. Due to the variation in length of the ethylene oxide chains in copolymers I, II, and III, few conclusions can be made regarding the differences in their surface activity. The observed differences may be due, in part, to the presence of one or more highly surface-active fractions in the samples, which are present in small concentrations.

Contact-angle θ data for the solutions on each low-energy surface are plotted in Figs. 2 to 5, as $\cos \theta$ against solution surface tension γ_{LV} . Additive 1 was $(\text{CH}_3)_3\text{Si}[\text{OSi}(\text{CH}_3)_2]_7(\text{CH}_2)_3\text{O}[(\text{CH}_2)_2\text{O}]_{7.2}\text{CH}_3$; additive 5 was bis(1H,1H-pentadecafluorooctyl)4-chlorophthalate; and additive 6 was bis(1H,1H-undecafluorohexyl)3-methylglutarate. Solid lines were arbitrarily drawn through either the propylene carbonate or the isopropylbiphenyl data points merely to indicate the general trend of the data. The $\cos\theta$ -vs- γ_{LV} plots for solutions of 1H,1H-pentadecafluorooctanol were nearly identical with those of the bis(1H,1H-undecafluorohexyl)3-methylglutarate solutions; therefore, the wetting data for the fluorinated alcohol solutions are not included. Since the dimethylsiloxane-ethylene oxide copolymers I, II, and III exhibited similar wetting behavior, only the wetting data for copolymer I are plotted. The wetting behavior of copolymer IV was the same as the other copolymers in isopropylbiphenyl but was markedly different when dissolved in propylene carbonate, where $\cos \theta$ actually went through a maximum as the solution surface tension decreased. At high concentrations the spreading drops of propylene carbonate containing copolymer IV showed a peculiar "tailing" at the solid/liquid/air intersection on each solid surface.

Included in each figure is the $\cos\theta$ -vs- γ_{LV} plot for a homologous series of pure n-alkane liquids. The n-alkane data, when extrapolated to $\cos \theta = 1$, give the accepted critical surface tension of wetting γ_c for each low-energy solid surface.

The contact-angle data on polyethylene for solutions of the surface-active additives in bis(2-ethylhexyl)sebacate, isopropylbiphenyl, and Aroclor 1232 gave values of γ_c very close to the n-alkane value, i.e., 31 dynes/cm, when extrapolated to $\cos \theta = 1$. However, the propylene carbonate solutions on polyethylene gave finite contact angles at solution surface tensions well below 31 dynes/cm. This poor wetting by the propylene carbonate solutions is similar to the wetting behavior reported by Bernett and Zisman (14) for aqueous solutions of highly fluorinated acids on polyethylene. They demonstrated that their results were due to adsorption of the fluorinated compounds onto the polyethylene, which reduced the wettability of the polymer surface. When we used the techniques employed by Bernett and Zisman (14) to demonstrate solute adsorption, we did not obtain conclusive evidence of adsorption of the fluorinated diesters, or the dimethylsiloxane-ethylene oxide copolymers, on polyethylene from propylene carbonate. Their procedure was to test for changes in wettability of the surface after it had been exposed to the surfactant solution. Only in the case of the highly polar perfluorooctyl alcohol was there evidence that an adsorbed layer of fluorocarbon molecules was present on the polyethylene after being immersed in propylene carbonate solutions of the alcohol. This does not rule

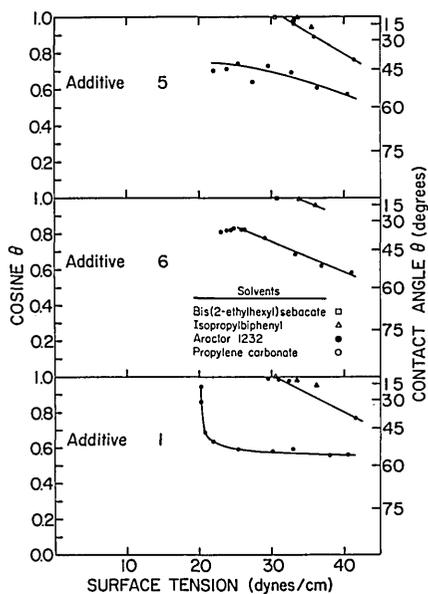


Fig. 2 - $\text{Cos } \theta$ vs solution surface tension for nonaqueous surfactant solutions on polyethylene

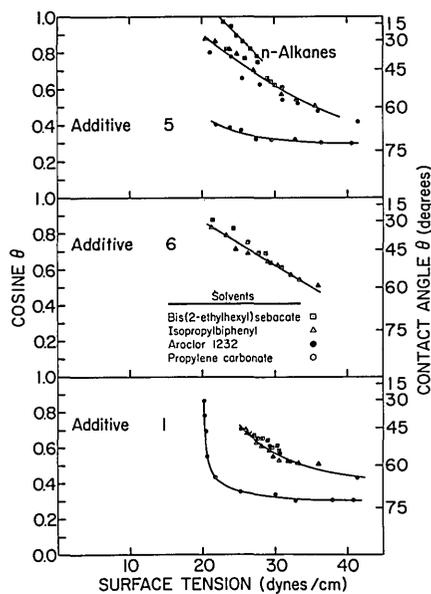


Fig. 3 - $\text{Cos } \theta$ vs solution surface tension for nonaqueous surfactant solutions on oriented monolayers of stearic acid adsorbed on stainless steel

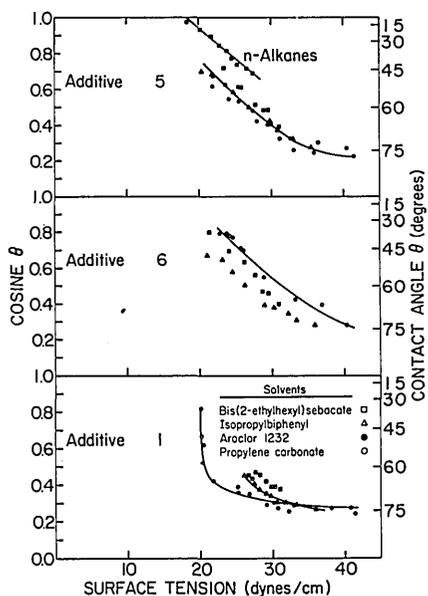


Fig. 4 - $\text{Cos } \theta$ vs solution surface tension for nonaqueous surfactant solutions on Teflon

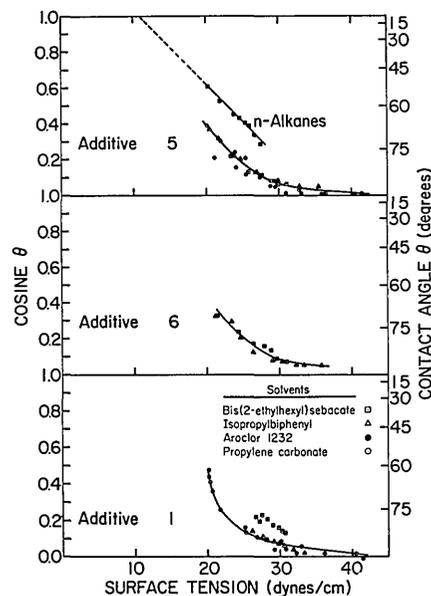


Fig. 5 - $\text{Cos } \theta$ vs solution surface tension for nonaqueous surfactant solutions on oriented monolayers of 11-(perfluorodecyl)undecanoic acid adsorbed on stainless steel

out the possibility of the other less polar additives also adsorbing to some extent from propylene carbonate; it may indicate only that they are more weakly held on the surface or more easily displaced from the polyethylene by the solvent or the pure liquids used in the wetting studies.

The solutions on the adsorbed stearic acid monolayers also gave higher contact angles than the n-alkanes of equivalent surface tensions. The propylene carbonate solutions were most notable in this regard. Again, no conclusive evidence of adsorption of our additives was detected using the technique of Bennett and Zisman (14).

On the fluorinated surfaces, Teflon and vertically oriented 11-(perfluorodecyl)-undecanoic acid monolayers, each of the solutions again gave much higher contact angles than n-alkanes of the same surface tension. The $\cos\theta$ -vs- γ_{LV} plots were also generally curved rather than linear, making it difficult to determine γ_c values by extrapolation. It is interesting that the propylene carbonate solutions on the low surface-energy fluorocarbons showed behavior similar to the other solutions, rather than the anomalous behavior observed on the hydrocarbon surfaces.

The $\cos\theta$ -vs- γ_{LV} curves for the propylene carbonate solutions of the dimethylsiloxane-ethylene oxide copolymers on the various solid surfaces were most unusual. On the hydrocarbon surfaces, they were displaced well below the other wetting curves, and on all surfaces they approached asymptotically a γ_c value of 20 dynes/cm. This is very close to the γ_c expected for a dimethylsiloxane surface and suggests that a layer of copolymer was deposited from the more concentrated solutions onto the fluorocarbon surfaces. Because of the low surface energy of the solid fluorocarbons, adsorption of monolayers of a hydrocarbon-containing copolymer is unlikely; it is more likely that a much thicker layer separated as a bulk phase from a saturated, or near-saturated, solution. In the case of copolymer IV the film was often thick enough to give visible interference colors.

Solutions of the fluorinated diesters in propylene carbonate and bis(2-ethylhexyl)-sebacate were observed to spread spontaneously on clean stainless steel. Solutions of the dimethylsiloxane-ethylene oxide copolymers and 1H, 1H-pentadecafluorooctanol in both propylene carbonate and isopropylbiphenyl failed to spread. The simple test used by Bennett and Zisman (14) indicated adsorption of 1H, 1H-pentadecafluorooctanol and adsorption of some component of the dimethylsiloxane-ethylene oxide copolymer on the stainless-steel surface but did not indicate adsorption of the diesters. The copolymer solutions gave contact angles of approximately 30 degrees on the clean stainless steel.

DISCUSSION

It is apparent that the effectiveness of the dimethylsiloxane-ethylene oxide copolymers as surface-active agents or wetting agents for nonaqueous systems will vary with the nature of the organic solvents; that it, they will not show the same degree of effectiveness in all organic liquids. Rather, their surface activity will depend on their organophobic-organophilic balance (or solubility balance) with respect to the specific liquid, as demonstrated earlier by Jarvis and Zisman (5,6) for fluorocarbon surfactant systems. Even though the dimethylsiloxane-ethylene oxide copolymers may, in general, be less effective than certain fluorocarbon derivatives, they do give remarkable reductions in the surface tensions of several organic liquids.

As given by Young's equation

$$\gamma_{LV} \cos \theta = \gamma_{SV} - \gamma_{SL} \quad (1)$$

the wetting of low-energy surfaces by the nonaqueous solutions will depend on the free energies of the interfaces involved. The solution surface tension γ_{LV} and the contact angle θ can be measured directly, but reliable estimates of the solid/liquid and solid/vapor interfacial energies are difficult to achieve, especially as a function of solute concentration. Therefore, a straightforward explanation of the wetting data cannot be made in terms of known surface energies. However, in a number of instances it may be possible, using Young's equation, to determine by inference whether or not adsorption is likely to have occurred.

The product $\gamma_{LV} \cos \theta$, which can be determined experimentally, is sometimes referred to as the "adhesion tension," and from Young's equation is equal to $\gamma_{SV} - \gamma_{SL}$. When there is no adsorption of an additive from solution at either the solid/liquid interface or the solid/vapor interface during a series of wetting experiments, γ_{SV} and γ_{SL} (and thus $\gamma_{LV} \cos \theta$) will necessarily remain constant as the solution surface tension is reduced. For solutions of the additives in bis(2-ethylhexyl)sebacate, isopropylbiphenyl, and Aroclor 1232 on polyethylene, $\gamma_{LV} \cos \theta$ was found to be essentially constant with decreasing surface tension, an indication that additive adsorption had not occurred at the polyethylene/air or polyethylene/solution interfaces. If adsorption had occurred, it would have had to take place at both interfaces simultaneously and in such a manner that the difference $\gamma_{SV} - \gamma_{SL}$ would remain constant. Such adsorption behavior would be most unusual, and in fact no adsorption was observed experimentally; i.e., no evidence was found of adsorbed material at the surface of polyethylene after exposure to these wetting solutions.

On the other hand, the calculated adhesion tensions of the propylene carbonate solutions on polyethylene initially decreased as the solution surface tensions were reduced, most likely due to a decrease in γ_{SV} as solute molecules adsorbed at the polyethylene/air interface. Adsorption from propylene carbonate solution at the solid/vapor interface was observed experimentally in the case of the perfluorooctyl alcohol but was not conclusively demonstrated for the diesters or the copolymers, which also showed decreases in $\gamma_{SV} - \gamma_{SL}$ as the solution surface tensions decreased. At higher concentrations $\gamma_{LV} \cos \theta$ for the polydimethylsiloxane-ethylene oxide copolymer solutions in propylene carbonate went through a minimum; at the same time there was evidence that multimolecular layers of the copolymer were accumulating at the polyethylene surface, possibly precipitating from the saturated and near-saturated solutions onto the solid/liquid as well as the solid/air interface.

On oriented stearic acid monolayers the adhesion tension also remained constant with decreasing solution surface tension for all additive solutions except those in propylene carbonate. For the propylene carbonate solutions $\gamma_{SL} \cos \theta$ initially decreased, again most likely due to solute adsorption at the solid/air interface, thereby decreasing γ_{SV} .

All surfactant solutions on both fluorocarbon surfaces gave adhesion tensions that increased rather than decreased with decreasing solution surface tension. For $\gamma_{SV} - \gamma_{SL}$ to increase with decreasing γ_{LV} , either γ_{SV} must increase or γ_{SL} must decrease. A decrease in γ_{SL} is the most reasonable explanation, because only with the concentrated copolymer solutions in propylene carbonate, where bulk additive appeared to be deposited on the surface from the near-saturated solutions, would an apparent increase in γ_{SV} be even plausible. It thus appears that adsorption of the surface-active additive is occurring at the fluorocarbon/solution interface but not at the hydrocarbon/solution interface, where the initial solid/liquid interfacial tension would be much less.

From Figs. 3, 4, and 5 it is seen that all of the additive solutions gave higher contact angles on the oriented stearic acid monolayers and both fluorocarbon surfaces than did the pure alkanes. This relatively poor wetting by the additive solutions could be due to their greater interfacial tension with respect to these surfaces as well as to solute adsorption. When spreading drops of two liquids with equivalent surface tensions are

placed on the same surface, it is apparent from Young's equation that the liquid with the lowest interfacial tension will give the lowest contact angle, if there is no solute adsorption. Table 1 gives values of γ_{SL} for the pure liquids against each solid surface calculated with Eq. 1, using the measured values of γ_{LV} and $\cos \theta$ and Fowkes' (15) calculated estimates of the surface-free energies of the organic solids γ_{SV} . These estimated γ_{SL} values show the interfacial energies of the substrate liquids to be much higher than the alkanes, high enough to account for much of the reduced wettability. Fowkes' values of γ_{SV} , based on dispersion forces, may be somewhat in error, especially for the fluorocarbons, but at least they demonstrate that the poor wetting does not necessarily imply solute adsorption in every case. It would be very difficult in many cases to decide from the evidence available whether adsorption is occurring just at the solid/air or the solid/liquid interface or at both interfaces simultaneously. More precise interpretation of the wetting data will require better techniques for actually detecting the presence of adsorbed molecules at the various solid/liquid and solid/air interfaces.

Table 1
Calculated Solid/Liquid Interfacial Tensions for Pure
Liquids on Organic Surfaces

Liquid	γ_{LV} (dynes/cm)	Solid/Liquid Interfacial Tension, γ_{SL} (dynes/cm)			
		Polyethylene	Stearic Acid Monolayer	Teflon	11-(perfluorodecyl)- undecanoic Acid Monolayer
		($\gamma_{SV}^* = 35.0$ dynes/cm)	($\gamma_{SV}^* = 22.1$ dynes/cm)	($\gamma_{SV}^* = 19.5$ dynes/cm)	($\gamma_{SV}^* = 13.0$ dynes/cm)
Hexadecane	27.6	(Spreads)	0.3	0.5	2.4
Bis(2-ethylhexyl)- sebacate	31.0	(Spreads)	3.0	7.4	10.8
Isopropylbiphenyl	35.2	1.6	4.2	9.9	11.3
Aroclor 1232	41.2	3.6	4.7	11.0	15.0
Propylene carbonate	40.6	11.2	9.8	10.3	12.3

*Estimated γ_{SV} interfacial tensions from Fowkes (15).

CONCLUSIONS

Dimethylsiloxane-ethylene oxide copolymers were found to be effective surface-active agents for organic liquids; in some liquids their effectiveness approached that of certain fluorine-containing compounds. The surface activity of the additives makes them effective wetting agents for nonaqueous systems, markedly improving their ability to wet low-energy solid surfaces, such as polyethylene, Teflon, and adsorbed monolayers of stearic acid and 11-(perfluorodecyl)undecanoic acid on stainless steel. In all solvents studied, except propylene carbonate, the wetting behavior of the dimethylsiloxane-ethylene oxide copolymer solutions appeared to be the same as the fluorocarbon solutions at equivalent solution surface tensions. However, in no instance did the additive solutions wet the low-energy surfaces as well as the pure alkane liquids of the same surface tensions. On the oriented stearic acid monolayers they even failed to spread spontaneously when their surface tensions were well below the accepted critical surface tension of wetting for $-\text{CH}_3$ surfaces. The inability of these nonaqueous solutions to show better wetting appears to be due to (a) the adsorption of solute at the organic-solid/air interface in certain cases and (b) the failure of the additives to reduce the relatively high interfacial tensions between the low-energy surfaces and the somewhat polar organic liquids.

On clean stainless-steel surfaces, solutions of the partially fluorinated diesters in propylene carbonate and bis(2-ethylhexyl)sebacate spread spontaneously. On the other

hand, solutions of the copolymers and perfluorooctyl alcohol in propylene carbonate and isopropylbiphenyl gave finite contact angles due to adsorption of the additives on the clean steel surfaces.

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DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Research Laboratory Washington, D.C. 20390		2a. REPORT SECURITY CLASSIFICATION Unclassified	
		2b. GROUP	
3. REPORT TITLE WETTING OF LOW-ENERGY SURFACES BY NONAQUEOUS SOLUTIONS OF DIMETHYLSILOXANE-CONTAINING OR FLUOROCARBON-CONTAINING SURFACTANTS			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) An interim report; work is continuing on the problem			
5. AUTHOR(S) (First name, middle initial, last name) W.D. Bascom, L.A. Halper, and N.L. Jarvis			
6. REPORT DATE February 27, 1969		7a. TOTAL NO. OF PAGES 13	7b. NO. OF REFS 15
8a. CONTRACT OR GRANT NO. NRL Problem C02-10		9a. ORIGINATOR'S REPORT NUMBER(S) NRL Report 6808	
b. PROJECT NO. RR 001-01-43-4751		9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
c.			
d.			
10. DISTRIBUTION STATEMENT This document has been approved for public release and sale; its distribution is unlimited.			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY Department of the Navy (Office of Naval Research), Washington, D.C. 20360	
13. ABSTRACT <p>The wetting of low-energy solid surfaces by nonaqueous solutions has been investigated with solutions of copolymers of dimethylsiloxane-ethylene oxide and solutions of fluorocarbon-containing surfactants. The organic liquids studied were propylene carbonate, bis(2-ethylhexyl)sebacate, isopropylbiphenyl, and a partially chlorinated biphenyl. Surface-tension-vs-concentration isotherms were determined for the surfactants in these liquids. The solid surfaces studied were stearic acid and 11-(perfluorodecyl)undecanoic acid monolayers on stainless steel, polyethylene, and Teflon. In nearly all instances, the surfactants produced a marked improvement in the wetting of the low-energy surfaces by the organic liquids; however, they did not cause spontaneous spreading of the organic liquids on the smooth, solid surfaces, even when the solution surface tensions were depressed below the critical surface tensions of wetting of the solids. The failure of these surfactants to cause spontaneous wetting appears to be related to (a) the adsorption of the surfactant at the organic-solid/air interface and (b) the failure of the surfactants to significantly reduce the organic-solid/organic-liquid interfacial tensions.</p>			

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Wettability Surfactants Surface Tension Low-energy surface wetting Dimethylsiloxane-containing surfactants Fluorocarbon-containing surfactants						