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REVIEW OF EMULSIFIED ANTIFOAMS FOR AIRCRAFT
LUBRICATING OILS.

By W. W. Woods and J. V. Robinson

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SUMMARY

The majority of effective antifoams are insoluble in the liquids which they defoam. The mechanism of defoaming by such insoluble emulsified antifoams is explained. Defoaming ability may be predicted from measurements of surface tension. It is shown theoretically that aircraft lubricating oils are more likely to be defoamed by antifoams of the insoluble emulsified type than by any other type.

The essential prerequisites applicable to all antifoaming additives active as emulsions in lubricating oil are listed. Four distinct types of emulsified antifoam theoretically can exist.

Partial solubility of antifoams in lubricating oils complicates surface-tension measurements on which predictions of defoaming ability are based. Reliable experimental methods of evaluation are discussed.

A survey is made of the experimental progress in emulsified antifoams. Effective examples of all four theoretical types have been found, and the prospects appear good for future development of more economical and entirely satisfactory antifoams.

INTRODUCTION

The search for antifoaming additives has previously been conducted haphazardly, with little or no theoretical guidance either as to the mechanism of defoaming or the essential prerequisites for an effective antifoam. In reference 1, a theory has been developed which permits the logical choice and improvement of insoluble antifoams and, furthermore, provides a basis for reviewing known antifoams. The present report integrates the extensive experience of the Stanford University laboratories in this field and presents a guide for further experimentation by workers in the future.

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MECHANISM OF DEFOAMING BY EMULSIFIED ANTIFOAMS

The mechanism of defoaming by insoluble agents has only recently been expounded (reference 1), although it has been known for many years that surface and interfacial tensions must be concerned. These anti-foams are now known to promote bubble coalescence as well as film rupture (and may even stabilize surface bubbles). The basic mechanism involved is apparently the simultaneous collision of two air bubbles with a small droplet of emulsified antifoam. This droplet enters both bubbles and spreads on their inner surfaces. The two air bubbles are thus momentarily connected by the droplet of liquid. Unequal surface tensions and the spreading of the antifoam on the inner surfaces of the bubbles complete the destruction of the lamella separating the bubbles, and they coalesce. The large bubbles thus formed are unstable and escape readily. The physical properties required for such action are

$$\sigma_F + \sigma_{DF} > \sigma_D$$

the entering requirement, and

$$\sigma_F > \sigma_{DF} + \sigma_D$$

the spreading requirement, where

σ_F	surface tension of foaming liquid
σ_D	surface tension of defoamer droplet
σ_{DF}	interfacial tension between defoamer droplet and foaming liquid

As the interfacial tension σ_{DF} is small for emulsions of reasonable stability, it can be seen that the prime prerequisite is that the surface tension of the emulsified defoamer be several dynes per centimeter lower than that of the foaming system. This mechanism is theoretically independent of the chemical nature of the foaming system and has been applied with good correlation by Robinson and Woods (reference 1) in the prediction of antifoaming action for a large number of additives tested in both aqueous and nonaqueous foaming systems.

PROBABILITY THAT EFFECTIVE ANTIFOAMS FOR LUBRICATING OILS
WILL BE OF EMULSION TYPE

A careful study of the recorded literature on antifoaming additives reveals that the majority of effective antifoams are not soluble in the foaming systems they defoam. (See reference 1.) The survey made in this laboratory has revealed no substances soluble in lubricating oil which are capable of permanently defoaming it.

There are certain grounds for believing that the absence of soluble antifoams for lubricating oils is more than fortuitous. All the known examples of soluble antifoams for other liquids, which have a permanent effect, act by removing or destroying the foam-stabilizing agent. Evidence has been accumulated which indicates that there is no specific foam-stabilizing agent in lubricating oil, but rather that the foaming is a property of the hydrocarbon mixture itself. Such evidence, which is presented in detail in reference 2, is that simple binary mixtures of pure nonfoaming hydrocarbons (for example, 80 percent toluene with 20 percent decane) will foam; that none of the fractions obtained by solvent extraction of aircraft lubricating oil will foam to the extent of the original oil; and that the foam stability of lubricating oils is almost directly proportional to their viscosity, a property of the bulk of the liquid.

Several instances are cited in the experimental work discussed in the present report in which the apparent defoaming effect of soluble substances proved to be temporary. Such a defoaming effect persists only as long as the antifoam remains undissolved. Typical examples of such temporary antifoams in aqueous systems are the higher alcohols (usually 6 to 10 carbon atom chains) commonly used to destroy foams in aqueous solutions of soaps and detergents.

ANALYSIS OF PROBLEM OF SELECTION OF
EMULSIFIED ANTIFOAMS

Criteria for Successful Antifoam

The mechanism of defoaming by emulsified antifoams and the operating conditions in aircraft engines being considered, a successful antifoam for aircraft lubricating oil should possess the following properties:

- (1) Relative insolubility in oil.
- (2) Dispersibility to a fine, stable emulsion.
- (3) Surface tension several dynes per centimeter lower than that of the oil at engine temperatures.

- (4) Nonvolatility at all engine operating temperatures.
- (5) Chemical compatibility with additives used in lubricating oil for purposes other than antifoaming.
- (6) No corrosiveness nor injuriousness to lubrication.
- (7) No decomposition to form compounds which are corrosive or deleterious to lubrication.

Types of Emulsified Antifoam

Theoretically, at least four types of emulsified antifoam which meet the foregoing requirements can be made:

Type 1: A single constituent of surface tension lower than that of the oil and insoluble therein, which forms stable emulsions with the oil.

Type 2: One constituent of surface tension lower than that of oil and insoluble therein, emulsions of which are stabilized by the addition of a second constituent.

Type 3: One constituent which is insoluble in oil, but which has its surface tension reduced and its emulsions stabilized by the addition of a second agent.

Type 4: One constituent which is insoluble in oil, but which has its surface tension reduced by a second constituent and its emulsions stabilized by a third constituent.

Distribution of Antifoam Components between Phases

Great experimental difficulties are encountered in obtaining data which may validly be applied to predicting antifoam action. Most compounds suitable as antifoams or used in compounding antifoams have appreciable, though often very low, oil solubilities. Thus, when an additive is dispersed in oil, the additive phase will often be found to contain dissolved oil and the oil phase, to contain dissolved additive. A common result of this mutual solubility is that the surface tension of the additive is raised and that of the oil lowered, even to the extent that antifoaming action is impossible. Unfortunately, direct measurement of the surface tension of a small amount of finely and stably dispersed additive is not experimentally feasible.

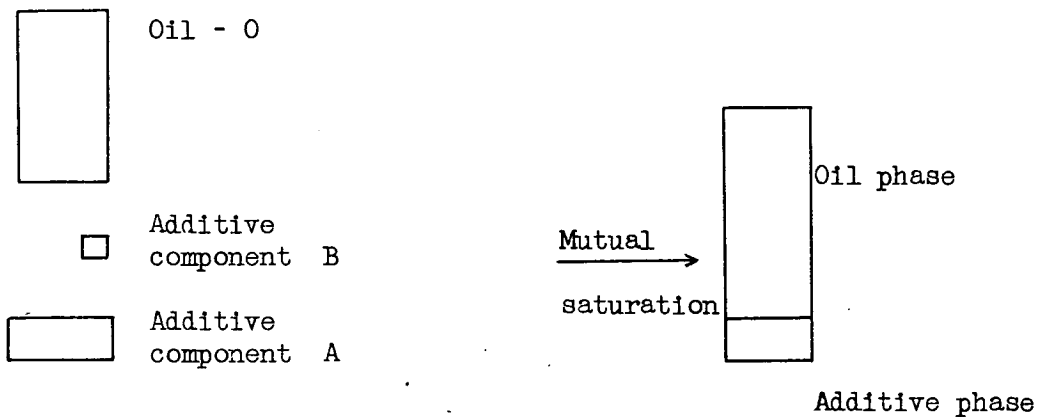
For type 1 antifoams, the additive is a single component, so that the concentration of the mutually saturated phases is independent of their relative quantities, provided that minor constituents are not.

selectively extracted. Therefore, mutually saturated phases may be prepared by mixing oil and additive in any more convenient ratio, allowing sufficient time for equilibrium to be reached, and separating the phases to measure their surface tensions.

For antifoams of types 2, 3, and 4, where the additive consists of two or more components, the components distribute between the additive and oil phases, and the concentration of the components in the two phases depends on their relative solubilities in each and on the relative amounts of each of the two phases.

The following analysis shows that the concentration of a component in each of two completely immiscible liquids in contact depends on the relative solubility of the component in each liquid and on the relative amounts of each liquid present. The symbols used in this analysis are as follows:

A	total weight of additive component A, grams
$[A]_{oil}$	concentration of A dissolved in oil phase, percent
B	total weight of additive component B, grams
$[B]_A$	concentration of B dissolved in additive phase, percent
$[B]_{oil}$	concentration of B dissolved in oil phase, percent
$f_1()$, $f_2()$	any functions of variables in parentheses
K	distribution coefficient $\left(\frac{[B]_{oil}}{[B]_A} \right)$
O	total weight of oil, grams
$[O]_A$	concentration of oil dissolved in additive phase, percent
X	weight of oil dissolved in additive phase, grams
Y	weight of A dissolved in oil phase, grams
Z	weight of B dissolved in oil phase, grams



Additive component B is the emulsifying agent and surface-tension depressant. For simplicity, assume that the oil O and the bulk of the additive A are completely insoluble in each other and that $O \gg B \ll A$ (as is true in the practical case). If Z grams of B travel from the additive phase to the oil phase, after mixing, then

$$[B]_{\text{oil}} = Z/O$$

$$[B]_A = (B - Z)/A$$

By definition,

$$K = \frac{[B]_{\text{oil}}}{[B]_A}$$

and, by substitution,

$$[B]_A = B/(A + KO)$$

or, since in the practical case $K > 1$ (emulsifiers promoting water-in-oil-type emulsions are quite oil-soluble),

$$KO \gg A$$

and

$$[B]_A = B/KO$$

Thus the concentration of an emulsifying agent or surface-tension depressant in the additive is found to depend on the amount of oil present, and the surface-tension depression varies with this concentration.

The equilibrium concentrations of the mutually saturated oil and additive phases can be computed, however, from experimentally measured solubilities, in order to make up solutions on which the proper surface tensions may be measured directly. The method is illustrated in equations (1) to (6) for type 2 and type 3 antifoams and a similar, though more complex, treatment can be derived for antifoams of type 4. (See preceding diagram.) First the distribution coefficient for component B between oil and component A must be determined by use of experimentally convenient oil-to-additive ratio. For this determination, an aliquot portion of either the oil or additive phase must be analyzed for B.

After analysis, the distribution coefficient is calculated:

$$K = \frac{[B]_{oil}}{[B]_A} \quad (1)$$

The next step is to measure the solubility of component A in the oil. However, the solubility of A in the oil may vary significantly with the concentration of B in the oil; that is,

$$[A]_{oil} = f_1([B]_{oil}) \quad (2)$$

Likewise, the solubility of the oil in the additive phase may depend upon the concentration of B in the additive phase:

$$[O]_A = f_2([B]_A) \quad (3)$$

It is assumed that the concentration of oil in A and of A in oil does not significantly affect the distribution coefficient of B.

With these data, the exact constitution of each phase can be calculated, regardless of the relative amounts of oil, component A, and component B used. This calculation is made as follows:

$$K = \frac{[B]_{oil}}{[B]_A} = \frac{\frac{Z}{O - X}}{\frac{B - Z}{A - Y}} \quad (4)$$

$$[A]_{oil} = Y/(O - X) = f_1([B]_{oil}) = f_1\left(\frac{Z}{D - X}\right) \quad (5)$$

$$[O]_A = X/(A - Y) = f_2 [B]_A = f_2 \left(\frac{B - Z}{A - Y} \right) \quad (6)$$

The difference $(O - X)$ may be considered equal to O , the amount of oil being relatively large. These are three independent functions relating three variables (X, Y, Z) ; hence equations (4), (5), and (6) may be solved to determine the exact constitution of each phase at equilibrium for any selected values of O, A , and B . If the constitution is known, each phase can be independently prepared in quantities sufficiently large for direct surface-tension measurements.

In practice, avoidance of these accurate but time-consuming methods of predicting antifoam action generally proves convenient when promising additives are to be screened from a large number of possibilities. For this reason, most of the work in this laboratory has been confined to room-temperature measurements of additive surface tension. Additives of surface tension lower than that of oil were thus selected from a large number of possibilities, and many of those selected proved to be effective antifoams. Examples of each of the four types of emulsified antifoam have been found. The experimental work described herein is only a beginning in this field, however, and should be regarded chiefly as a guide to further experimentation.

TEST PROCEDURE

Surface Tensions

The experimental surface tensions reported in this paper were measured by the ring method with a Cenco du Nouy Precision Tensiometer. The ring employed was a Cenco platinum-iridium ring of 4.00-centimeter mean circumference with a radius ratio of 40.2. Readings obtained with this instrument should be corrected for the weight of liquid raised by the ring. Inasmuch as this work was essentially a survey intended to reveal substances of surface tension considerably below that of oil, and as the densities of most of the additives are near that of oil, no corrections were made. However, corrections for this ring have been calculated (from the tables of Harkins and Jordan, reference 3) and are tabulated for reference:

Apparent surface tension (dynes/cm)	Correction to be subtracted	
	Density	
	0.9	1.0
10	1.75	1.84
20	2.43	2.55
25	2.62	2.80
30	2.72	2.97
35	2.71	3.03
40	2.63	3.00
45	2.46	2.90
50	2.22	2.73
55	1.91	2.51
60	1.51	2.19

Solubility

Most of the solubilities at 100° C were obtained by visual inspection of test tubes containing 10 cubic centimeters of oil and approximately 0.1 centimeter (0.1 gram in the case of solids) of the additive. The tubes were placed in an oven to be heated, then removed and shaken, and the presence or the absence of undissolved material noted.

In some cases, particularly those in which the additive was insoluble at 100° C, the tubes were cooled to room temperature and examined again for the presence of undissolved material.

Cases in which the additive was very soluble in the oil at room temperature were noted incidentally, without special solubility tests.

If the additive dissolves, it is denoted soluble S, and, if undissolved material is still visible by the tube test, it is denoted insoluble I.

Foam Tests

The foam-test results reported in this paper are reported in detail (references 4 to 10). The foam results quoted were obtained by one or several of the following methods:

- (1) Air bubbling at 100° C. (These data are preferred, where available.)
- (2) Aeration and evacuation at room temperature and at 100° C.

- (3) Beating and evacuation, at room temperature and at 100° C.
(This method is the least dependable of the four.)
- (4) Electric-kitchen-mixer beating at room temperature. (These data are preferred, where available.)

The methods have been fully described in a previous report (reference 4).

The foam-test grading system used is as follows:

- | | |
|---|--|
| A | only traces, or no foam |
| B | foaming reduced to approximately one-fifth of original |
| C | foaming reduced to approximately one-third to one-half of original |
| D | foaming reduced by less than one-half of original |
| E | no effect |
| F | foam stabilized |

RESULTS

The measured surface tensions of organic substances and their mixtures were intended to permit the selection of compounds and mixtures of compounds which would effectively defoam aircraft lubricating oil by the mechanism previously described. As mentioned in a preceding section, this survey was conducted by measuring surface tensions of antifoam constituents separately from the oil. Strictly speaking, only those surface tensions are valid which represent mixtures having the composition of the oil and antifoam phases after they have had sufficiently long contact to permit equilibrium to be established and when they are present in the relative quantities in which they will be actually used in service. However, consideration of the qualitative solubilities of the various substances in oil, in conjunction with the surface-tension data obtained, permits a rough evaluation of potential antifoam ability which is of value.

Such qualitative observations on solubility as have been noted are therefore included in the tables. Since nonvolatility is a requisite of all constituents of an antifoam for aircraft lubricating oils, boiling points are tabulated for those substances for which they were available.

The data in general have been grouped in the tables according to their applicability to the consideration of antifoam types 1, 2, 3, or 4, in that order. Most of the data are included in tables I to X.

The surface tensions of existing military aeronautical lubricating oils (unused) have been found to lie between 34 and 35 dynes per centimeter (uncorrected, 31.3 and corrected, 32.3) at room temperature. The effect of use in aircraft engines is a slight lowering of these values. The extent of the lowering is apparently dependent on the duration and the severity of use but has not been observed to be greater than 3 dynes per centimeter. Therefore, additives of any type which exhibit surface tensions much above 30 dynes per centimeter (uncorrected) are not likely to defoam both new and used oils.

Table I presents experimental surface-tension and oil-solubility data for a variety of organic compounds. Solubilities are expressed as insoluble I or soluble S, at an additive concentration of approximately 1 percent, with BKH medicinal mineral oil and Aeroshell 120 as solvents. Boiling-point data (from handbooks and critical tables) are also included for compounds when volatility at 100° C may preclude their use as antifoaming agents.

Table II presents the results of foam tests on some of the more promising or theoretically interesting single-constituent additives. Although these foam-test data have previously been reported in detail, they have never before been correlated with additive surface tension and solubility, as is done in table II.

Table II contains three cases of apparent foam inhibition (at room temperature) where the additive is oil-soluble. In each of these cases, the testing was a rapid, but crude, evacuation method and has never been rechecked or compared with any other test method. Quite probably the defoaming effect is temporary and results from the slowness of the additive in dissolving in the viscous oil.

The defoaming effect shown by 2-nitrobutanol-1 is also contrary to the current theory inasmuch as the surface tension of this additive is much higher than that of oil. The sample of 2-nitrobutanol-1 is, however, impure (opaque brown in color), containing suspended material. The defoaming action may be due to the suspended material of unknown surface tension rather than the 2-nitrobutanol-1 itself.

A number of compounds suitable for the insoluble components of type 2 antifoams are listed in table III together with their experimentally determined surface tensions. The essential prerequisite for this type of emulsified foam inhibitor is that it shall consist of an oil-insoluble component having a surface tension lower than that of the oil to be defoamed and a dispersing agent which adequately emulsifies the insoluble component without causing either its solubilization or serious reduction of the surface tension of the oil. Table III incidentally contains certain compounds which are somewhat effective as single-constituent antifoams (see table II), but of which the antifoaming efficiency might be improved by the addition of an emulsifying agent.

The results of foam tests on a number of type 2 antifoams are given in table IV. Notations are made of cases in which the emulsifying agent is known to have caused solubilization of the additive in the lubricating oil. For example, with the butyl carbitol and diethyl laurylamido phosphate antifoam, butyl carbitol was observed to be insoluble in the lubricating oil. The mixture, however, is soluble although the rate of solution is slow. Consequently, only temporary defoaming results. Similarly, for mixtures of castor oil and Aerosol OT (a type 3 antifoam; see table IX), castor oil was noted to be insoluble in the lubricating oil at 100° C, but after the addition of Aerosol OT and subsequent foam testing at 100° C, no trace of insoluble material could be seen. This same observation was made with the antifoam mixture of sulfonated castor oil and lead Aerosol OT.

Table V presents the results of surface-tension measurements on solutions of certain substances in Aeroshell 120 lubricating oil. Several of these substances are effective emulsifying agents for type 2 antifoams, as is shown in table IV. In connection with table IV, the addition of oleic acid increases the solubility of zinc palmitate in lubricating oil without appreciable effect on the surface tension of the oil.

Although type 4 antifoams are more complex than type 3 in that the further addition of an emulsifying agent is required, both types require surface-tension depressants, and consequently similar experimental data are needed. Practically no information exists in the literature dealing with surface-tension measurements on solutions of chemicals of known structure in several nonaqueous solvents. The data in tables VI, VII, and VIII were collected to provide a background for the selection of nonaqueous surface-tension depressants from a large number of commercially available surface-active materials.

Table VII represents an extension of this exploratory work on the surface-tension depression of nonaqueous solvents into the field of commercial surface-active agents.

In aqueous systems, surface-tension depression caused by the addition of surface-active material is generally accompanied by a reduction in interfacial tension against oil. A low interfacial tension is generally regarded as essential to easy emulsification. Inasmuch as glycerol and the glycols are similar to water in their molecular association, it was considered probable that a similar lowering of interfacial tension would be caused by substances which depress the surface tensions of these polyhydric alcohols. Table VIII presents experimental data indicating the relation between surface- and interfacial-tension lowering for solutions of two surface-tension depressants in glycerol.

Table IX lists a number of effective antifoams of types 3 and 4, together with their foam-test ratings. Table X lists a number of agents found ineffective by foam tests. The tests summarized in tables IX and X are reported in detail in references 4 to 10.

DISCUSSION

Single-Constituent Emulsified Antifoams (Type 1)

Study of table II reveals that only one entirely satisfactory antifoam of this type has been found, namely, Dow Corning Fluid Type 200 (presumably a mixture of polymers of different molecular weights). This additive is unique in that it combines extremely low surface tension and low solubility in all military aeronautical lubricating oils with non-volatility and self-dispersibility. Its emulsions in oil, however, are not indefinitely stable. In an early experiment, an oil (Gulf 120) which had been rendered completely nonfoaming by the addition of 0.01 percent Dow Corning Fluid was set aside in a bottle for 3 months. At the end of that time, a sample was taken from the top of the bottle and retested for foaming. It was then found that the antifoaming effect was much less pronounced (grade C) and that agitation of the bottle was necessary to redisperse the additive and to cause the reappearance of complete defoaming.

A simple criterion has been provided by this report to guide the search for other efficient and more economical antifoams. The main stumbling block to such a development is the acute lack of surface-tension measurements on organic liquids likely to be insoluble in lubricating oil. Such information as exists in the literature is widely scattered and mostly confined to compounds of moderate or high oil solubility. A few surface-tension measurements have been made in this laboratory (see table I) and may be useful in focusing attention on the potentialities of certain types of organic compound. The following observations are drawn from the data of table I:

(1) Approximately one hydroxyl group to four carbon atoms is required in alcoholic compounds to avoid high oil solubility.

(2) Polyhydric alcohols are highly associated as evidenced by their high surface tensions.

(3) Polyhydric alcohols can be esterified with oil-soluble fatty acids in order to promote oil emulsification and to obtain oil-insoluble esters having surface tensions lower than that of lubricating oil. In general, the use of oleic or naphthenic acids appears to cause excessive oil solubility.

(4) Polyhydric alcohols may be replaced by mixed alcohol-ketones or mixed alcohol-ethers in the foregoing esterification.

(5) Mixed esters of polyhydric alcohols, fatty acids, and phosphoric acids may be made, the phosphate (or pyrophosphate) group reducing oil solubility.

Data on the solubilities of additives in one type of hydrocarbon oil apparently cannot validly be applied to another type. Table I shows that additive solubility is different in two hydrocarbon oils of widely divergent chemical constitution. Furthermore, evidence exists which supports the belief that solubilities vary markedly even in a series of aircraft lubricating oils. Previously reported foam tests have indicated that antifoams which are quite effective for one aircraft lubricating oil may be totally ineffective for another despite the fact that the surface tensions of the two oils are equal.

A study of table II reveals three cases of grade C defoaming at room temperature despite the solubility data indicating that these additives are soluble at this temperature. This phenomenon is presumed to result from high oil viscosity, which renders the rate of solution of the additive very slow. In each of these cases, the foam testing was by a rapid but crude evacuation method (long since discarded) and has never been rechecked by other test methods. The defoaming effect shown by 2-nitrobutanol-1 can be explained only on the supposition that the suspended material visible in the sample is the actual defoaming agent, since the surface tension of the mixture is high.

Table I lists only a few of the possible complex esters, yet it is noteworthy that many of these have surface tensions lower than that of lubricating oil. Furthermore, some of these esters exhibit definite defoaming action at 100° C, as shown in table II.

Antifoams in Which an Oil-Insoluble Constituent of Low Surface Tension is Combined with an Emulsifying Agent (Type 2)

As in the case of single-component antifoams, the development of satisfactory type 2 antifoams depends on the discovery of oil-insoluble compounds of high boiling point and low surface tension. In this case, however, the restrictions are less severe inasmuch as self-emulsification is not required. Thus simple compounds, such as butyl cellosolve, may be utilized in combination with a wide variety of commercial emulsifying agents. Table III lists a number of commercially available chemicals which show promise as the insoluble constituents of type 2 antifoams. It should be noted that this table also contains some complex compounds, such as diethylene glycol monooleate, which exhibit some action as type 1 antifoams. (See table II.) Conceivably, the antifoaming action of these compounds might be improved by better emulsification achieved by the addition of emulsifying agents.

Table IV presents the results of a few foam tests on type 2 emulsified antifoams, compounded from oil-insoluble compounds listed in table III and commercial emulsifying agents. Table IV, in comparison with table II, indicates that type 2 antifoams are of definite practical significance and, furthermore, that type 1 antifoams are of limited defoaming action; for example, diethylene glycol monooleate can be

greatly improved by the addition of an emulsifying agent. Cases of anti-foam failure due to solubilization caused by the emulsifying agent are not infrequent. The use of oil-soluble emulsifying agents is, unfortunately, necessary inasmuch as emulsions are desired in which the oil is the continuous phase (Bancroft's rule). Solubilization, however, can often be minimized by a change in the concentration of the emulsifying agent used or by suitable selection of the emulsifier.

Emulsifying agents may be selected which do not seriously lower the surface tension of lubricating oil. (See table V.) Soaps are particularly interesting in view of low cost, chemical stability, compatibility with lubricating additives, and proved success. (See zinc palmitate, table IV.) In general, the soaps exhibit low oil solubility, but their solubility may be greatly increased by the addition of small amounts of free fatty acids.

Antifoams in Which an Oil-Insoluble Constituent of High

Surface Tension is Combined with a Surface-

Tension Depressant (Types 3 and 4)

Although type 4 antifoams are more complex than type 3 in that the further addition of an emulsifying agent is required, both types are similar in that they require surface-tension depressants. The experimental data reported in table VI indicate that the surface tensions of highly associated compounds insoluble in lubricating oil (for example, glycerol, glycols, and triethenolamine) may be greatly depressed by the addition of small amounts of many simple agents. On the other hand, depression of the surface tension of compounds already possessing low surface tensions (such as 2-methyl pentanediol-2, 4; diacetone alcohol; acetonyl acetone; and butyl carbitol) is difficult. The data in table VI suggest that alkyl compounds possessing alcohol and amine functional groups should be effective as surface-tension depressants for the polyhydric alcohols. Table VII represents an extension of this search for surface-tension depressants into the field of highly surface-active agents of more complex chemical composition.

Many of these compounds cause sufficient surface-tension depression for practical defoaming of lubricating oil at concentrations as low as 2 percent of the total additive. However, many substances effective as surface-tension depressants have appreciable oil solubilities. When the compounded additive is dispersed in lubricating oil, the surface-tension depressant is distributed between the oil and the additive phases. The results of this distribution may be to deplete the additive phase to the extent that surface-tension depression is insufficient, to lower the surface tension of the oil phase below that of the additive phase, or to do both.

The economic advantage of using very low total additive concentrations (of the order of 0.1 percent) in oil emphasizes the necessity of using surface-tension depressants much more soluble in the additive phase than in the lubricating oil. Otherwise, the surface-tension depressant is lost into the oil. Depending on the distribution coefficient of the surface-tension depressant, a somewhat larger amount of it is generally necessary than is required to cause the desired surface tension of the additive. The surface-tension depressant in the additive may likewise be expected to lower the surface tension of the oil to some extent. However, inspection of table V reveals that even a 0.125-percent solution of Aerosol OT (a good surface-tension depressant for polyhydric alcohols) in the oil causes a reduction of only 1.4 dynes per centimeter in the surface tension of the oil.

The migration of a fraction of the surface-tension depressant to the oil phase may even be necessary for the proper emulsification of type 3 antifoams. Table VIII indicates that surface-tension depressants for the polyhydric alcohols also cause reduction of the interfacial tension against lubricating oil. Although low interfacial tension is essential to easy dispersion of an antifoam, low interfacial tension does not imply emulsion stability. The fraction of the surface-active agent dissolved in oil may well function as an emulsifying agent for the additive phase. In this connection, the calcium and lead salts of Aerosol OT, which favor the water-in-oil type of emulsion, exhibit good defoaming effects at lower concentrations in glycerol than in the case of the sodium salt, which slightly favors the oil-in-water type of emulsion.

If every surface-tension depressant is bifunctional in nature, there is no real basis for a separate classification of type 3 and type 4 antifoams. However, at least one additive compounded of glycerol and an oil-insoluble surface-tension depressant has been discovered which exhibits a surface tension lower than that of lubricating oil but which has no defoaming action (that is, monoboleyl dipolyglycol o-phosphate, tables I, VII, and X). Quite possibly, the addition of an oil-soluble emulsifying agent is indicated as essential. Another case which probably should be classified as a type 4 antifoam is the Aerosol-OT - glycerol - triethanolamine oleate defoamer. In this case, the sodium salt (Aerosol OT) favors the oil-in-water type of emulsion. Antifoaming action is definitely improved by the addition of triethanolamine oleate, which presumably acts as an aid to formation of emulsions of the water-in-oil type.

Table IX presents a list of effective antifoams known to be either type 3 or 4. The experimental work has not progressed to the point where correlation of foam tests and the surface tension of each phase can be made.

CONCLUDING REMARKS

Effective antifoams for lubricating oils, that can be used in concentrations as small as 0.1 percent, have been shown to be most probably of the insoluble emulsified type.

Insoluble emulsified antifoams should have a surface tension lower than that of the oil and must form stable emulsions in it, in addition to fulfilling certain other requirements.

The antifoaming ability of substances can be predicted with a high degree of correlation from simple measurements of surface tension and solubility and with accuracy from more complex measurements.

The number of substances and mixtures which can fulfill the requirements for effective antifoams appears to be potentially large. Data have been accumulated which may serve as a guide in designing the molecules of antifoam constituents.

Stanford University

Stanford University, Calif., September 1, 1945

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TABLE I.- SURFACE TENSION, OIL SOLUBILITY, AND BOILING POINTS
OF VARIOUS ORGANIC SUBSTANCES

Substance	Boiling point (°C)	Uncorrected surface tension at room temperature (dynes/cm)	Solubility of 1-percent concentration (a)			
			BKH mineral oil		Aeroshell 120	
			Temperature			
Room	100° C	Room	100° C			
Alcohols						
Ethanol	78	30.4	I			
Butanol	118	26.4	I			
Hexanol		28.3	S			
Octanol		27.8	S			
Decanol		30.6	S			
Dodecanol		31.0	S			
2-Methyl pentanediol-2,4	196	31.2	I		I	I
2-Ethyl hexanediol-1,3		32.2	S			
Ethylene glycol	^b 197	51.1			I	I
Diethylene glycol	^c 245	47.0			I	I
Polyethylene glycol		44.3			I	I
Glycerol	290	55-63	I		I	I
2-Nitrobutanol-1		41.4			I	I
2-Amino 2-methyl propanol-1		35.4	I			
2-Amino 2-ethyl propanediol-1,3		44.4	S		S	
Ketones and mixed alcohol-ketones						
Diacetone alcohol	165	31.4	I		I	I
Acetylacetone		38.0	I		I	I
Ethers and mixed alcohol-ethers						
Hexyl ether		27.9	S			
Butyl cellosolve	171	31.0	S	S	I	I
Butyl carbitol	231	32.8	S	S	I	I
Esters						
Propylene glycol monolaurate		34.0	S			
Propylene glycol dicitrioleate		38.0	S			
Diglycol laurate		32.6	S	S	I	I
Diethylene glycol monöoleate		34.0	I			
Diglycol dinapthenate		34.8	S		S	S
Nonaethylene glycol monöoleate		35.7	S			
Glyceryl monöoleate		33.3	S			
Glyceryl monoricinoleate		38.0		I		I
Glyceryl dioleate		34.5	S	S	S	S
Mannide monöoleate		32.0	S	S	S	S
Sorbitol dilaurate		33.6	S		I	S
Butyl cellosolve laurate		32.0	S			
Carbitol maleate		40.1	I	I		
N-dibutyl phthalate		35.6	S			
Glycol bori-borate		47.0	S	S		
Phosphate esters						
Ethyl phosphate	216	31.8	I		I	
Ethyl oleyl glycol o-phosphate		34.3	I		I	I
Diethyl laurylamido phosphate		31.5			I	S
Monöoleyl dipolyglycol o-phosphate		32.5	S		I	I
Tetraoctyl pyrophosphate		33.7	I	I		
Diocetyl stearylamine pyrophosphate		(d)	S	S		
Octyl tripolyphosphate		(d)	I	I		
Trioctyl tripolyglycol tetrapolyphosphate		29.4	S	S	I	I
Phosphated stearylamine		(d)		S	I	S

^aS indicates more than 1-percent soluble; I, less than 1-percent soluble.

^b200 mm.

^c250 mm.

^dSolid.



TABLE I.- SURFACE TENSION, OIL SOLUBILITY, AND BOILING

POINTS OF VARIOUS ORGANIC SUBSTANCES - Concluded

Substance	Boiling point (°C)	Uncorrected surface tension at room temperature (dynes/cm)	Solubility of 1-percent concentration (a)			
			BKH mineral oil		Aeroshell 120	
			Temperature			
			Room	100° C	Room	100° C
Vegetable oils						
Olive oil		35.6		S		
Castor oil		38.0		I		
Sulfonated castor oil		(e)		I		
Turkey red oil		33.6		S		
Silicon compounds						
Ethyl silicate	166	26.4				I
Castor oil silicate		37.6				I
Glyceryl silicate		36.2				I
Dimethyl silicone monomer		21.6				I
Dow Corning Fluid Type 200		23.4				I
Commercial surface-active agents						
Span 20 Anhydrous		30.0	S		S	
Wettal		30.2	S			
Tween 80		37.8	I	I		
Morpeloil 455		35.6	I	I		
Sapamine MS		32.5	I			
Penetrol 60		36.4	I	I		
Naccolene F		27.7	I	I		
Alronol (100 percent)		33.0	I	I		
Oronite wetting agent		(d)	I	I		

^aS indicates more than 1-percent soluble, I, less than 1-percent soluble.

^dSolid.

^eSemisolid.



TABLE II. - SURFACE TENSION AND OIL SOLUBILITY
OF SINGLE-CONSTITUENT ANTIFOAMS AND THEIR
EFFECT ON FOAMING OF LUBRICATING OIL

[Foam-test data from references 4 to 10]

Single-constituent antifoam	Uncor- rected surface tension (dynes/cm)	Foam-test grade (a)		Solubility in Aeroshell 120 (b)	
		Temperature		Room	100° C
		Room	100° C		
Ineffective additives					
Glycerol	55-63	E		I	I ^{S^c}
Glycol boron-borate	47.0	D		S ^c	I ^{S^c}
Diethylene glycol	47.0	E		I	I
2-Amino 2-ethyl propanediol-1,3	44.4	E		S	
Carbitol maleate	40.1	E		I	I
Glyceryl monoricinoleate	38.0	E			I
Tween 80	37.8	E,D		I ^c	I ^c
Castor oil silicate	37.6		E		I
Nonaethylene glycol monoolate	35.7	F		S ^c	
2-Amino 2-methyl propanol-1	35.4	E		I	
Propylene glycol monolaurate	34.0	D		S ^c	
Glyceryl monoolate	33.3	F		S ^c	
Effective additives					
^d 2-Nitro butanol-1	41.4	B	F	I	I
Diglycol dinaphthenate	34.8	C	E	S	S
Glyceryl dioleate	34.5	C	F	S	S
Ethyl oleyl glycol o-phosphate	34.3	B		I	I
Diethylene glycol monoolate	34.0	C		I ^c	
Tetraoctyl pyrophosphate	33.7	B	C	I ^c	I ^c
Sorbitol dilaurate	33.6	A	E	I	S
Diglycol laurate	32.6	A	C	I	I
Mannide monoolate	32.0	C	E	S	S
Sapamine MS	32.5	A		I ^c	
Ethyl phosphate	31.8	A	D	I	
Diethyl laurylamido phosphate	31.5	A	E	I	I
Monoolyl dipolyglycol o-phosphate	29.4	A	E	I	I
Trioctyl tripolyglycol tetrapolyphosphate	29.4	D	C	I	I
Naccolene F	27.7	B		I ^c	I ^c
Ethyl silicate	26.4	A	C		I
Dow Corning Fluid Type 200	23.4	A	A	I	I
Dimethyl silicone monomer	21.6	B	C	I	I

^aThe foam-test grades have the following significance:

- A Only traces, or no foam
- B Foaming reduced to approximately 1/5 of original
- C Foaming reduced to approximately 1/3 to 1/2 of original
- D Foaming reduced by less than 1/2 of original
- E No effect
- F Foam stabilized



^bS indicates more than 1-percent soluble; I, less than 1-percent soluble.

^cMineral oil used as solvent; no data on Aeroshell 120.

^dAppearance of sample indicates that it is highly impure.

TABLE III.- SUBSTANCES SUITABLE AS
 INSOLUBLE CONSTITUENTS OF
 TYPE 2 ANTIFOAMS

Substance	Uncorrected surface tension at room temperature (dynes/cm)	Boiling point (°C)
Butyl cellosolve	31.0	171
Butyl carbitol	32.8	231
Diacetone alcohol	31.4	166
Dimethyl silicone monomer	21.6	
2-Methyl pentanediol-2,4	31.2	196
Naccolene F	27.7	
Sapamine MS	32.5	
Trioctyl tripolyglycol tetrapolyphosphate	29.4	
Diethylene glycol monöoleate	34.0	
Ethyl phosphate	31.8	216
Ethyl silicate	26.4	166



TABLE IV.- RESULTS OF FOAM TESTS

ON TYPE 2 ANTIFOAMS IN

AEROSHELL 120

Insoluble component	Emulsifying agent	Foam-test grade (1)	
		Temperature	
		Room	100° C
Butyl carbitol	Tergitol	D	-----
	Penetrant 4 wax	A	-----
	Lead Aerosol OT		
Diethyl lauryl amido phosphate		A→E ²	-----
Butyl cellosolve	Tergitol	B	-----
	Penetrant 4 wax	A	-----
Lead Aerosol OT			
2-Methyl pentanediol-2,4	Cationic Agent C ³	-----	-----
	Zinc palmitate	A	B
Sapamine MS	Calcium Aerosol OT	-----	A
	Aerosol OT	A	A
Diethylene glycol monöleate			
	Aerosol OT ⁴	A	A→E

¹The foam-test grades have the following significance:

- A Only traces, or no foam
- B Foaming reduced to approximately 1/5 of original
- C Foaming reduced to approximately 1/3 to 1/2 of original
- D Foaming reduced by less than 1/2 of original
- E No effect
- F Foam stabilized

²Emulsifying agent solubilizes otherwise insoluble component.

³This emulsifying agent is volatile at 100° C. It solubilizes 2-methyl pentanediol-2,4 to a considerable extent and causes lowering of the surface tension of the oil.

⁴Probably also lowered the surface tension of the oil from 34.0 dynes per centimeter.



TABLE V.- SURFACE TENSION OF AEROSHELL 120
CONTAINING DISSOLVED SUBSTANCES OF
INTEREST AS CONSTITUENTS OF
ANTIFOAMS

Substance	Concentration (percent)	Uncorrected surface tension at 100° C (dynes/cm)
Zinc palmitate	0.000	28.6
	.005	27.9
	.014	27.9
	.028	28.0
	.080	28.1
	.140	28.1
	.280	28.0
Sodium oleate	.000	28.6
	.200	28.3
	.500	28.4
	1.000	28.3
Zinc palmitate containing 20-percent oleic acid	.550	28.4
Aerosol OT	.000	^a 31.0
	.125	^a 29.6
	.500	^a 28.2

^aAt 80° C.



TABLE VI.- SURFACE TENSIONS OF BINARY MIXTURES OF SIMPLE COMPOUNDS

Compound	Surface tension (dynes/cm)								
	Percent solute								
	0	2	4	8	10	12	15	25	100
Solvent, triethanolamine									
n-Butanol	50.0	46.6	42.0	40.2	41.0		38.0		26.4
n-Hexanol		36.5	37.0	37.2	37.5		35.2		28.3
n-Octanol		39.0	34.2	35.3	32.0		34.8		28.7
n-Decanol		33.0	32.3	32.2	32.1		32.2		30.6
n-Dodecanol		33.0	32.8	32.6	32.3		32.2		31.0
Cetyl alcohol		(1)							(2)
Capric acid		47.2	46.0	43.9	42.0		40.6		(2)
Caprylic acid		47.2	43.0	39.9	39.7		37.5		30.8
Oleic acid		35.2	34.1	33.0	32.2		35.2		34.5
Palmitic acid		41.5	39.0	38.7	38.5		38.0		(2)
Ricinoleic acid		38.0	38.0	38.0	38.3		37.5		37.5
Stearic acid		42.2	43.0	44.5	56.2		(1)		(2)
Hydrocinnamic acid		50.3	50.2	50.0	49.8		46.0		(2)
Lauryl sulfonic acid							40.0		(2)
Toluene sulfonic acid							51.0		(2)
Nacconol NR sulfonic acid		38.0	36.0	33.8	33.4		33.3		33.0
Butylamine		35.4	35.0	34.2	33.7		33.5		26.0
Heptylamine		40.0	39.7	38.0	37.2		37.7		28.5
Octylamine		37.8	35.5	35.8	35.5		34.5		29.0
Diamylamine		42.0	41.0	35.3	33.0		30.0		25.5
Diethylene triamine		46.5	46.0	44.0	37.6		40.3		44.0
Aniline		50.0	49.4	49.0	49.0		48.8		43.5
β-Naphthylamine		51.0	51.0	50.5	(1)				(2)
α-Amino diphenyl		50.5	49.9	49.5	49.5		49.0		(2)
Solvent, diethylene glycol									
n-Butanol	47.0	40.5	35.8	30.2	29.6		28.6		26.4
n-Hexanol		40.2	38.4	36.2	33.5		35.1		28.3
n-Octanol		36.5	34.2	35.7	34.6		33.7		28.7
n-Decanol		36.0	34.0	32.3	32.6		31.7		30.6
n-Dodecanol		34.0	32.2	32.0	31.9		32.0		31.0
Cetyl alcohol		(1)							(2)
Solvent, glycerol									
2-Methyl pentanediol-2,4	55.0		51.0	46.0	41.0		37.6	34.8	31.2
2-Ethyl hexanediol-1,3					34.0		34.0	34.0	32.2
2-Amino 2-methyl propanol-1							52.0	47.0	35.0
2-Amino 2-methyl propanediol-1,3								63.0	
2-Amino 2-ethyl propanediol-1,3					45.7		43.0	43.0	46.0
Acetamide					60.0		59.0	58.0	(2)
Aerosol OT			31.3	30.5	30.6		30.4	29.5	(2)
Aerosol AY			33.0		32.0		31.4	31.0	(2)

¹Insoluble.
²Solid.

TABLE VI.- SURFACE TENSIONS OF BINARY MIXTURES
OF SIMPLE COMPOUNDS - Concluded

Compounds	Surface tension (dynes/cm)								
	Percent solute								
	0	2	4	8	10	12	15	25	100
Solvent, diacetone alcohol									
Ethanol	31.4	32.3	32.4	32.7	34.1		33.8	32.9	30.4
n-Butanol		32.4	32.1	31.5	31.4		31.5	30.5	26.4
n-Hexanol		33.0	32.5	32.1	32.0		31.9		28.3
n-Octanol		31.8	31.5	31.4	31.0		31.0		28.7
n-Decanol		31.7	31.5	31.4	31.4		31.4		30.6
n-Dodecanol		31.4	31.3	31.3	31.3		31.1		31.0
Cetyl alcohol		31.5	31.5	31.3	31.5		31.5		(2)
Solvent, acetonylacetone									
Ethanol	38.0						37.3	26.8	30.4
n-Butanol							35.4	31.0	26.4
n-Hexanol							34.6	32.4	28.3
n-Octanol							34.7	33.2	28.7
n-Decanol							35.3	34.0	30.6
n-Dodecanol							35.4	34.2	31.0
Butylamine		36.4	34.2	28.7	28.4		28.2		26.0
Heptylamine		36.7	36.6	35.7	35.0		34.4		28.5
Octylamine		36.8	36.7	35.5	34.9		33.9		29.0
Diamylamine		36.4	35.0	31.1	32.7		31.1		25.5
Aniline		36.5	36.7	37.2	37.2		38.2		43.5
Solvent, 2-methyl pentanediol-2,4									
n-Hexanol	31.2	31.0			31.0				28.3
n-Dodecanol		31.6	31.4	31.1	31.1		31.3		31.0
Cetyl alcohol		31.9	31.9	31.9	31.3		31.0		(2)
Octylamine					31.2				29.0
Oleic acid					31.4				34.5

²Solid.



TABLE VII.- SURFACE TENSIONS OF MIXTURES CONTAINING
COMPLEX SUBSTANCES

Mixture	Surface tension (dynes/cm)										
	Percent solute										
	0	2	4	5	8	10	15	25	50	75	100
Solvent, glycerol											
Butyl cellosolve laurate	58.0	42.5	40.5		39.0	37.1	37.0				32.0
Diglycol laurate		31.8	30.8		(1)						32.6
Nonaethylene glycol monolaurate		37.0	36.6		36.5	36.4	36.2				35.7
Propylene glycol monolaurate		(1)									34.0
Propylene glycol diricinoleate		47.0	44.6		46.0	46.9	47.0				38.0
Glyceryl monöoleate		33.3	33.3		33.0	33.0	33.0				33.3
Glyceryl dioleate		36.6	36.0		36.0	36.0	35.6				34.5
Glyceryl monostearate		(1)									(2)
Mannide monöoleate		33.2	33.0		32.6	32.6	32.5				32.0
Sorbitol dilaurate		32.0	32.0		31.5	32.0	32.0				33.6
Octyl tripolyphosphate						33.5	31.0	32.5			(2)
Trioctyl tripolyglycol tetrapolyphosphate						32.1	31.7	30.8			29.4
Phosphorated stearylamine						33.0	(1)				(2)
Diethyl laurylamido phosphate						32.0	32.0	31.6			
Diethylamino ethyl phosphatidic acid						34.0	35.0	37.0			34.0
Monöoleyl dipolyglycol o-phosphate						30.5	31.0	32.0			32.0
Ethyl oleyl glycol o-phosphate						34.0	34.0	34.0			34.3
Morpeloil 455		39.0	37.0			36.0		36.0			35.6
Naccolene F		40.0	35.5		36.5	36.5	35.5	(1)			
Alronol (100 percent)						31.5	31.5	31.5			33.5
Glyceryl silicate		38.0	38.5		38.3	37.5	37.9				36.2
Glycol bori-borate						55.0	51.0	47.2			47.0
Solvent, triethanolamine											
Igepon A	50.0	38.0	36.0		34.5	36.0	36.5				(2)
Hytergen							(1)				
Glyceryl monoricinoleate		38.5	39.4		38.4	38.7	38.7				38.0
Diglycol dinaphthenate		39.7	38.8		37.7	37.0	36.8				34.8
Diethyl laurylamido phosphate			33.0			33.0	32.6	32.0			
Cyclopon A Extra							(1)				
Span 20						32.3	32.0	32.5			30.0
Oronite wetting agent		39.3	37.0		35.5	34.8	34.2				(2)
Naccolene F		35.0	33.0		30.8	30.5	29.5				27.7
Igepon T		(1)									
Solvent, acetonylacetone											
Span 20	37.0					33.7	32.7	33.0	33.5	32.2	30.0
Diethyl laurylamido phosphate				36.5		35.7	35.0	34.7			
Solvent, diacetone alcohol											
Diethyl laurylamido phosphate	31.4			31.4		31.3	31.4	31.3			
Span 20						32.0	32.0	32.6	33.2	32.2	30.0
Cationic Agent C				32.9		33.8	30.5	(1)			(2)

¹Insoluble.

²Solid.



TABLE VII.- SURFACE TENSIONS OF MIXTURES CONTAINING
COMPLEX SUBSTANCES - Concluded

Mixture	Surface tension (dynes/cm)										
	Percent solute										
	0	2	4	5	8	10	15	25	50	75	100
Solvent, butyl carbitol											
Mannide monöleate		32.3	32.8		33.0	33.0	32.9				
Sorbitol dilaurate		32.5	32.8		32.8	33.0	32.9				
Diethyl laurylamido phosphate			27.7			27.9	28.0	28.0			
Span 20						33.0	33.0	33.0	33.0		
Naccolene F			32.7		32.0	31.8	31.4				
Solvent, 2-methyl pentanediol-2,4											
Igepal CTA	31.2							32.8	33.6		
Diethylene glycol monöleate						32.0			32.8		
Catylon D						31.6					
Aquasol AR (75 percent)						31.6					
Triton X-100						31.3					
Solvent, diethylene glycol											
Diethyl laurylamido phosphate	47.0			33.2		33.2	32.7	32.9			
Span 20						32.5	32.5	32.0	32.0		30.0
Naccolene F			32.5		29.8	28.3	28.7	28.2	27.7		
Solvent, ethylene glycol											
Naccolene F			31.8		31.3	30.2	29.0	28.8	28.2		

TABLE VIII.- SURFACE TENSIONS OF MORPELOIL 455
AND AEROSOL OT IN GLYCEROL AND INTERFACIAL
TENSIONS AGAINST AEROSHELL 120

Solute	Concentration (percent)	Uncorrected surface tension (dynes/cm)	Interfacial tension (dynes/cm)
Morpeloil 455	0.0	55.0	26.5
	1.6	38.9	7.1
	4.7	37.0	6.5
	12.5	36.0	2.5
	30.3	36.0	1.8
	56.0	35.9	2.1
	Aerosol OT	0.0	55.0
5.0		31.3	3.0
10.0		30.6	----
15.0		30.4	2.6
20.0		30.2	2.4
25.0		29.5	2.1
30.0		29.4	2.2
40.0		30.0	2.2



TABLE IX.- EFFECTIVE TYPES 3 AND 4 ANTIFOAMS

[Data from references 4 to 10]

Insoluble constituent	Surface-active agent	Foam-test grade ¹	
		Temperature	
		Room	100° C
Glycerol	Aerosol OT	A	A
	Aerosol OT plus triethanolammonium oleate	A	
	Aerosol MA	A	
	Aerosol 1B	A	
	Calcium Aerosol OT	A	A
	Lead Aerosol OT	A	A
	Sodium lauryl sulfate	A	
	Sodium heptadecyl sulfate	A	
	Gardinol WA	A	
	Alronol (100 percent)	D	
	Triethanolammonium oleate	D	
	Diethyl laurylamido phosphate		A
	Octyl tripolyphosphate	A	A
	Tetraoctyl pyrophosphate		B
Diethylene glycol	Calcium Aerosol OT	A	A
	Lead Aerosol OT	A	A
Triethanolamine	Lead Aerosol OT	A	
	Triethanolammonium oleate plus Lead Aerosol OT		A
Erythritol	Aerosol OT	A	
Sorbitol	Aerosol OT		A
	Tergitol Penetrant 4		A
	Tergitol Penetrant 7		A
	Tergitol 08		A
	Phosphorated octylamine		A
	Diethyl laurylamido phosphate		A
Xylitol	Aerosol OT		A
Castor oil	Aerosol OT	B	F ²
	Calcium Aerosol OT	A	F ²
Sulfonated castor oil	Lead Aerosol OT	A	F ²

¹The foam-test grades have the following significance:

- A Only traces, or no foam
- B Foaming reduced to approximately 1/5 of original
- C Foaming reduced to approximately 1/3 to 1/2 of original
- D Foaming reduced by less than 1/2 of original
- E No effect
- F Foam stabilized

²Surface agent solubilizes otherwise insoluble component.



TABLE X.- INEFFECTIVE TYPE 3 ANTIFOAMS

[Data from references 4 to 10]

Insoluble component	Antifoam	Insoluble component	Antifoam
Glycerol	Aluminum oleate Sodium palmitate Lead stearate Lauryl sulfonic acid Sodium cetyl sulfate Cetyl pyridinium chloride Dioctyl stearylamine pyrophosphate Monoleyl dipolyglycol o-phosphate Aerosol DGA Alkaterge-0 Avirol AH Extra Catol 607 Emulphor 0 Morpeloil 455 Sapamine MS	Sorbitol	Aluminum oleate Penatrol 60 Sodium naphthenate Magnesium naphthenate Sodium oleate Sodium lignin sulfonate Capryl laurylamine tripolyphosphate Turkey red oil Tween 20 Tween 60 Tween 81 Tween 85 Alronol (100 percent) Emulsol 607 Aerosol OS Santamine No. 3
		Diethylene glycol	Penatrol 60
		Triethanolamine	Diethyl laurylamido phosphate

