

Evaluation of the Efficiency of Silicone Polyether Additives as Antifoams in Crude Oil

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ABSTRACT: It is common for crude oil from wells to be accompanied by gas and water because of the presence of natural surfactants in the oil that stabilize the associated water. This causes foaming during processing in gas/oil separators because of the constant agitation and shear forces, which reduce the efficiency of the process and require chemical control by the addition of defoaming additives, or antifoams. In this work, we evaluated the chemical and physicochemical properties of commercial antifoam products based on silicone polyethers along with their efficiency in inhibiting foaming and water/oil (W/O) phase separation. The commercial surfactants were characterized by NMR spectroscopy, size exclusion chromatography, determination of solubility in different solvents, and measurement of the surface and interfacial tensions.

A method to test the formation of foam in oil was used to mimic the operating conditions in gas/oil separators. Finally, tests were performed with the addition of aliquots of the additive solutions (30% p/v) in oil to evaluate their efficiency in breaking up the foam under different conditions. The results show that the most polar additive (SL2) was the most efficient in breaking up the foam. Additive SP1, which formed a heterogeneous phase in the oil, was also an efficient foam inhibitor and helped to separate these phases. The antifoam tests showed that these additives did not stabilize W/O emulsions, so they could be used in gravitational separation tanks in the field. © 2011 Wiley Periodicals, Inc. *J Appl Polym Sci* 124: 4149–4156, 2012

Key words: additives; interfaces; polyethers; silicones

INTRODUCTION

In oilfields, gravitational separation tanks are generally used to separate the oil, gas, and water phases, remove emulsifying reagents present at the phase interfaces, and permit the coalescence of the water droplets associated with the crude oil being pumped. Although there are many factors that influence the performance of these separators, the main problem is the formation of foam because this hampers mechanical control of the liquid and can lead to spills from tanks and equipment. Besides this, foam takes up space in the tanks, reduces the separation capacity and efficiency, and increases the drag of the liquid phase in the gas phase and vice versa, sometimes to the point of requiring shutdowns of the process.¹

The stabilization of water in oil (W/O) is caused by the presence of natural surfactants in crude oil (asphaltenes, resins, and other components) that

form an emulsion. This fluid, when subjected to a shearing process, leads to the formation of foam, which is stabilized by these surfactants.^{2,3}

The injection of silicone additives has been used for many years to control foam in crude oil in gravitational separators. Despite the excellent efficiency of these additives, oil companies want to reduce the quantity of silicone in their processes because this product can lead to the deposition of silica at the surface of catalysts during the hydrotreatment step at refineries and reduce their efficiency.⁴

Laboratory tests are important because they allow a better understanding of the behavior of the antifoam additives in different conditions of the separation process and contribute to an improvement in the separation efficiency.⁵

Fraga et al.⁵ developed a method to evaluate foaming in crude oil in the laboratory to mimic the operating conditions in gas/oil separators in the field. This method was employed with six crude oil samples of different origins, and the performance was tested on silicone antifoams with different molar masses in two of these oil samples. The results show that the oils with high viscosity did not generate foam, even when they had high levels of foam-stabilizing species (resins and asphaltenes). On the other hand, the oils with low viscosity had a low foam volume, and the foam had a low stability

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because the liquid drained between the foam lamellae. Therefore, the viscosity of crude oils is a determining factor in predicting whether or not a foam will form and, if so, its stability over time.

In another work,⁶ the performance of different additives based on polyethers was assessed on foam breakdown through this method. The best performing silicone polyether sample was the most polar one, which could form heterogeneous particles in the medium and destabilize the foam. This additive was also the one that reduced the crude oil's surface tension the least; this showed that this silicone polyether acted more within the medium than at the surface of the liquid film. Among the poly(ethylene oxide)-poly(propylene oxide) block copolymers tested, the most efficient was that with the greatest affinity for water (the most polar). It was also the additive that least reduced the oil sample's surface tension.

In this study, we evaluated the efficiency of silicone polyether-based additives as antifoams for the petroleum industry. In addition, we also evaluated the efficiency of these additives in the breakdown of W/O emulsions. Because antifoam additives are mainly used in gravitational separation tanks, it was also very important to evaluate their influence on the separation of the water and oil phases.

EXPERIMENTAL

Materials

We evaluated the foam-inhibiting potential of six samples of silicone polyethers with different molar masses. The samples were donated by Momentive (São Paulo, Brazil). All of the samples were used as received, and the structures of the samples were provided by the donor company. The samples in this study were called SL1 and SL2 (samples with linear chains) and SP1, SP2, SP3, and SP4 (samples with branched chains).

The crude oil sample used was from a Brazilian well and was donated by Petrobras (Rio de Janeiro, Brazil). It was also characterized with regard to density by the determination of the levels of saturated hydrocarbons, total aromatic hydrocarbons, resins, and asphaltenes (Table I).^{6,7}

The solvents cyclohexane, decane, cyclohexane, and *n*-heptane were used to evaluate the solubility of the antifoam samples. All of the solvents were provided by Vetec (Rio de Janeiro, Brazil) and were used as received.

Methods

NMR and size exclusion chromatography (SEC) analysis of the additives

The NMR tests were performed in a Varian Mercury 300 NMR spectrometer (São Paulo, Brazil) operating at

TABLE I
Chemical Composition and Density Values of the Oil Samples

Property	Petroleum
Water content (wt %)	0.05
Density (° American Petroleum Institute (API))	21.2
Hydrocarbons	40.7
Saturates (wt %)	
Aromatics (wt %)	34.1
Resins (wt %)	22.9
Asphaltenes (wt %)	2.4

a frequency of 300 MHz for the ¹H-NMR analyses. Samples (15 mg in 2 mL of deuterated chloroform) were placed in a 10-mm o.d. test tube, and the probe temperature during spectra acquisition was set at 30°C.

The SEC analyses were performed in a Waters 600E size-exclusion chromatograph (São Paulo, Brazil) with a refractive-index detector and columns containing styrene-divinylbenzene copolymer (104-103-500-100 Å). The solvent used was tetrahydrofuran. The calibration curve was obtained with polystyrene standards with small molar masses. This technique permitted us to obtain the average numerical molar mass.

Preparation of the solutions

All of the solutions used in this study were obtained by dissolution of the samples of silicone polyether in toluene. The mass of the samples and the volume of the solvent were calculated to obtain a concentration of 30% w/v, which is commonly used in oil fields. The volume necessary to conduct each test was taken from these solutions.

Solubility tests

The solubility tests of the silicone-based surfactant samples were performed in a test tube immersed in a beaker containing water and placed over an agitation and heating plate. Solutions containing 10% w/v of each additive were heated and then cooled. The temperatures were determined by a thermometer placed in the test tube. The temperature range analyzed was 10–75°C.

Triplicates were prepared of each solution, and there were cloud-point temperature readings for each solution, which were determined by the average between the temperature at which the first indication of clouding appeared and the temperature at which the clouding disappeared.

Determination of the surface tension of the samples

The values of the surface tension or interfacial tension of the systems were obtained by the Du Nöuy ring and pendant drop methods.

All of the measurements were made in triplicate, and only the values with variations of less than 1 mN/m were considered.

Du Nöuy method

The surface tensions of the additives and additive solutions (in toluene at a concentration of 30% w/v) were measured by the Du Nöuy ring method with a Krüss K10ST digital tensiometer (São Paulo, Brazil) at 30°C. The values of the interfacial tension oil/additive solution and W/O with additives dissolved in the oily phase were also determined.

Pendant drop method

The surface tensions of the oil samples, with or without aliquots of the additive in toluene (30% w/v), were measured by the pendant drop method with an automatic goniometer (model OCA-20, Dataphysics (São Paulo, Brazil)). All of these measures were carried out at 25°C. These measurements were performed to observe the activity of the additive on the surface of oil as a function of time

Tests of the additives' efficiency as antifoams

The tests with the oil sample were performed with a procedure described in previous works^{5,6} and under preselected conditions (pressure = 200 psi, temperature = 60°C, and conditioning time = 1 h). Different aliquots of solutions containing 30% w/v of the silicone-based antifoaming additives were added during the tests to evaluate the efficiency of these additives by this methodology. All of the tests were run in duplicate.

The foam height was read at intervals of time until constant consecutive values were attained; this indicated the total breakup of the foam. The percentage foam formed in each interval was calculated with eq. (1):

$$\text{Foam (\%v/v)} = \frac{H - H_F}{H_F} \times 100 \quad (1)$$

where H is the height reached by the foam on the scale at each time interval and H_F is the final height reached by the liquid after all of the foam was destroyed.

Tests of the gravitational separation efficiency of the samples

The performance of the additive solutions prepared as described previously was evaluated with W/O gravitational separation tests, or bottle tests, to test the as-prepared emulsion. The test and the

emulsion preparation were described in previous publications.⁸⁻¹⁰

The efficiency of each formulation used in these tests was calculated by application of eq. (2):

$$EF_{\text{WO}} = (V_{\text{WS}}/V_{\text{WT}}) \times 100 \quad (2)$$

where EF_{WO} is the efficiency of the gravitational separation of water and oil (vol %), V_{WS} is the volume of water separated during the test (mL), and V_{WT} is the volume of total water inside the test tube (mL).

The performance of silicone polyether samples at a concentration range between 40 and 1200 ppm active matter of the product was evaluated by the bottle test with the prepared emulsion. Tubes containing the emulsion and surfactant were shaken vigorously in a heated bath at 60°C. The separation of water was read at intervals of 5, 10, 15, 20, 25, 35, 45, 55, 65, and 75 min.

RESULTS AND DISCUSSION

Characterization of the additive samples

According to the company that donated the samples, they were composed of two types of silicone polyether. The structures are shown in Figures 1 and 2. The ¹³C-NMR analysis of the commercial silicone samples (SL1 and SP1) are shown in Figure 3. The others presented similar spectra, with variations in the chemical shift areas.

The silicon content in the linear chains was obtained by calculation of the number of carbon atoms (B) and according to the same procedure shown in a previous work.⁵ The concentrations (n 's) of the ethylene oxide (EO) chains were calculated by subtraction of the average molar mass numbers calculated by SEC from the molar masses calculated for the remainder of the molecule (from the results obtained by NMR).

For branched samples, the silicon and EO concentrations in the chains were calculated by the following equations:

$$2z + w + 6 = A \quad (3)$$

$$w = B \quad (4)$$

$$2nw = C \quad (5)$$

where A is the total area of peaks located between -2 and 2 ppm, B is the peak area located at 22 ppm, C is the total area of peaks located between 69 and 72 ppm, z is the number of silicone units not substituted, w is the number of silicone units substituted, and n is the number of EO units.

The values obtained from these equations were added in another equation [eq. (6)], suggested from

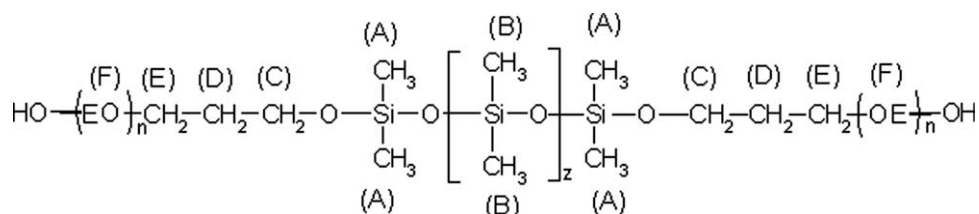


Figure 1 Linear chain structure of silicone polyether.

the molecular weight of each part of the branched silicone polyether chains:

$$74z + 118w + 44nw + 162 = M_n \quad (6)$$

where M_n is the number-average molecular weight of each additive.

The silicon and EO concentrations obtained for the silicone polyether samples by ^{13}C -NMR and their molecular weights are shown in Table II.

We observed that samples SL1, SL2, and SP1 had silicone chains with lower molecular weights in their structures, which were similar. Moreover, sample SL2 had a higher content of EO units than sample SP1.

Samples SP2 and SP4 had silicone chains with the highest molar masses (near each other). In this case, sample SP4 was more polar because of its higher EO content.

Finally, sample SP3 appeared to have silicone and EO chains of intermediate size in relation to the two groups described previously.

Solubility tests of the additives

The solubility tests of the silicone polyether samples were conducted at 10% w/v in different solvents with different solubility parameter values (δ): water, acetone, toluene, cyclohexane, and *n*-heptane.

The results show that all of the samples were soluble in solvents with solubility parameters between those of acetone (20.3 $\text{MPa}^{1/2}$) and *n*-heptane

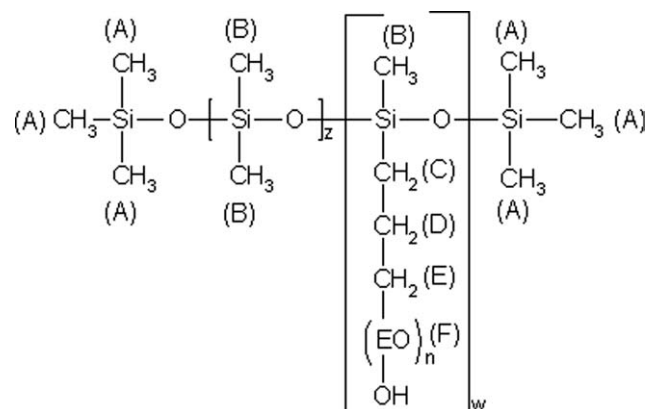


Figure 2 Graft chain structure of silicone polyether.

(15.1 $\text{MPa}^{1/2}$). This behavior was due to the amphiphilic nature of these materials. Sample SL2 was also soluble in water, and SL1 and SP1 were partially soluble in this solvent.

These results agree with those obtained previously from the chemical structures of these additives (Table II): SL1, SL2, and SP1 were more polar samples.

Determination of the surface tensions of the samples

The surface tensions of the oil sample, with and without the presence of the additive solutions, are shown in Figure 4. The purpose of these measures

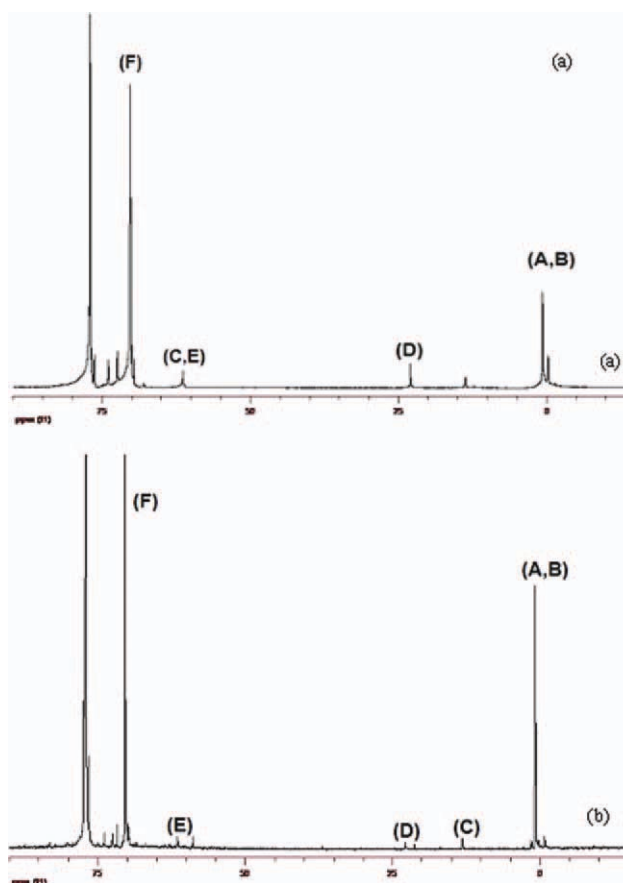


Figure 3 ^{13}C -NMR spectra of samples (a) SL1 and (b) SP3. [Color figure can be viewed in the online issue, which is available at [wileyonlinelibrary.com](http://www.interscience.wiley.com).]

TABLE II
Characterization of the Antifoam Additives

Sample	M_n^a	M_w^b	M_w/M_n	z^c	w^d	n^e	M_n^f
SL1	2085	2648	1.2	8	—	15	—
SL2	2378	2635	1.1	7	—	19	—
SP1	5648	7980	1.4	9	5	17	5158
SP2	13649	21769	1.6	50	7	30	13928
SP3	12019	15435	1.3	35	7	25	11116
SP4	14227	21927	1.5	45	7	36	15406

^a M_n , number-average molecular weight obtained by SEC.

^b M_w , weight-average molecular weight obtained by SEC.

^c z , number of nonsubstituted silicon units.

^d w , number of silicon units substituted.

^e n , number of EO units.

^f M_n , number-average molecular weight obtained by NMR [eq. (6)].

was to analyze the surface behavior of the oil samples after the addition of each antifoam solution. The temperature was 25°C, and the measurements were interrupted after 10 min of testing.

Analysis of the surface tensions of the oil showed that the presence of the additives reduced the oil's surface tension because of the amphiphilic character of the additive molecules. The SP1 and SL2 samples, which were more polar (Table II), caused the smallest reduction in the surface tension values. This behavior indicated that these samples were less adsorbed on the surface and, consequently, were more dispersed in the oil medium.

The other sample from the group with low silicone content but with lower polarity (SL1) reduced the oil's surface tension more; this indicated that its molecules were adsorbed more easily at the oil's surface. For these three samples (SL1, SL2, and SP1), the surface tension values stabilized after approximately 5 min.

On the other hand, for the samples with higher molar masses (SP2, SP3, and SP4; Table III), the oil's surface tension declined more slowly, and even at the longest time interval tested (10 min), these values were still declined slightly.

We expected the silicone polyether samples with low molar masses (SL1, SL2, and SP1) to be homogenized in the oil more easily. However, for these samples, the higher polarity of SL2 and SP1 appeared to reduce the solubility of these additives in the oil and promote the formation of a heterogeneous phase in this medium; this hampered or even prevented the diffusion of their molecules to the oil surface. On the other hand, the hydrophilic-lipophilic balance of the other additives (SL1, SP2, SP3, and SP4) with respect to the silicone chains appeared to make their molecules more soluble in oil; it also facilitated their migration to the oil/air interface and reduced the surface tension of this system.

The surface tension values of the additives and additive solutions and the interfacial tension

between the oil sample and pure silicone polyether additives were measured by the Du Noüy ring method (Table III). These measures were performed to calculate three coefficients: entering (E), stretching (S), and bridging (B); these were derived from the change in the free energy when the oil droplet penetrated the air/water interface or spread on the surface:¹¹

$$E = \sigma_{aw} + \sigma_{ow} - \sigma_{oa} \quad (7)$$

$$S = \sigma_{aw} - \sigma_{ow} - \sigma_{oa} \quad (8)$$

$$B = \sigma_{aw}^2 + \sigma_{ow}^2 - \sigma_{oa}^2 \quad (9)$$

where σ_{aw} is the air/water interfacial tension, σ_{ow} is the oil/water interfacial tension and σ_{oa} is the oil/air interfacial tension. The more positive the coefficient is, the more important the phenomenon is to foam suppression.

If $E > 0$, the droplet penetrates at the air/water interface, whereas if $S > 0$, the oil spreads, forming a thin duplex film on the surface and causing the foam cells to rupture.¹¹

In the particular case of this work, the air/water surface was replaced by the air/petroleum surface, and the oil was formed of molecules of the additive.

For the additive solutions (Table III), the highest surface tension values were obtained with the samples having greatest polarity. These altered the surface tension of toluene the least (28.6 mN/m) among the group of samples with similar molar masses.

The values of E and S and the bridging coefficient (B) calculated from the results shown in Table III are displayed in Table IV. E and the bridging coefficient were positive in all of the systems analyzed; this indicated that these systems could act as antifoaming agents for crude oil. Also, there appeared to be

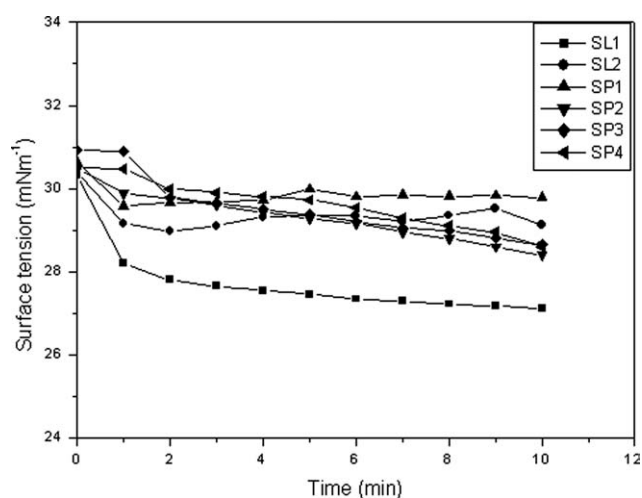


Figure 4 Variation of the surface tension as a function of time for samples of pure oil and after the addition of additive solutions at a concentration of 40 ppm.

TABLE III
Surface Tension of the Additives and Interfacial Tension of the Additives/Petroleum

Additive	Surface tension of the additive (mN/m)	Surface tension of the additive solution (mN/m) ^a	Interfacial tension of the additive/petroleum (mN/m)	Interfacial tension of the water/petroleum (mN/m) ^b
— ^c	—	—	—	23.4
SL1	22.6	25.8	19.3	19.4
SL2	22.5	26.5	20.5	20.4
SP1	22.5	26.4	20.9	20.9
SP2	22.4	25.8	22.7	21.5
SP3	— ^d	25.7	22.3	22.0
SP4	22.4	26.1	22.1	21.8

Error of the measures = ± 0.1 mN/m; surface tension of the solvent (toluene) = 28.6 mN/m; surface tension of petroleum = 31.0 mN/m.

^a The solution concentration was 30 wt % (additive in toluene).

^b With aliquots of the additive solutions dissolved in the oil phase.

^c In the absence of additives.

^d Measurement not carried because the sample was solid.

two bridging mechanisms at work: bridging–stretching and bridging–dewetting.¹²

We also used the Du Noüy ring method to measure the tension at the interfaces of the emulsions formed by water droplets dispersed in the oil. These emulsions are often present in gravitational separation tanks.

These measurements were conducted with the additive solutions mixed in the oil phase of the emulsion because these are more stable in this phase.

These results indicate that the more polar samples had greater adsorption at the W/O interface; this resulted in greater reduction of the W/O interfacial tension.

Tests of the additives' efficiency as antifoams

The tests were performed with additive concentrations of 30 wt % with the additives dissolved in toluene. Aliquots of these formulations were added to the crude oil sample so that the final additive concentrations in the oil were 20 and 50 ppm.

Figures 5 and 6 show the results for each test. To evaluate the influence of toluene in breaking up the foam, we also ran the tests only with the presence of

this solvent at the same concentration of 50 ppm. These results are shown in Figure 6. It could be seen that toluene had little influence on the stability of the foam.

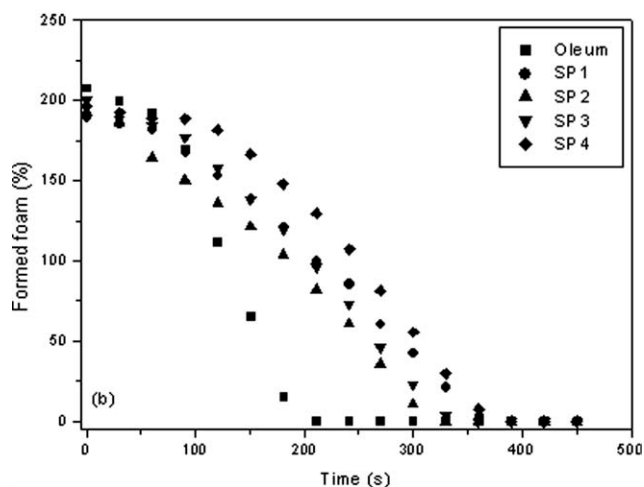
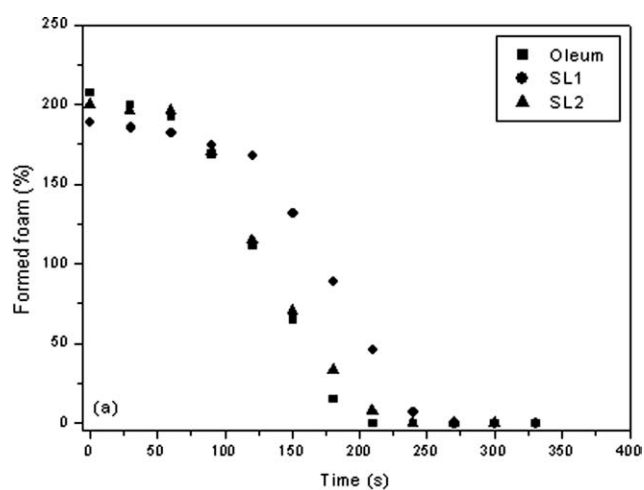


Figure 5 Efficiency tests of the silicone polyether solutions as antifoaming additives in the oil: (a) linear chain and (b) graft chain samples.

TABLE IV
E and S Values

Additive	E (mN/m)	S (mN/m)	B (mN ² /m)
SL1	27.7	−10.9	823
SL2	29.0	−12.0	875
SP1	29.4	−12.4	891
SP2	31.3	−14.1	974
SP3	—	—	—
SP4	30.7	−13.5	948

B, bridging formation coefficient.

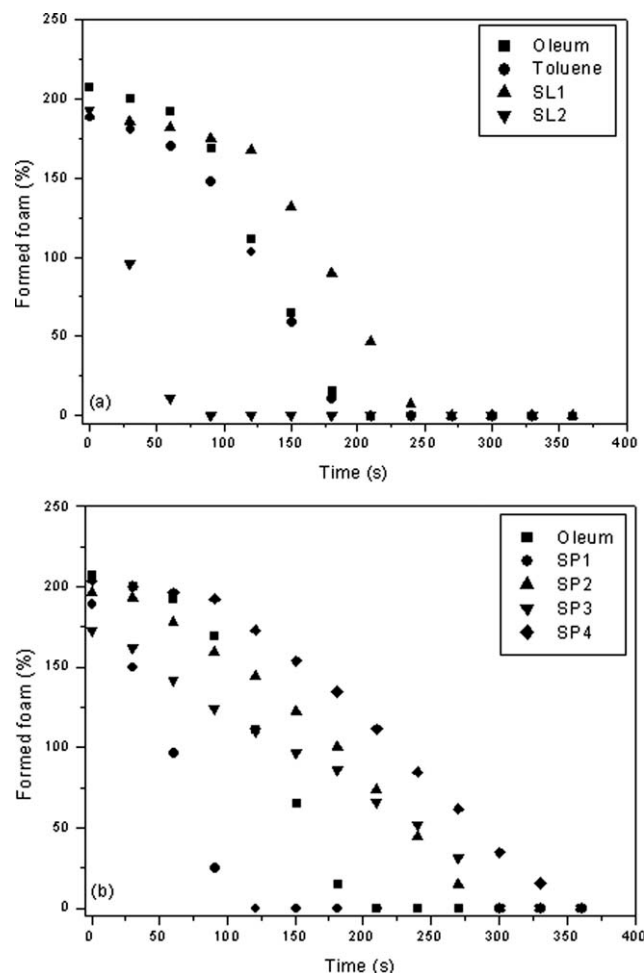


Figure 6 Efficiency tests of the silicone polyether solutions as antifoaming additives in the oil: (a) linear chain and (b) graft chain samples.

For all of the silicone polyether samples, the results show that the solution with the lowest additive concentration (20 ppm, Fig. 5) did not break down the foam.

At a higher concentration (50 ppm, Fig. 6), comparison of the linear samples showed that sample SL2 was more efficient than SL1 in destroying the foam because, after formation, it was very unstable and broke up completely in under 90 s.

According to ref. ¹³, the activity of antifoams strongly depends on their capacity to penetrate the gas/water interfacial barrier and rupture the liquid film formed.

As seen in the surface tension results of the oil samples (Fig. 4), additive SL2 had little effect in reducing the surface tension of the crude oil; this indicated that this silicone polyether acted more within the foam's liquid film than at its surface.

In the presence of branched silicone polyether additives, the results show that sample SP1 (Fig. 6) performed better in the breaking down the foam than the other samples with branched structures.

This fact could also be attributed to the behavior observed previously in the surface tension results of the oil sample (Fig. 4): this additive did not significantly reduce the oil's surface tension. This indicated that the hydrophilic-lipophilic balance of its molecules caused the formation of a heterogeneous phase in the oil medium and favored its antifoaming action.

The SL1, SP2, SP3, and SP4 additives caused the largest reduction in surface tension values of the oil sample and also stabilized the foam formed because of their adsorption on this surface and low dispersion in the oil medium.

Finally, among the samples that were most efficient (SL2 and SP1), SL2 reduced the foam the fastest. This behavior could be attributed to its lower molecular weight, which provided a better distribution of its molecules in the oil medium and caused faster breakage of the liquid foam film.

This behavior was in agreement with the results reported in ref. 14, which showed that antifoam additives were initially deposited on the surface of the solution in the form of large, oily drops. The compound was dispersed during agitation of the foaming solution, and this was greatly facilitated when the components diffused well at the solution's surface. If the compound was highly viscous and/or did not diffuse well, its dispersion could be impaired, and as a result, the antifoam activity could decline.

Tests of the gravitational separation efficiency of the samples

The performance of the additives in destabilizing the W/O emulsions was evaluated by the bottle test.¹⁰ To evaluate the stability of the synthetic W/O

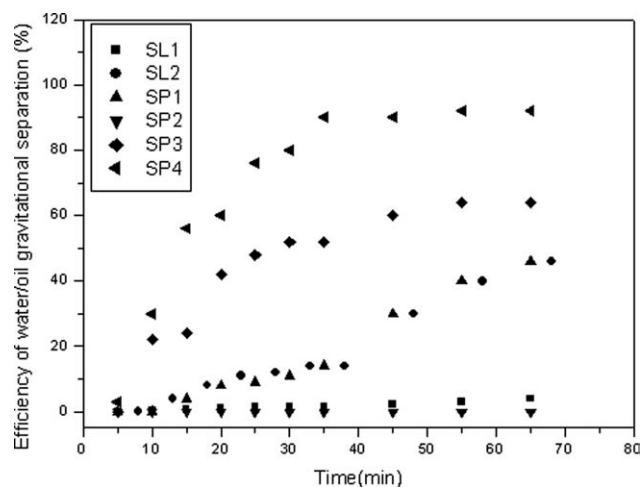


Figure 7 Efficiency of the gravitational separation of the synthetic W/O emulsion of the polyether silicon additives at a concentration of 50 ppm (temperature = 60°C).

emulsions used in this study, emulsions with salt-water as the aqueous phase and the crude oil sample as the oil phase were prepared without any additive. These emulsions were then placed in a heated bath at the temperature for carrying out the gravitational separation tests (60°C). The W/O emulsions remained stable after 70 min, a sufficiently long period for the addition of any of the additives to cause them to destabilize if there had been any antifoaming action.

Figure 7 shows the curves for gravitational separation tests after the addition of 50 ppm additive solution. The results of these tests show that although all the samples reduced the W/O interfacial tension, which indicated the adsorption of their molecules at this interface, these additives did not stabilize the emulsions. This behavior could be observed by the breakdown of the emulsions promoted by the presence of these additives, even when they only caused a small water separation. Sample SP2 did not cause any separation of the W/O phases; this indicated a possible stabilization of the emulsion. However, further studies are necessary to confirm the behavior of this additive.

Sample SP1, which was efficient as an antifoam agent (Fig. 6), also helped break down the W/O emulsion, as shown in Figure 7. On the other hand, sample SL2, which was the best antifoam additive, did not help in this process, although this additive also did not increase the stability of this emulsion. Therefore, we concluded that the samples with good antifoam activity could be used in gravitational separation tanks without impeding the efficiency of the process of breaking down W/O emulsions.

Finally, from the results obtained, we concluded that more efficient separation of the W/O phases could be obtained by an increase in the concentration of silicone in the chains of these additives, mainly observed in the curves of samples SP1, SP3, and SP4. However, the low polarity of sample SP2 [observed by the ratio between the levels of poly(ethylene oxide) and silicone of these samples; Table II] reduced the efficiency of this additive.

CONCLUSIONS

The hydrophilic–lipophilic balance of the chains of silicone polyether was the determining factor for their efficiency in breaking down foam in crude oil. Among the samples evaluated, the most polar ones and those with the lowest silicone content were the most efficient in this application.

Of the best antifoam additives (SL2 and SP1), that with the lowest molar mass (SL2) was most efficient because of the better distribution of its molecules in the petroleum medium; this caused faster rupture of the liquid foam film.

The samples with the highest molar masses and lowest polarity stabilized the foam formed in the oil because of their greater adsorption at the oil's surface.

E and the bridging coefficient (B) calculated were positive; this indicated that these systems could act as antifoam agents for crude oil, with the most probable mechanisms being the formation of bridges and stretching.

None of the additives tested caused stabilization of the W/O emulsions. The efficiency in separating these phases increased with higher silicone content, but the least polar sample did not cause any separation of these phases.

The results obtained in this work allowed us to conclude that the assessment of additives for the demulsification of crude oil should be carried out together with their evaluation as antifoam agents because good demulsifiers can cause the stabilization of foam in oil.

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References

- Chilingarian, G. V.; Robertson, J. O.; Kumar, S. *Dev Pet Sci* 1987, 19, 59.
- Shaban, I. H. *Gas Sep Purif* 1995, 9, 81.
- Poindexter, M. K.; Zaki, N. N.; Kilpatrick, P. K.; Marsh, S. C.; Emmons, D. H. *Energy Fuels* 2002, 16, 700.
- Pape, G. P. *J Pet Technol* 1983, 35, 1197.
- Fraga, A. K.; Rezende, D. A.; Santos, R. F.; Mansur, C. R. E. *Braz J Pet Gas* 2011, 5, 21.
- Rezende, D. A.; Bittencourt, R. R.; Mansur, C. R. E. *J Pet Sci Eng* 2011, 76, 172.
- Ramalho, J. B. V. S.; Ramos, N. A.; Lucas, E. F. *Chem Chem Technol* 2009, 3, 53.
- Mansur, C. R. E.; Barboza, S. P.; González, G.; Lucas, E. F. *J Colloid Interface Sci* 2004, 271, 232.
- Mansur, C. R. E.; Lechuga, F. C.; Mauro, A. C.; González, G.; Lucas, E. F. *J Appl Polym Sci* 2007, 106, 2947.
- Pacheco, V. F.; Spinelli, L. S.; Lucas, E. F.; Mansur, C. R. E. *Energy Fuels* 2011, 25, 1659.
- Nemeth, Z.; Racz, G.; Koczó, K. J. *Colloid Interface Sci* 1998, 207, 386.
- Denkov, D. N. *Langmuir* 2004, 20, 9463.
- Pugh, R. J. *Adv Colloid Interface Sci* 1996, 64, 67.
- Chaisalee, R.; Soontravanich, S.; Yanumet, N.; Scamehorn, J. F. *J Surfactants Detergents* 2003, 6, 345.