Separation Science and Technology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713708471

Removal of Detergents from Aqueous Solutions by Foaming

WŁOdzimierz Zwierzykowski[a]; Krystyna B. Mędrzycka[a]
[a] DEPARTMENT OF FAT CHEMISTRY AND TECHNOLOGY, INSTITUTE OF ORGANIC AND FOOD CHEMISTRY AND TECHNOLOGY GDAŃSK TECHNICAL UNIVERSITY, GDAŃSK, POLAND

To cite this Article Zwierzykowski, WŁOdzimierz and Mędrzycka, Krystyna B.(1973) 'Removal of Detergents from Aqueous Solutions by Foaming', Separation Science and Technology, 8: 1, 57 — 69
To link to this Article: DOI: 10.1080/00372367308057989
URL: http://dx.doi.org/10.1080/00372367308057989

SEPARATION SCIENCE, 8(1), pp. 57–69, 1973

Removal of Detergents from Aqueous Solutions by Foaming

WŁODZIMIERZ ZWIERZYKOWSKI and
KRYSTYNA B. MĘDRZYCKA

DEPARTMENT OF FAT CHEMISTRY AND TECHNOLOGY
INSTITUTE OF ORGANIC AND FOOD CHEMISTRY AND TECHNOLOGY
GDAŃSK TECHNICAL UNIVERSITY
GDAŃSK, POLAND

Abstract

The anionic (sodium tetrapropylenebenzenesulfonate, Nansa HS-55) and nonionic (polyethoxylated alkylphenol, Alfenol) detergents were removed by the foaming method. It was found that there is a possibility of improving the foaming effect of a nonionic detergent by the introduction of a feeding solution into the foam phase. As far as an anionic detergent is concerned, the influence of the kind of feeding was minor in the case of aqueous solutions as well as with those containing sodium chloride. A simple graphic method is presented for the determination of the number of the foaming processes or the number of columns which are to be used in order to obtain the required detergent removal effect.

INTRODUCTION

The problem of removing detergents from waste water has become very important because of the continuous increase in their use. Biodegradation of those compounds is not a complete solution of the problem because not all detergents are susceptible to it (*1–4*). Unfortunately, together with an increase in the production of detergents that are easily susceptible to biodegradation (*5*, *6*), the production of some compounds with desirable useful properties but which are not easily decomposed will also be increased.

In recent years attention has been given to foaming as a method suitable for removing all surface-active substances (*7–14*). The investigation carried out was mainly concerned with the removal of anionic and cationic surfactants. The influence of some of the process parameters upon the degree of detergents removal by foaming was investigated. Among other things investigated were the dependence of the foaming effect on the concentration of the detergent in the feeding solution, the flow rates of the solution and gas (*7*, *12*, *14*), the concentration of inorganic salts in the solution (*8*, *11*, *12*, *14*), and the dimensions of the column (*7*, *10*).

A similar column as used by Newson (*9*) (fig. 1) was used for the tests in the present study. A material balance of the foaming process that was being conducted in a continuous manner is described by the following equations (*9*):

$$V_o = V_r + V_f \tag{1}$$

$$V_oC_o = V_rC_r + V_fC_f \tag{2}$$

$$V_fC_f = V_fC_r + V_gA\Gamma_r \tag{3}$$

Transformation of Eqs. (1)–(3) yields the following equation for describ-

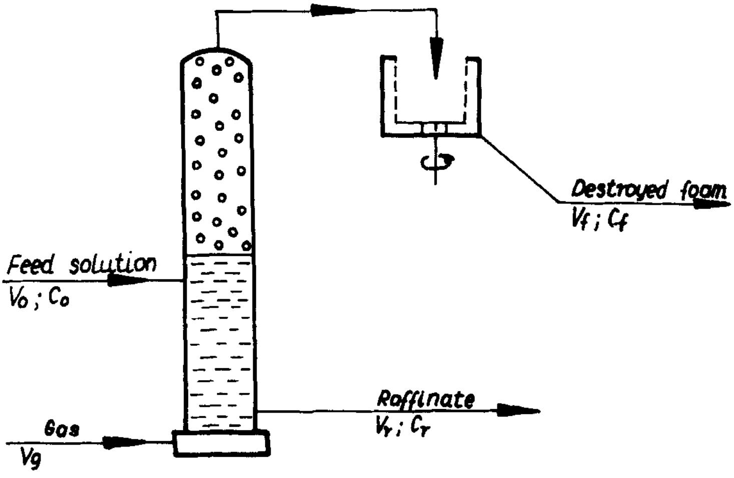

FIG. 1. Scheme of foaming column.

ing the continuous work of the column

$$\frac{C_o}{C_r} = 1 + \frac{V_g A}{V_o} \frac{\Gamma_r}{C_r}$$

The decontamination factor (C_o/C_r) is the most important criterion for the evaluation of the column operation, but it is insufficient. Many time a high decontamination factor is connected with an increased amount of water removed with the foam. That is why we have introduced a so-called foam enrichment factor. It expresses the relation of the quantity of water to the quantity of the detergent that is being removed in the foam.

$$\frac{(V_f/V_o)100\%}{(V_f C_f/V_o C_o)100\%} = \frac{C_o}{C_f}$$

The C_o/C_f coefficient has values from 0 to 1, the process being more favorable the lower the coefficient.

In the present work results are given for experiments in which the column height of the solution feed was changed. A method is also presented for the calculation of the process number that should be carried out under given conditions in order to obtain the appropriate concentration of the detergent in the raffinate.

EXPERIMENTAL

All the experiments were carried out in an 810-mm long, 45 mm diameter glass column at V_g = 10 l/hr, V_o = 2.93 l/hr, h_i/h_f = 0.67. Solutions of Alfenol 8 (polyethoxylated alkylphenol, R = 8–10, n = 9–10, containing 98% of surface active substance) and of Nansa HS-55 (sodium tetrapropylenebezenesulfonate containing 72% of surface active substance) were subjected to foaming.

The processes were conducted in a continuous manner.

In the first series of experiments the column was fed with the solution to the liquid phase at 320 mm height or to the foam phase at 510 mm height, the other parameters being as described above. The experiments were conducted with Alfenol at concentrations from 30 to 420 mg/liter. The dependence of the decontamination factor on the initial concentration of the detergent is shown for those processes in Fig. 2. It appears that feed to the foam phase (Curve 1) gives a decidedly better detergent removal effect than feed to the liquid phase (Curve 2). This is most clearly

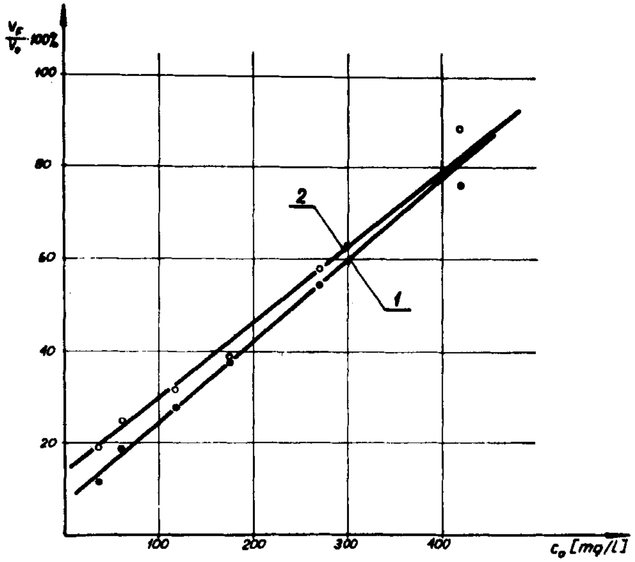

Fig. 3. The dependence of water removal with the foam on the concentration of Alfenol in the solution. (1) Feeding into the liquid phase. (2) Feeding into the foam phase.

seen at lower detergent concentrations. For example, at a concentration of $C_o = 62$ mg/liter with feed to the liquid phase, the decontamination factor mounted to 3.2 while with feed to the foam phase gave $C_o/C_r = 24.0$. Thus, by changing the technique of feed, an effect almost 8 times better is obtained in the removal of the detergent in this case.

The dependence $(V_f/V_o)100 = f(C_o)$ for the same processes is shown in Fig. 3. It is a diagram which gives information on the quantity of water removed with the foam. It follows from the diagram that the quantity of water is higher, i.e., the process is less favorable, the more concentrated is the solution subjected to foaming. Further, it follows from the diagram that processes conducted at column feed to foam are less favorable in this respect.

An improvement of the foaming effect (increasing the C_o/C_r value) is

Fig. 2. Decontamination factor dependence of Alfenol on its concentration in the solution. (1) $h_i = 50$ cm, feeding into the foam phase. (2) $h_i = 24$ cm, feeding into the liquid phase.

associated with a higher loss of water removed with the foam. An evaluation of the process and a selection of parameters merely on the basis of these two coefficients is difficult. That is why a diagram has been worked out for the dependence of the foam enrichment factor on the concentration of the initial detergent (Fig. 4). From Fig. 4, which refers to the same processes shown in Figs. 2 and 3, it follows that lower C_o/C_f values are obtained in the case of column feed at the foam phase than at feed to the liquid phase. On the basis of Figs. 2 and 4 it is possible to ascertain that feed of the foaming column to the foam is highly favorable. That statement, however, is justified only for Alfenol. In the case of foaming Nansa solutions, feed to foam improves the effect of the process to a very small degree only. A slight increase of the decontamination factor and an insignificant decrease of the foam concentration coefficient is obtained. Results achieved in the Nansa foaming processes conducted in the same way as for Alfenol are shown in Figs. 5 and 6. The solid line represents the Nansa foaming process from aqueous solutions containing NaCl, and

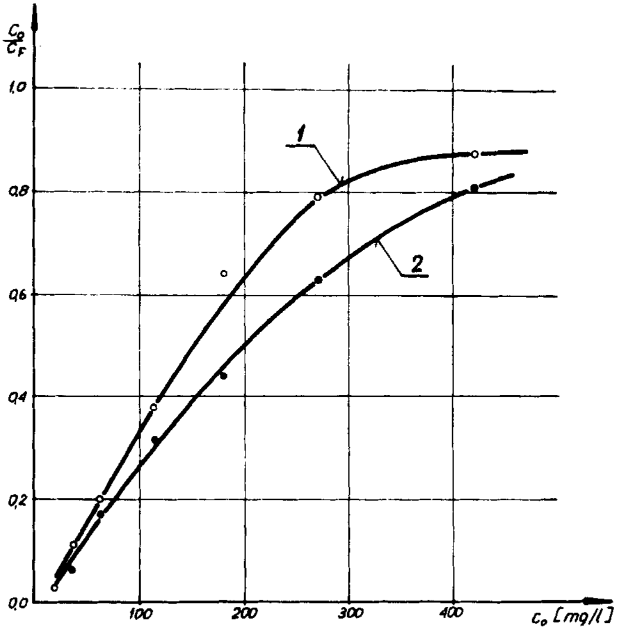

FIG. 4. The influence of Alfenol concentration in the solution on the foam enrichment factor. (1) Feeding into the liquid phase. (2) Feeding into the foam phase.

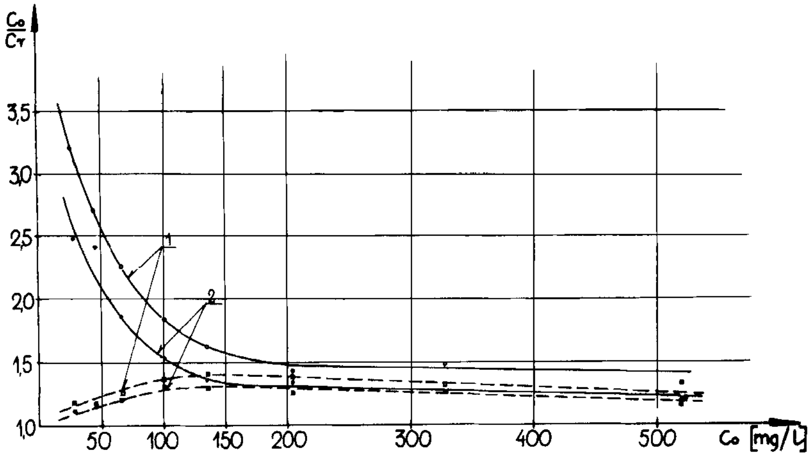

FIG. 5. Decontamination factor dependence on Nansa concentration in the solution. (1) Feeding into the foam phase. (2) Feeding into the liquid phase. (——) Nansa in 0.01 N NaCl aqueous solution. (- -) Nansa in aqueous solution.

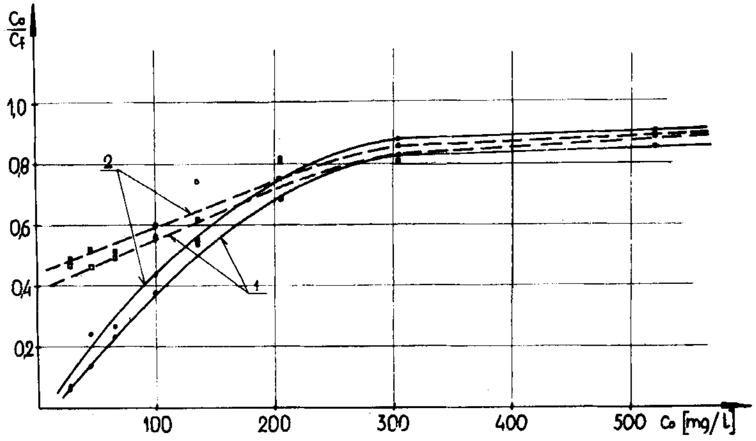

FIG. 6. Variation of foam enrichment factor with the Nansa concentration in the solution. (1) Feeding into the foam phase. (2) Feeding into the liquid phase. (——) Nansa in 0.01 N NaCl aqueous solution. (- -) Nansa in aqueous solution.

the broken line from solutions containing no NaCl. The improvement of the sodium tetropropylenebenzenesulfonate removal factor in the foaming process by the introduction of sodium chloride is much higher than by the change of the method of feeding the column.

In order to make comparison of the removal effect of anionic and nonionic detergents possible, an equation $n = f(C_o)$, in which n is the relation of the decontamination factors in a case of feeding to the foam phase and to the liquid phase, has been used. Thus this equation reveals how many times the decontamination factor is improved by a change in the feeding method. From Fig. 7 it may be seen that n is very high for low concentrations of Alfenol in the solution. In the case of Nansa, n has very small values, approximately 1.1–1.2, and is not dependent upon the Nansa concentration in the initial solution.

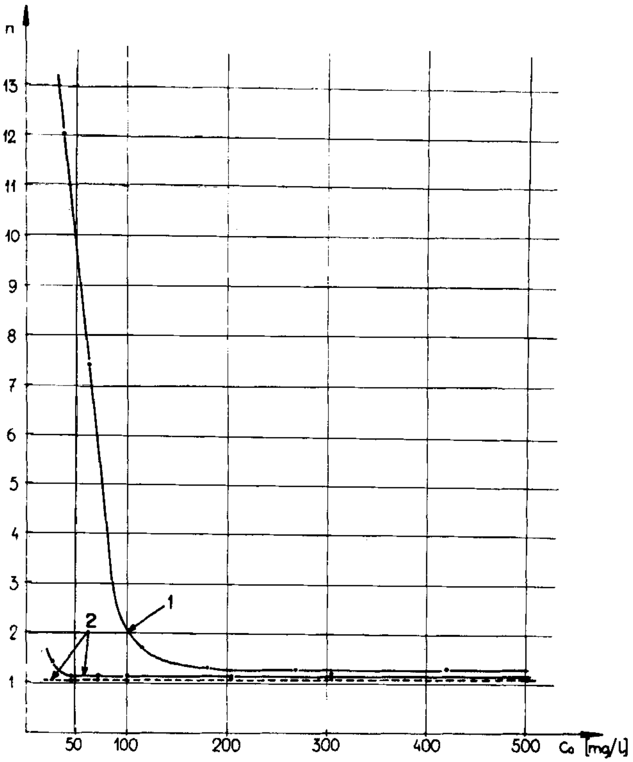

FIG. 7. Variation of "n" with the detergent feed concentration. (1) Alfenol. (2) Nansa. (- -) In aqueous solution.

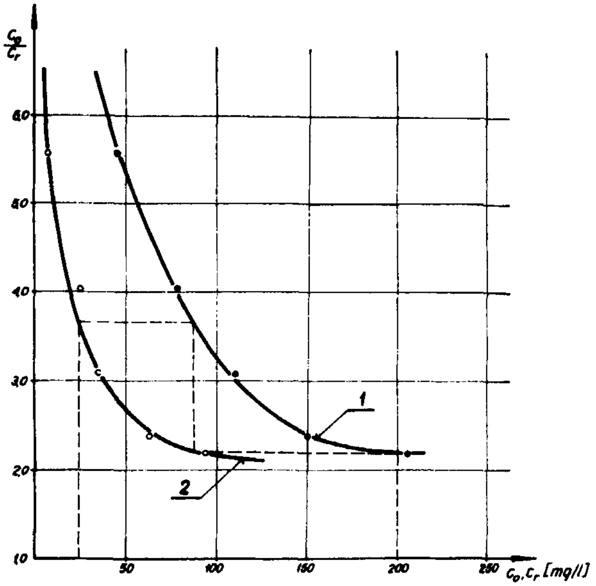

FIG. 8. Decontamination factor dependence for Alfenol on its concentration in feed and raffinate. (1) $C_o/C_r = f(C_o)$. (2) $C_o/C_r = f(C_r)$.

In one foaming process the detergent dependency upon the state of equilibrium of the absorption processes at the interfaces of the system is removed to a certain degree. The raffinate obtained from foaming may be subjected to further cleaning as many times as necessary in order to obtain a solution with the minimum required concentration. Thus it is possible to conduct multistep foaming. In order to determine the number of columns or processes that are necessary for cleaning the solution to the required detergent concentration, an equation representing the following two dependencies has been worked out: $C_o/C_r = f(C_o)$ and $C_o/C_r = f(C_r)$.

Figure 8 shows such the dependencies for Alfenol in relation to the foaming processes at the following parameters: $V_o = 1.88$ l/hr; $V_g = 10$ l/hr; $h_l = 50$ cm; $h_l/h_f = 0.67$. Curve 1 represents the dependence $C_o/C_r = f(C_o)$, and Curve 2 the dependence $C_o/C_r = f(C_r)$.

Similarily, Fig. 9 shows the relevant dependences for Nansa HS-55 which was subjected to foaming under the same conditions as Alfenol. The determination of the process number necessary for obtaining a final solution with a predetermined concentration is carried out as shown by

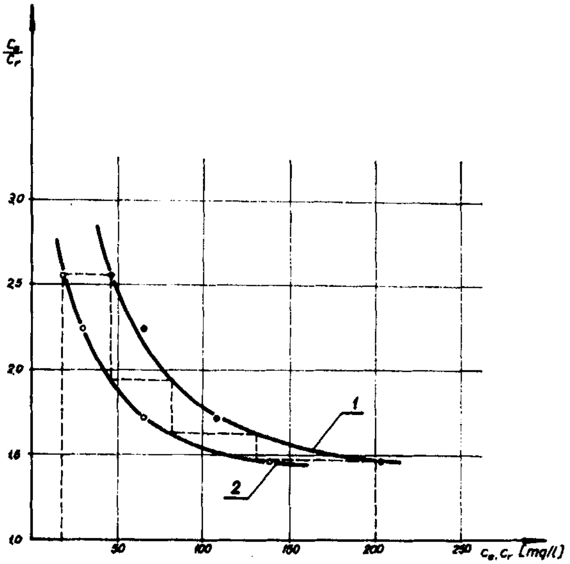

FIG. 9. Decontamination factor dependence for Nansa on its concentration in feed and raffinate. (1) $C_o/C_r = f(C_o)$. (2) $C_o/C_r = f(C_r)$.

the dotted line in the diagrams. From Fig. 8 it follows that in order to obtain a solution of approximately 25 mg/liter concentration from an Alfenol solution with a 200-mg/liter concentration, it is necessary to conduct two consecutive foaming processes under the given conditions. In other words, it is necessary to use a set-up composed of two columns with identical working parameters. If the same effect is wanted with Nansa, a set-up composed of four columns must be used.

Similarily, it is possible to evaluate the advantage from the foaming process with the column fed at the foam phase. Figure 10 shows the dependencies $C_o/C_r = f(C_o)$ and $C_o/C_r = f(C_r)$ for the Alfenol foaming process with the column fed to the liquid phase. The column working parameters were as follows: $h_l = 32$ cm; $h_l/h_f = 0.64$; $V_o = 2.93$ l/hr; $V_g = 10$ l/hr; $h_i = 24$ cm.

Figure 11 refers to a series of Alfenol foaming processes with the column fed to the foam phase at $h_i = 50$ cm. The other parameters were the same as in Fig. 10.

A comparison of Figs. 10 and 11 shows that in order to diminish the Alfenol concentration in a solution from approximately 420 to 30 mg/liter, it is necessary to conduct various numbers of foaming processes.

In the case of processes with feed to the liquid phase, it is necessary to use four identical columns; in the case of processes with feed to the foam phase, only three columns need to be used.

Those results have once again confirmed that the work of the foaming column is more effective when the feed is given to the foam phase.

CONCLUSIONS

Possibilities have been investigated for the improvement of the removal effect of anionic sodium tetrapropylenebenzenesulfonate) and nonionic (polyethoxylated alkylphenol) detergents by changing the method of feeding a continuously operating column. Removal of nonionic compounds was several times better when the column was fed to the foam phase than for feeding to the liquid phase. This is especially true, with detergents at concentrations of less than 100 mg/liter. Such a favorable effect, however, is not found in the case of sodium tetrapropylene-benzenesulfonate, where a change of the method of feed improves the

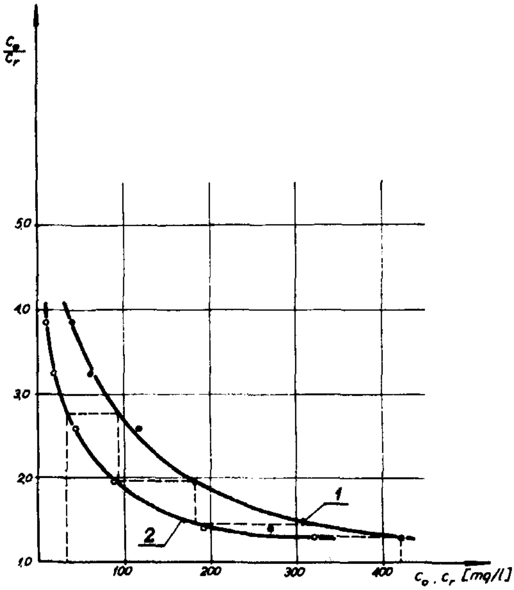

FIG. 10. Decontamination factor dependence for Alfenol on its concentration in feed and raffinite for column feeding into the liquid phase.
(1) $C_o/C_r = f(C_o)$. (2) $C_o/C_r = f(C_r)$.

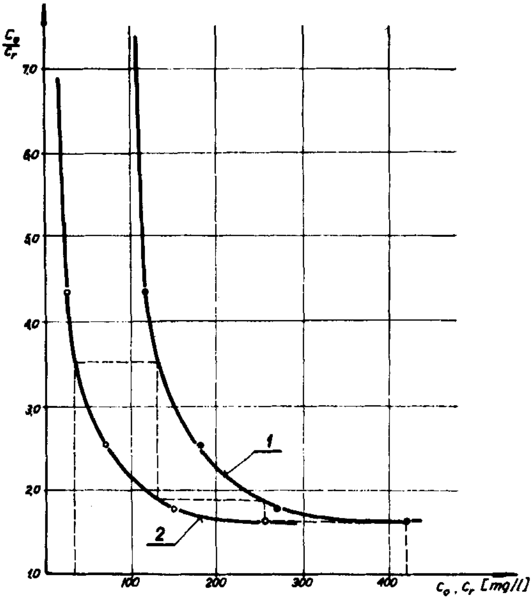

FIG. 11. Decontamination factor dependence for Alfenol on its concentration in feed and raffinate for column feeding into the foam phase. (1) $C_o/C_r = f(C_o)$. (2) $C_o/C_r = f(C_r)$.

detergent removal effect only very slightly. This can be explained by the fact that the surface adsorption velocity of oxyethylene derivatives is many times higher than the adsorption velocity of alkylarylsulfonates.

A simple method has been found for graphic determination of the number of foaming processes indispensable for obtaining the final required concentration of the detergent in the raffinate. On the basis of the determined dependencies $C_o/C_r = f(C_o)$ and $C_o/C_r = f(C_r)$, a step line similar to the calculation of the number of theoretical plates for a rectification column has been traced. It has been shown by this graphic method that the number of foaming processes needed to obtain identical effects in the removal of detergents with alkylarylsulfonate is higher than in the case of foaming the solutions of oxyethylated alkylphenols.

SYMBOLS

V	volume flow rate
c	detergent concentration

A	surface area per unit volume of air in a foam
Γ	surface excess
h_l	height of the liquid phase
h_f	height of the foam phase
h_i	height of feeding the column with solution
C_o/C_r	decontamination factor
C_o/C_f	foam enrichment factor
V_o/V_f	volume reduction

Subscripts

g	relating to gas flow
o	relating to feeding solution
r	relating to raffinate solution
f	relating to collapsed foam

REFERENCES

1. J. K. Weil and A. J. Stirton, *J. Amer. Oil Chem. Soc. 41*, 355 (1964).
2. Q. W. Osborn and J. H. Benedict, *Ibid.*, *43*, 141 (1966).
3. C. Hammerton, *J. Appl. Chem. 5*, 517 (1955).
4. E. S. Lashen and J. C. Lamb, *Water Works West. Eng. 4*(12), 56 (1967).
5. R. A. Conway, C. H. Vath, and C. A. Renn, *Ibid.*, *2*(1), 28 (1965).
6. M. A. Linter and L. Long; *J. Amer. Oil Chem. Soc.*, *46*, 601 (1969).
7. C. A. Brunner and D. G. Stephan, *Ind. Eng. Chem. 57*, 40 (1965).
8. R. B. Grieves, *J. Sanit. Eng. Div., Amer. Soc. Civil Eng.*, *92*, 41 (1966).
9. I. A. Newson, *J. Appl. Chem.*, *16*, 43 (1966).
10. R. B. Grieves and R. K. Wood, *Amer. Inst. Chem. Eng. J.*, *10*, 456 (1964).
11. R. B. Grieves and D. Bhattacharyya, *Nature*, *204*, 31, 441 (1964).
12. W. Zwierzykowski and K. Medrzycka, *Chem. Stosowana*, *14*, 463 (1970).
13. E. Rubin and J. Jorne, *J. Colloid Interface Sci.*, *33*(2), 208 (1970).
14. R. B. Grieves, I. U. Ogbu, D. Bhattacharyya, and W. L. Conger, *Separ. Sci.*, *5*(5), 583 (1970).

Received by editor June 13, 1972