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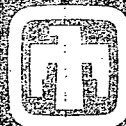
MASTER

# AQUEOUS FOAM SURFACTANTS FOR GEOTHERMAL DRILLING FLUIDS: I. SCREENING

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Prepared by Sandia Laboratories, Albuquerque, New Mexico 87115  
and Livermore, California 94550 for the United States Energy Research  
and Development Administration under Contract AEC(29)-789

January 1980



Sandia Laboratories

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ABSTRACT

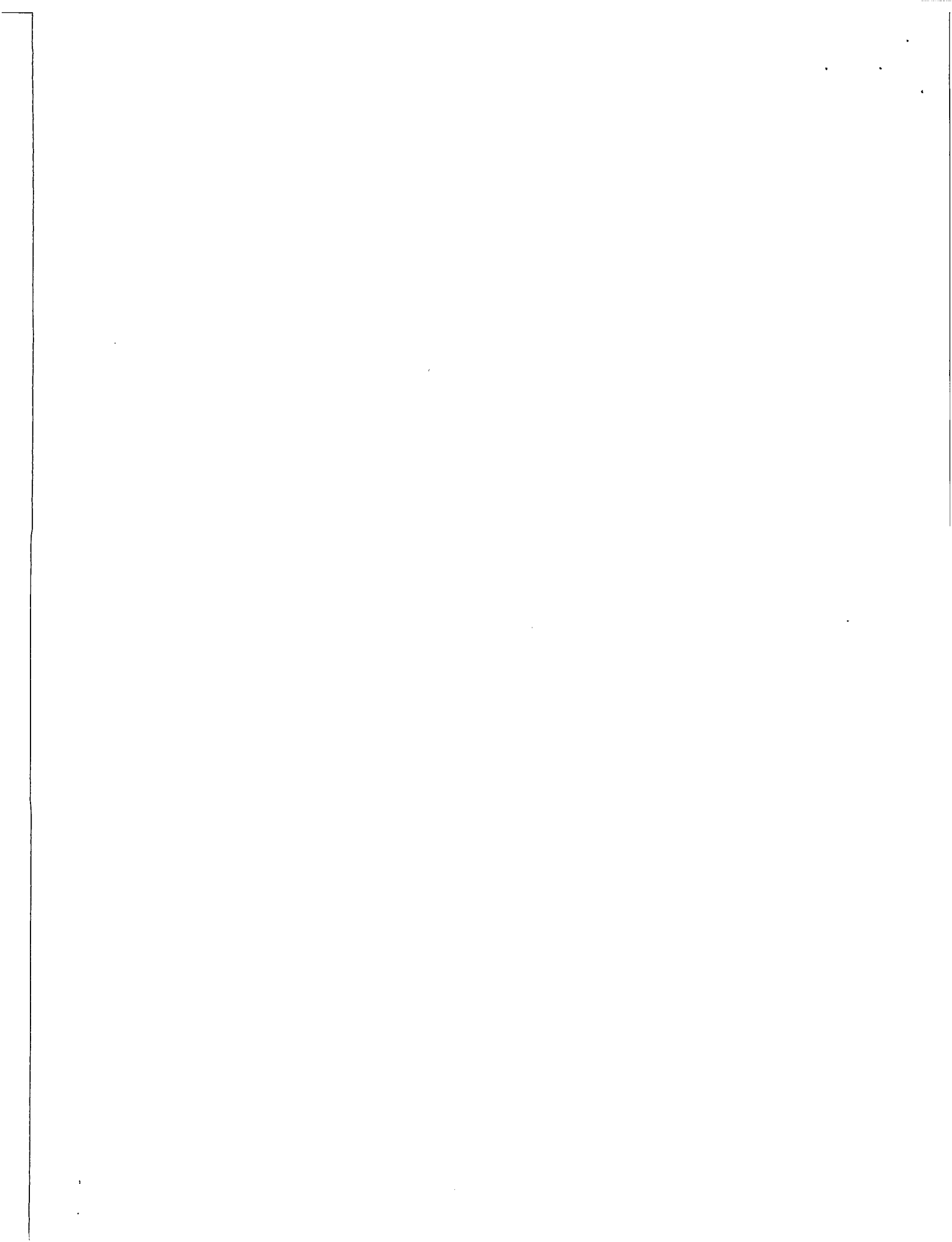
Aqueous foam is a promising drilling fluid for geothermal wells because it will minimize damage to the producing formation and would eliminate the erosion problems of air drilling. Successful use of aqueous foam will require a high foaming surfactant which will: 1. be chemically stable in the harsh thermal and chemical environment, and 2. form stable foams at high temperatures and pressures. This paper presents the procedures developed to generate and test aqueous foams and the effects of a 260°C temperature cycle on aqueous surfactant solutions. More than fifty selected surfactants were evaluated with representatives from the amphoteric, anionic, cationic, and nonionic classes included. Most surfactants were severely degraded by this temperature cycle; however, some showed excellent retention of their properties. The most promising surfactant types were the alkyl and alkyl aryl sulfonates and the ethoxylated nonionics.

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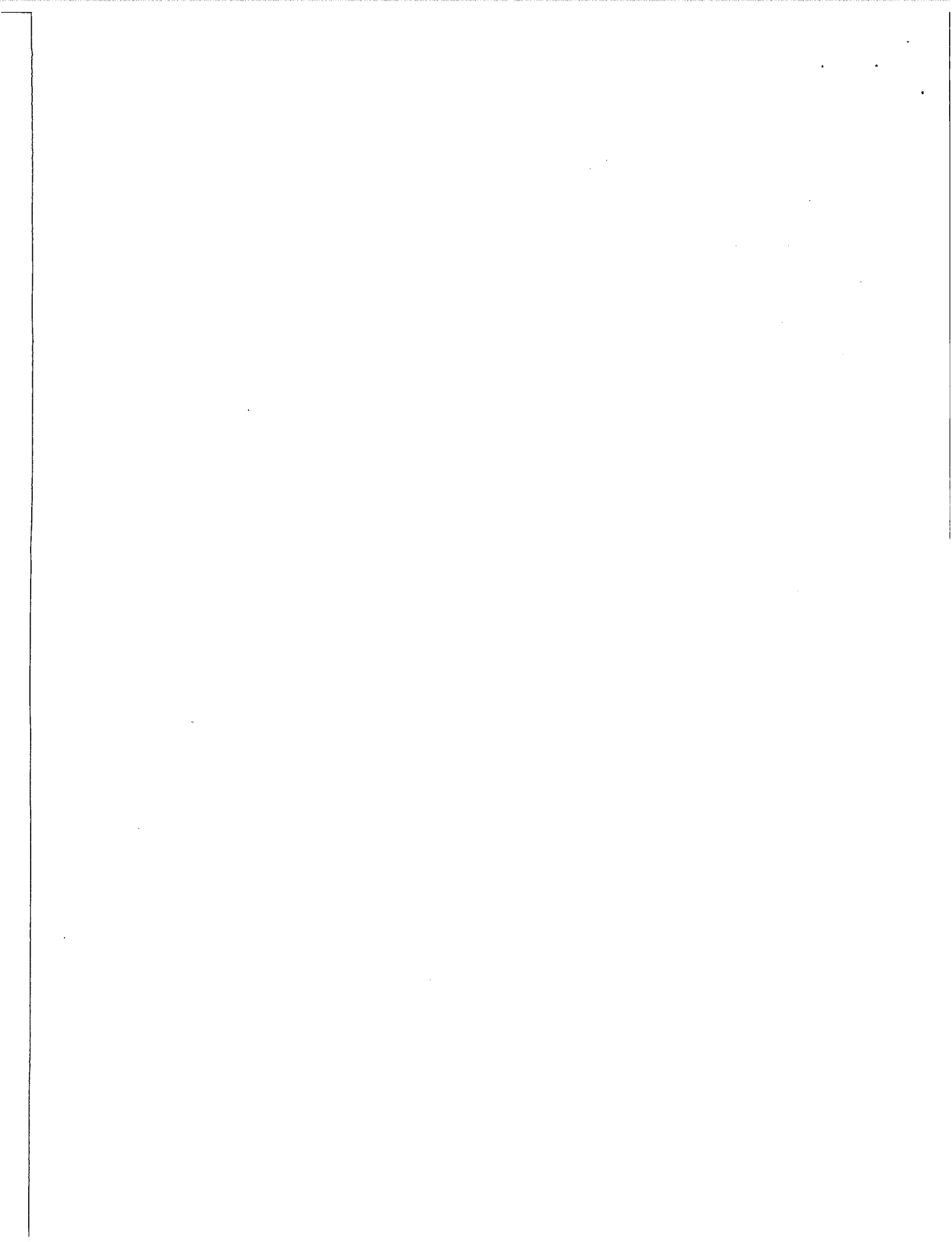
\* This work was supported by the U. S. Department of Energy, (DOE) under contract DE-AC04-76 DP00789.

\*\* A U. S. DOE facility.



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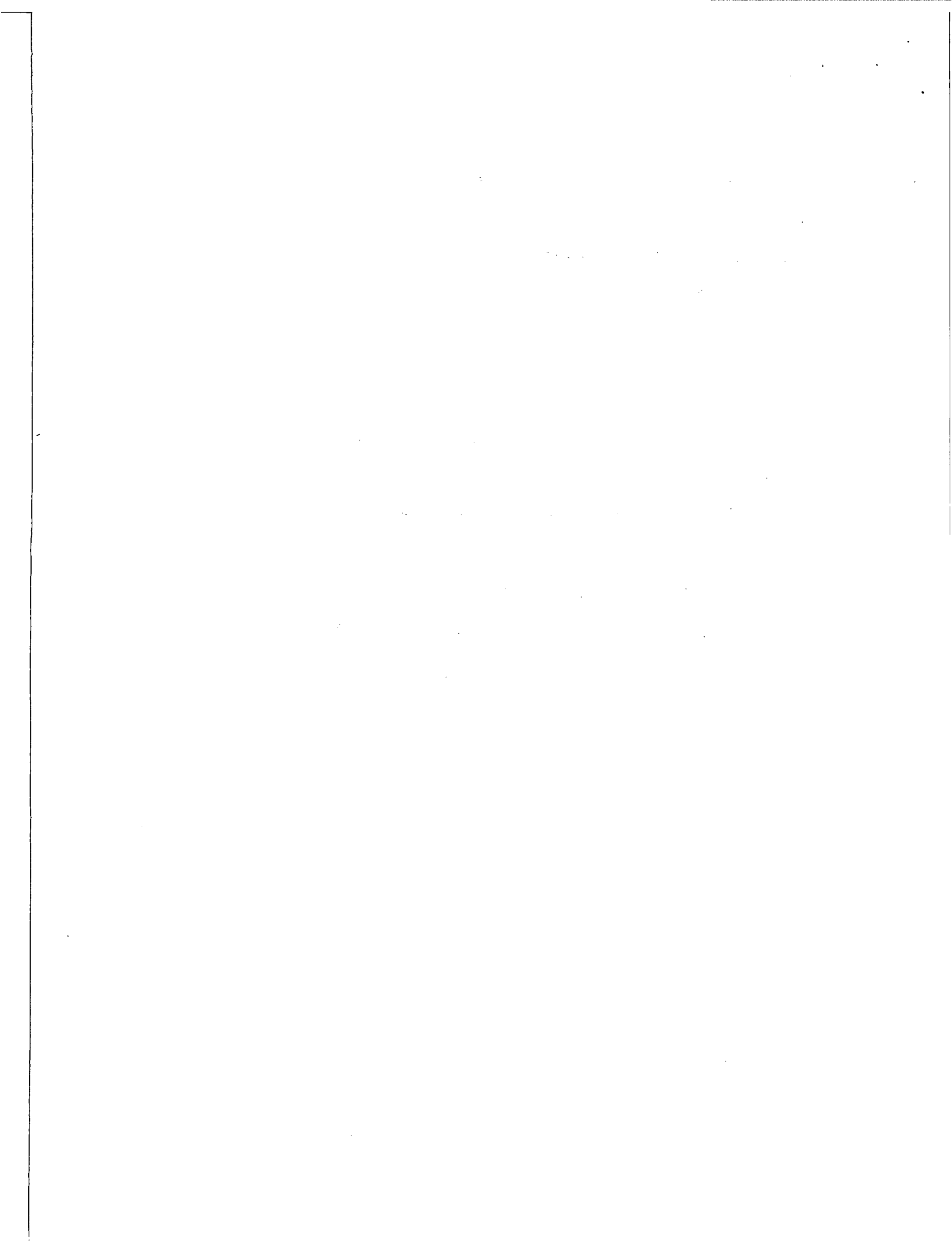
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## INTRODUCTION

Deep well rotary drilling requires the use of a drilling fluid which has many functions including; removal of solids, cooling, lubrication, and pressure control.<sup>1,2</sup> Water based muds, made with Bentonite or native clays, are the most commonly used drilling fluids. Many other fluids including oil based muds, aqueous foams, and air or other gases are also used.<sup>3</sup> Aqueous foams have been used as a fluid in wells for workovers and drilling operations around the world.<sup>4-7</sup> Some work has also been done to determine the properties of aqueous foams for drilling fluid applications.<sup>8-11</sup> These references illustrate that aqueous foam is a useful drilling fluid noted for its excellent lifting ability, high penetration rates, and low annular velocities.

Drilling geothermal wells presents some unique problems as evidenced by the fact that geothermal well drilling costs are two to four times the cost of oil or gas wells. Aqueous foams have been identified as a promising drilling fluid in the under-pressured formations frequently found in geothermal reservoirs.<sup>12</sup> The advantages of foam for geothermal drilling are: 1. it will not harm the producing formations, and 2. the low annular velocities will greatly reduce the erosion of the drill string caused by air drilling. Successful use of foam will require a foaming agent system that will not degrade rapidly in the harsh thermal and chemical environment and that will form stable foams in a high temperature and

pressure environment. Some work has been done with aqueous foams at high temperatures for cleanout and stimulation in oil wells<sup>4</sup> and for geothermal drilling.<sup>13</sup>

Because of its low density, successful use of foam will require a high pressure rotary drilling head suitable for geothermal well use. This will allow balanced drilling thus allowing control of formation water and steam. Corrosion problems may require the use of nitrogen rather than air to make the foam. If corrosion inhibitors can be found that will work in the high temperature geothermal environment, this may not be necessary.

The first step in developing foam drilling fluids for geothermal use is to find chemically stable foaming agents or surfactants to make the foam. This paper will present the results of a study to determine the thermal stability of a wide variety of commercially available surfactants in aqueous solution. Tests were run on the solution and foams made with the solution before and after exposure to 260°C for two hours. These tests have shown that several types of commercially available surfactants may be suitable foaming agents for geothermal drilling.

## EXPERIMENTAL

Surfactant solutions were exposed to a 260°C (500°F) aging cycle in heavy wall corrosion resistant stainless steel tubing with "SWAGELOK" end caps. The solutions were prepared by mixing fifty weight percent of the surfactant as received in deionized water. A few surfactants were aged as 1.0 and 0.2 weight percent solutions in a Baroid 500 cc high temperature aging cell due to limited solubility. This is noted where applicable in the data. The aging cycle consisted of the following: a. ambient to 260°C-two hours b. 260°C-two hours and c. 260°C to ambient-three hours. All containers were cleaned and run through the 260°C temperature cycle between uses to minimize contamination from previous samples.

Aqueous foams for evaluation were made by metering nitrogen gas and surfactant solution into a static mixer as illustrated in Figure 1. Commercially available static mixers, such as "Kenics," work well however a tube filled with coarse stainless steel wool provided more uniform foams over a broader flow range than the commercial mixers. This technique of foam generation gave uniform small celled foams with controlled density for evaluation. The density of all foams was controlled to  $45.0 \pm 5.0 \text{ Kg/m}^3$  except as noted.

Foams were made with the surfactant solutions before and after exposure to the 260°C temperature cycle. Density and time to fifty percent by weight drainage were determined on each foam sample. The values reported are the average of

three determinations. Drainage time was measured using the setup shown in Figure 2. The foams were also evaluated qualitatively by observing their cell structure. Ratings of good, fair, and poor were assigned on the basis of the uniformity of their cell structure. Solution pH was also measured before and after exposure using a Beckman model 4500 digital pH meter. The pH values reported are the average of two determinations.

## SURFACTANTS

A wide variety of high foaming surfactants were selected for evaluation on the basis of their chemical structure and/or supplier's recommendations. Amphoteric, anionic, cationic, and nonionic types with varying chemical structure were evaluated. The books by Schwartz and Perry<sup>13,14</sup> and McCutcheons<sup>15</sup> were used extensively to determine chemical structure and availability respectively.

Amphoteric surfactants evaluated were the betaines, amido betaines, sulfo amido betaines, an imidazolene compound, and a proprietary fluoro-chemical material. Most anionic surfactants evaluated were sulfonic acid salts or sulfonates. Alkyl, alkyl aryl, and perfluoro alkyl sulfonates were included. Other anionic types tested were an ethoxylated alkyl sulfate and an amide linked carboxylic acid salt. Cationic types evaluated were an imidazolene compound, ethoxylated tertiary amines, and a proprietary fluorochemical material. The nonionic surfactants tested were ethoxylated fatty alcohols, ethoxylated alkyl aryl alcohols, and a polyoxypropylene - polyoxyethylene block copolymer.

## RESULTS AND DISCUSSION

The effects of a 260°C temperature cycle on amphoteric, anionic, cationic and proprietary, and nonionic surfactants are presented in Tables I-IV. The surfactants are identified by chemical type and reference number. The trade names and suppliers are given in Appendix A. The original properties or properties before exposure given are density, drainage time, cell structure rating, and solution pH. The effects of the temperature cycle are shown in the last three columns listing; change in drainage, change in pH, and cell structure rating.

The density range of  $45.0 \pm 5.0 \text{ kg/m}^3$  was chosen as representative of the preformed stable foams used as drilling fluids. This density is equivalent to a liquid volume fraction of 0.045 or a weight of 0.37 lbs/gal. A few of the poorer foaming surfactants would not make foams of  $45.0 \pm 5 \text{ kg/m}^3$  in our generator. This is noted in the original cell structure column.

Foam drainage is defined as the time to fifty percent weight loss of a preformed foam. It is a measure of density stability of the foam. Foams with long drainage times or good density stability are desirable for drilling fluid applications. The drainage data are presented as the time in minutes to 50 percent by weight drainage and the percentage difference in drainage time between the original and exposed sample.

All foams tested were qualitatively evaluated for cell structure and given ratings of good--small uniform cells, fair-nonuniform cell structure and poor-nonuniform cells with large voids. This test is important because it indicates that degradation products from the surfactant are acting as antifoamers or defoamers in the solution. This implies that higher temperatures or longer times would give solutions incapable of making foams. This would be disastrous for foam drilling fluid applications. Some foams made with surfactants exposed to 260°C retained or even improved their drainage time; however, they would not make fine-uniform celled foams indicating the importance of this rating. Many surfactant solutions would not make foams after exposure to 260°C. This is noted with a "no foam" rating in the aged cell structure column.

The change in pH can only be treated as a relative value indicative of surfactant degradation. The mechanisms of the surfactant degradation would have to be understood before any additional meaning can be obtained from these data.

The data are presented somewhat arbitrarily in the order of decreasing stability as indicated by the change in drainage after exposure to 260°C. Although drainage is important, the true value of a surfactant for geothermal foam drilling must also consider the change in foam cell structure, solution pH and other factors yet to be evaluated. This ordering system does tend to put the best surfactants at the top of the list in each class. All data presented are the average of



three determinations.

The aging data presented in Table I on amphoteric surfactants shows that these materials, as a class, performed poorly. Only one, a coco betaine, had good cell structure after aging accompanied by a 28.0 percent decrease in drainage time. A cetyl betaine gave a small decrease in drainage time; however, the poor foam cell structure after aging indicates problems will arise after longer exposure times. Most of the amphoteric surfactants produced no foam at all after exposure to 260°C. It is interesting to note that one of the surfactants giving no foam is another coco betaine, indicating that there are differences between surfactants sold as the same chemical type from different manufacturers. One surprise in these data was the failure of a fluorochemical surfactant, normally noted for its chemical stability.

The anionic surfactants showed less degradation as a class as shown in Table II. Most anionic surfactants evaluated made foam after our 260°C cycle. The best anionic surfactants evaluated were a sodium alkyl aryl polyether sulfonate and a sodium alkyl amide sulfonate which both show small changes in drainage time, good cell structure after exposure, and small changes in pH. The first surfactant listed, a sodium alkyl ester sulfonate, showed a large increase in drainage time. In this case, hydrolytic cleavage of the ester linkage will generate a fatty alcohol which is an excellent foam stabilizer which probably explains this surprising result. Although promising, this result must be viewed with caution as the foam cell structure was

rated only fair after exposure to 260°C. Other anionic surfactants which will be evaluated in future tests are the alpha olefin sulfonate and the triethanol amine alkyl aryl sulfonate. Because of the known hydrolytic instability of the sulfuric esters (sulfates), very few were evaluated. Data on an ethoxylated ammonium alkyl sulfate and an alkyl sulfate are included.

The data on cationic and proprietary surfactants are given in Table III. The cationic surfactants, as a class, performed poorly. One, an ethoxylated amine, had an increase in drainage time; however, it had poor cell structure after aging. Several proprietary foaming agents, recommended for foam drilling, were evaluated. One system, which is recommended for use as a foaming agent with steam in oil well stimulation procedures, performed well. This system gave a moderate decrease in drainage, good cell structure, and a small change in solution pH after aging.

The nonionic surfactants, as a class, performed well as shown in Table IV. After exposure to 260°C, two showed an increase in drainage time and made foams with good cell structures. One, an ethoxylated fatty alcohol, gave very little shift in solution pH.

Surfactants selected for further evaluation are listed in Table V with selected data. Selection was based first on their performance in these screening tests but also on their chemical structures. This study is the first step in finding

useful surfactants for geothermal foam drilling fluids. The promising surfactants will now be exposed to acidic, basic and simulated geothermal brine solutions at 260°C and higher temperatures. These tests will establish the chemical stability of surfactant solutions in various chemical environments. The final step to establish surfactant usefulness will be to make and evaluate aqueous foams at high temperatures and pressures in an autoclave. Successful surfactants from these tests will then be formulated with additives such as corrosion inhibitors, scale inhibitors, antioxidants, and caustic chemicals to make foaming agent systems for geothermal drilling.

## CONCLUSIONS

Techniques have been developed to expose aqueous surfactant solutions to a high temperature cycle, to generate foams with controlled density, and to evaluate the foams made. These techniques were used to evaluate more than fifty surfactants to establish their resistance to a 260°C temperature cycle as a first step in finding surfactants for use as foaming agents for geothermal drilling. Most surfactants evaluated were severely degraded by the 260°C temperature; however, about one in five showed good resistance. These promising surfactants will be tested after exposure to various chemical environments at 260°C and higher temperatures and pressures in a continuing program to find foaming agents for geothermal drilling.

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TABLE I  
EFFECT OF 260°C ON AMPHOTERIC SURFACTANT SOLUTIONS

CHEMICAL TYPE	REF. NO. (1)	ORIGINAL PROPERTIES			pH	EFFECT OF 260°C		CELL STRUCTURE
		DENSITY (KG/M <sup>3</sup> )	DRAINAGE TIME/MIN.	CELL STRUCTURE		CHANGE IN DRAIN. %	CHANGE IN pH	
CETYL BETAINE	1	46.4	5.63	GOOD	7.08	-4.08	+1.45	POOR
COCO BETAINE	2	45.6	6.83	GOOD	5.12	-28.3	+1.82	GOOD
COCO AMIDO BETAINE	3	47.0	5.66	GOOD	6.23	-38.5	+1.60	POOR
COCO BETAINE	4	47.6	5.22	GOOD	7.65	-39.6	-0.36	POOR
COCO IMIDAZOLINE BETAINE	5	45.8	6.32	GOOD	10.27	-49.8	-4.53	GOOD
COCO AMIDO BETAINE	6	46.2	5.29	GOOD	6.00	-50.5	+1.97	POOR
COCO BETAINE	7	48.5	4.96	GOOD	6.50	NO DATA	+0.62	POOR
COCO BETAINE	8	44.6	6.79	GOOD	5.27	NO FOAM	+1.83	NO FOAM
COCO AMIDO BETAINE	9	48.7	5.03	GOOD	5.07	NO FOAM	+1.77	NO FOAM
SULFO COCO AMIDO BETAINE	10	45.3	5.33	GOOD	6.54	NO FOAM	+0.67	NO FOAM
SULFO COCO AMIDE BETAINE	11	48.2	6.44	GOOD	7.59	NO FOAM	-0.03	NO FOAM
COCO AMINO ACID, K SALT	12	44.5	4.85	GOOD	10.17	NO FOAM	-1.84	NO FOAM
COCO IMIDAZOLINIUM DERIVATIVE	13	46.8	6.35	GOOD	8.06	NO FOAM	-1.34	NO FOAM
COCO IMIDAZOLINE BETAINE	14	45.7	6.82	GOOD	9.50	NO FOAM	-1.72	NO FOAM
PROPRIETARY FLUORO-CHEMICAL	15	44.4	9.83	GOOD	4.56	NO FOAM	-1.27	NO FOAM

(1) See Appendix A for trade names and suppliers.

TABLE II  
EFFECT OF 260°C ON ANIONIC SURFACTANT SOLUTIONS

CHEMICAL TYPE	REF. NO. (1)	ORIGINAL PROPERTIES				EFFECT OF 260°C		
		DENSITY (KG/M <sup>3</sup> )	DRAINAGE TIME/MIN.	CELL STRUCTURE	pH	CHANGE IN DRAIN. %	CHANGE IN pH	CELL STRUCTURE
SODIUM ALKYL ESTER SULFONATE	16	41.4	7.28	GOOD	6.50	+232.	-2.65	FAIR
POTASSIUM PERFLUORO ALKYL SULFONATE	17	92.8	2.58	HIGH DENSITY	5.30	+49.2	-0.76	FAIR
SODIUM ALKYL AMIDE SULFONATE	18	48.9	4.05	GOOD	8.02	-5.18	-0.81	FAIR
SODIUM ALKYL ARYL POLYETHER SULFONATE	19	46.1	5.12	GOOD	5.81	-3.51	+0.78	GOOD
SODIUM ALPHA OLEFIN SULFONATE	20	43.8	7.84	GOOD	8.39	-5.86	-2.73	GOOD
SODIUM ALKYL AMIDE SULFONATE	21	43.1	4.97	GOOD	7.37	-8.60	-0.32	GOOD
SODIUM ALPHA OLEFIN SULFONATE	22	48.6	7.82	GOOD	8.30	-12.0	-0.59	GOOD
SODIUM ALKYL AMIDE CARBOXYLIC ACID	23	46.4	5.86	GOOD	6.85	-19.4	-1.41	FAIR
TEA ALKYL ARYL SULFONATE	24	45.1	8.74	GOOD	6.93	-20.4	-0.28	GOOD
SODIUM ALKYL ARYL SULFONATE	25	79.1	4.27	HIGH DENSITY	7.84	-21.0	+1.14	POOR
SODIUM ALKYL SULFONATE	26	44.7	5.62	GOOD	5.84	-25.0	-1.21	POOR
SODIUM ALPHA OLEFIN SULFONATE	27	44.8	8.38	GOOD	8.10	-45.9	-2.31	POOR
SODIUM ALPHA OLEFIN SULFONATE	28	44.0	9.04	GOOD	10.40	-54.5	-1.86	GOOD
ETHOXYLATED AMMONIUM ALKYL SULFATE	29	44.5	5.88	GOOD	6.87	-73.7	-3.88	POOR
SODIUM ALKYL SULFONATE	30	44.8	5.01	GOOD	7.32	NO DATA	+1.04	POOR
POTASSIUM PERFLUORO ALKYL SULFONATE (2)	31	89.6	2.78	HIGH DENSITY	8.46	NO FOAM	-4.54	NO FOAM
PROPRIETARY ANIONIC	32	45.6	7.64	GOOD	6.79	NO FOAM	-3.46	NO FOAM
PROPRIETARY ANIONIC	33	42.5	6.62	GOOD	6.49	NO FOAM	-4.40	NO FOAM
SODIUM ALKYL SULFATE	34	43.5	8.53	GOOD	9.53	NO FOAM	-6.80	NO FOAM

(1) See Appendix A for trade names and suppliers.

(2) Aged and tested as 0.2%/wt solution.



TABLE III  
EFFECT OF 260°C ON CATIONIC AND PROPRIETARY SURFACTANT SOLUTIONS

<u>CHEMICAL TYPE</u>	<u>REF. NO. (1)</u>	<u>ORIGINAL PROPERTIES</u>			<u>CELL STRUCTURE</u>	<u>pH</u>	<u>EFFECTS OF 260°C</u>		
		<u>DENSITY (KG/M<sup>3</sup>)</u>	<u>DRAINAGE TIME/MIN.</u>	<u>CHANGE IN DRAIN. %</u>			<u>CHANGE IN pH</u>	<u>CELL STRUCTURE</u>	
<u>CATIONIC</u>									
ETHOXYLATED AMINE	35	43.1	3.17	GOOD	9.44	+23.0	-0.96	POOR	
ETHOXYLATED AMINE	36	150.	7.20	HIGH DENSITY	9.53	NO FOAM	-1.37	NO FOAM	
PROPRIETARY FLUOROCHEMICAL	37	46.7	8.06	GOOD	6.09	NO FOAM	-2.07	NO FOAM	
ALKYL HYDROXYETHYL IMIDAZOLINE	38	54.7	4.73	HIGH DENSITY	10.81	NO FOAM	NO DATA	NO FOAM	
<u>PROPRIETARY</u>									
NOT GIVEN	39	43.8	8.63	GOOD	9.51	-17.0	+0.23	GOOD	
NOT GIVEN	40	50.8	6.28	GOOD	6.92	-47.4	+1.35	POOR	
NOT GIVEN	41	45.3	6.92	GOOD	7.90	-50.0	+0.30	POOR	

(1) See Appendix A for trade names and suppliers.

TABLE IV  
EFFECT OF 260°C ON NONIONIC SURFACTANT SOLUTIONS

CHEMICAL TYPE	REF. NO. (1)	ORIGINAL PROPERTIES				EFFECT OF 260°C		
		DENSITY (KG/M <sup>3</sup> )	DRAINAGE TIME/MIN.	CELL STRUCTURE	pH	CHANGE IN DRAIN. %	CHANGE IN pH	CELL STRUCTURE
ETHOXYLATED FATTY ALCOHOL	42	44.7	3.42	GOOD	5.85	+20.2	-0.02	GOOD
ETHOXYLATED ALKYL ARYL ALCOHOL	43	47.2	3.87	GOOD	6.33	+11.6	-1.70	GOOD
ETHOXYLATED LAURYL ALCOHOL (POE = 12)	44	48.7	3.10	GOOD	5.55	-2.9	-0.56	FAIR
ETHOXYLATED TRIDECYL ALCOHOL	45	44.2	3.12	GOOD	5.85	-5.4	-1.86	GOOD
ETHOXYLATED NONYL PHENOL	46	47.0	3.20	FAIR	5.31	-5.9	-0.02	FAIR
ETHOXYLATED LAURYL ALCOHOL (POE = 23)	47	49.2	3.33	GOOD	6.43	-8.7	-0.99	GOOD
ETHOXYLATED OCTYL PHENOL (POE = 40)	48	44.9	3.42	FAIR	6.27	-11.1	-0.11	FAIR
ETHOXYLATED OCTYL PHENOL (POE = 70)	49	46.3	3.68	POOR	6.16	-11.4	-0.22	POOR
POLYOXYETHYLENE POLYOXYPROPYLENE BLOCK COPOLYMER	50	57.4	4.94	HIGH DENSITY	7.08	-16.4	-2.65	FAIR
PROPRIETARY NONIONIC	51	44.6	9.46	GOOD	6.72	NO FOAM	INSOLUBLE	NO FOAM

(1) See Appendix A for trade names and suppliers.

TABLE V  
SURFACTANTS SELECTED FOR FURTHER EVALUATION

<u>CHEMICAL TYPE</u>	<u>REFERENCE NUMBER</u>	<u>CHANGE IN DRAINAGE %</u>	<u>CELL STRUCTURE AFTER AGING</u>	<u>CHANGE IN pH</u>
COCO BETAINE	2	-28.3	GOOD	+1.82
SODIUM ALKYL ESTER SULFONATE	16	+232.	FAIR	-2.65
POTASSIUM PERFLUORO ALKYL SULFONATE	17	+49.2	FAIR	-0.76
SODIUM ALKYL ARYL POLYETHER SULFONATE	19	-3.51	GOOD	+0.78
SODIUM ALPHA OLEFIN SULFONATE	20	-5.86	GOOD	-2.73
SODIUM ALKYL AMIDE SULFONATE	21	-8.60	GOOD	-0.32
SODIUM ALPHA OLEFIN SULFONATE	22	-12.0	GOOD	-0.59
TRIETHANOL AMINE ALKYL ARYL SULFONATE	24	-20.4	GOOD	-0.28
ETHOXYLATED TERTIARY AMINE	35	+23.0	POOR	-0.96
PROPRIETARY	39	-17.0	GOOD	+0.23
ETHOXYLATED FATTY ALCOHOL	42	+20.2	GOOD	-0.02
ETHOXYLATED ALKYL ARYL ALCOHOL	43	+11.6	GOOD	-1.70
ETHOXYLATED LAURYL ALCOHOL	47	-8.70	GOOD	-0.99

APPENDIX A  
SURFACTANTS EVALUATED

<u>REFERENCE NUMBER</u>	<u>CHEMICAL TYPE</u>	<u>TRADENAME</u>	<u>SUPPLIER</u>
1	CETYL BETAINE	PRODUCT BCO	DUPONT DE NEMOURS & CO.
2	COCO BETAINE	VELVETEX BC	TEXTILANA CORP.
3	COCO AMIDO BETAINE	VELVETEX BAW	TEXTILANA CORP.
4	COCO BETAINE	VELVETEX BCW	TEXTILANA CORP.
5	COCO IMIDAZOLENE BETAINE	CARSONAM C	CARSON CHEMICALS INC.
6	COCO AMIDO BETAINE	CARSONAM 3	CARSON CHEMICALS INC.
7	COCO BETAINE	EMCOL C-37-18	WITCO CHEMICAL CORP.
8	COCO BETAINE	VARION CDG	ASHLAND CHEMICAL CO.
9	COCO AMIDO BETAINE	SCHERCOTAIN CAB	SCHER CHEMICALS
10	SULFO COCO AMIDO BETAINE	SCHERCOTAIN SCAB	SCHER CHEMICALS
11	SULFO COCO AMIDO BETAINE	VARION CAS	ASHLAND CHEMICAL CO.
12	COCO AMINO ACID, K SALT	MAFO C-12	MAZER CHEMICALS INC.
13	COCO IMIDAZOLINIUM DERIVATIVE	SCHERCOTERIC MS-2	SCHER CHEMICALS
14	COCO IMIDAZOLINE BETAINE	CARSONAM C-SF	CARSON CHEMICALS INC.
15	PROPRIETARY FLUORO-CHEMICAL	ZONYL FSB	DUPONT DE NEMOURS & CO.
16	SODIUM ALKYL ESTER SULFONATE	LANTHANOL LAL	STEPHAN CHEMICAL CO.
17	PERFLUORO ALKYL SULFONATE, K SALT	FLUORAD FC-95	3M CO.
18	SODIUM ALKYL AMIDE SULFONATE	IGEPON TM-43	GAF CORP.
19	SODIUM ALKYL ARYL POLYETHER SULFONATE	TRITON X-200	ROHM & HAAS CO.
20	SODIUM ALPHA OLEFIN SULFONATE	SULFRAMIN 14/16 AOS	WITCO CHEMICAL CORP.
21	SODIUM ALKYL AMIDE SULFONATE	IGEPON TC-42	GAF CORP.
22	SODIUM ALPHA OLEFIN SULFONATE	LAKEWAY 301-10	LAKEWAY CHEMICALS INC.
23	SODIUM ALKYL AMIDE CARBOXYLEC ACID	SARCOSYL NL-30	CIBA-GIGY CORP.
24	TEA ALKYL ARYL SULFONATE	NINEX N-300	STEPHAN CHEMICAL CO.
25	SODIUM ALKYL ARYL SULFONATE	BIOSOFT D35X	STEPHAN CHEMICAL CO.
26	SODIUM ALKYL SULFONATE	ALKANOL 189 S	DUPONT DE NEMOURS & CO.
27	SODIUM ALPHA OLEFIN SULFONATE	BIOTERGE AS-40	STEPHAN CHEMICAL CO.
28	SODIUM ALPHA OLEFIN SULFONATE	LAKEWAY 301-10-UB	LAKEWAY CHEMICALS INC.
29	ETHOXYLATED AMMONIUM ALKYL SULFATE	ALIPAL CS-128	GAF CORP.
30	SODIUM ALKYL SULFONATE	PETROWET R	DUPONT DE NEMOURS & CO.
31	POTASSIUM PERFLUORO ALKYL SULFONATE	FLUORAD FC-98	3M CO.
32	PROPRIETARY ANIONIC	RICHONOL X-7079	THE RICHARDSON CO.
33	PROPRIETARY ANIONIC	RICHONOL 7103	THE RICHARDSON CO.
34	SODIUM ALKYL SULFATE	DUPONOL ME	DUPONT DE NEMOURS & CO.
35	ETHOXYLATED AMINE	VARONIC K215 LC	ASHLAND CHEMICAL CO.
36	ETHOXYLATED AMINE	VARONIC T205 LC	ASHLAND CHEMICAL CO.
37	PROPRIETARY FLUORO-CHEMICAL	ZONYL FSC	DUPONT DE NEMOURS & CO.
38	ALKYL HYDROXYETHYL IMIDAZOLINE	VARINE C	ASHLAND CHEMICAL CO.
39	PROPRIETARY	THERMOPHOAM BW-D	FARBEST CORP.
40	PROPRIETARY	THERMOPHOAM A	FARBEST CORP.
41	PROPRIETARY	AMPLI-FOAM	MILCHEM INC.
42	ETHOXYLATED FATTY ALCOHOL	WITCONOL SN-90	WITCO CHEMICAL CO.
43	ETHOXYLATED ALKYL ARYL ALCOHOL	WITCONOL NP-120	WITCO CHEMICAL CO.
44	ETHOXYLATED LAURYL ALCOHOL	TRICOL LAL-12	EMERY INDUSTRIES
45	ETHOXYLATED TRIDECYL ALCOHOL	TRICOL TDA-11	EMERY INDUSTRIES
46	ETHOXYLATED NONYL PHENOL	TRITON N-401	ROHM AND HAAS CO.
47	ETHOXYLATED LAURYL ALCOHOL	TRICOL LAL-23	EMERY INDUSTRIES
48	ETHOXYLATED OCTYL PHENOL	TRITON X-405	ROHM & HAAS CO.
49	ETHOXYLATED OCTYL PHENOL	TRITON X-705	ROHM & HAAS CO.
50	POE-POP BLOCK COPOLYMER	PLURONIC F-87	BASE WYANDOITE
51	PROPRIETARY NONIONIC	TRITON BG-10	ROHM & HAAS CO.

# AQUEOUS FOAM GENERATOR

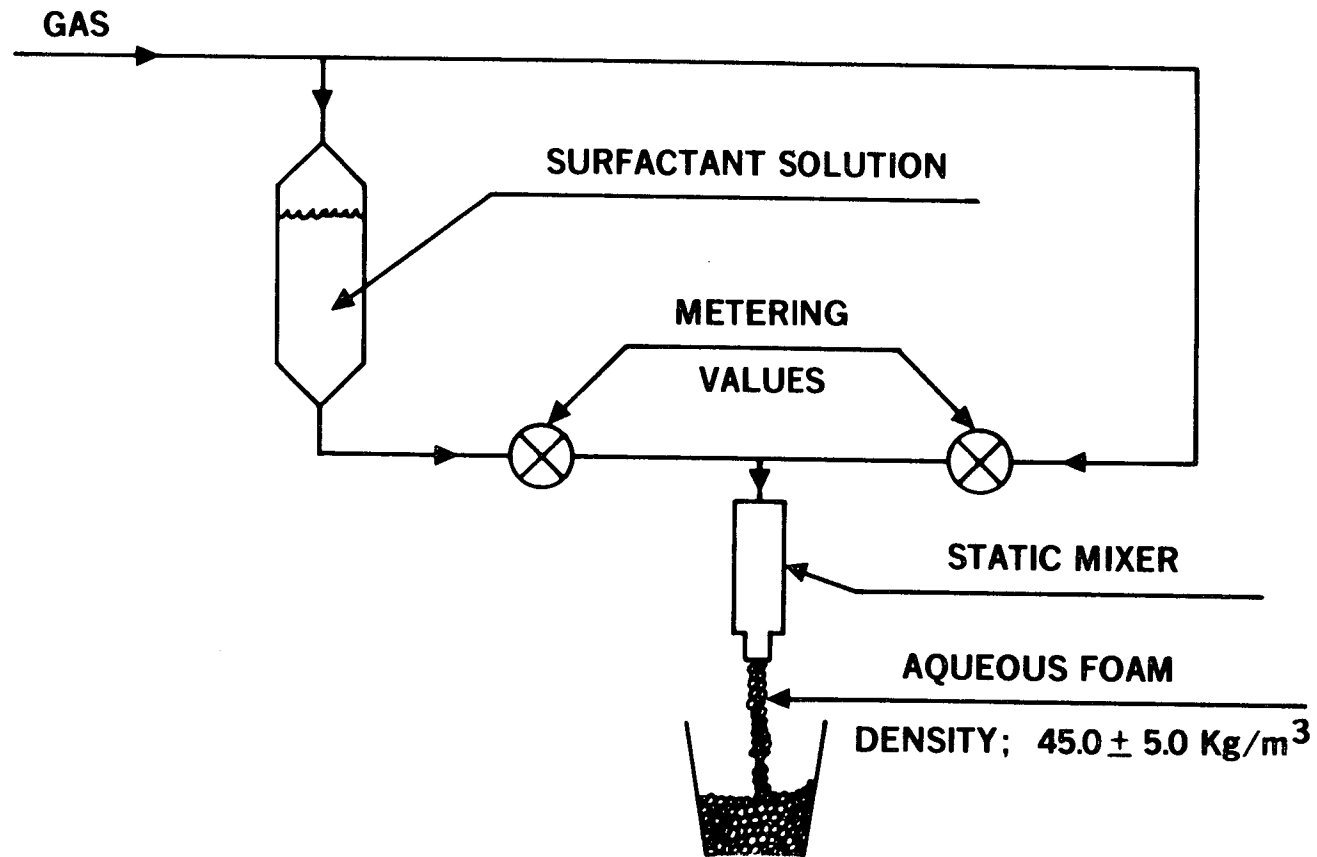


FIGURE 1

# FOAM DRAINAGE TEST

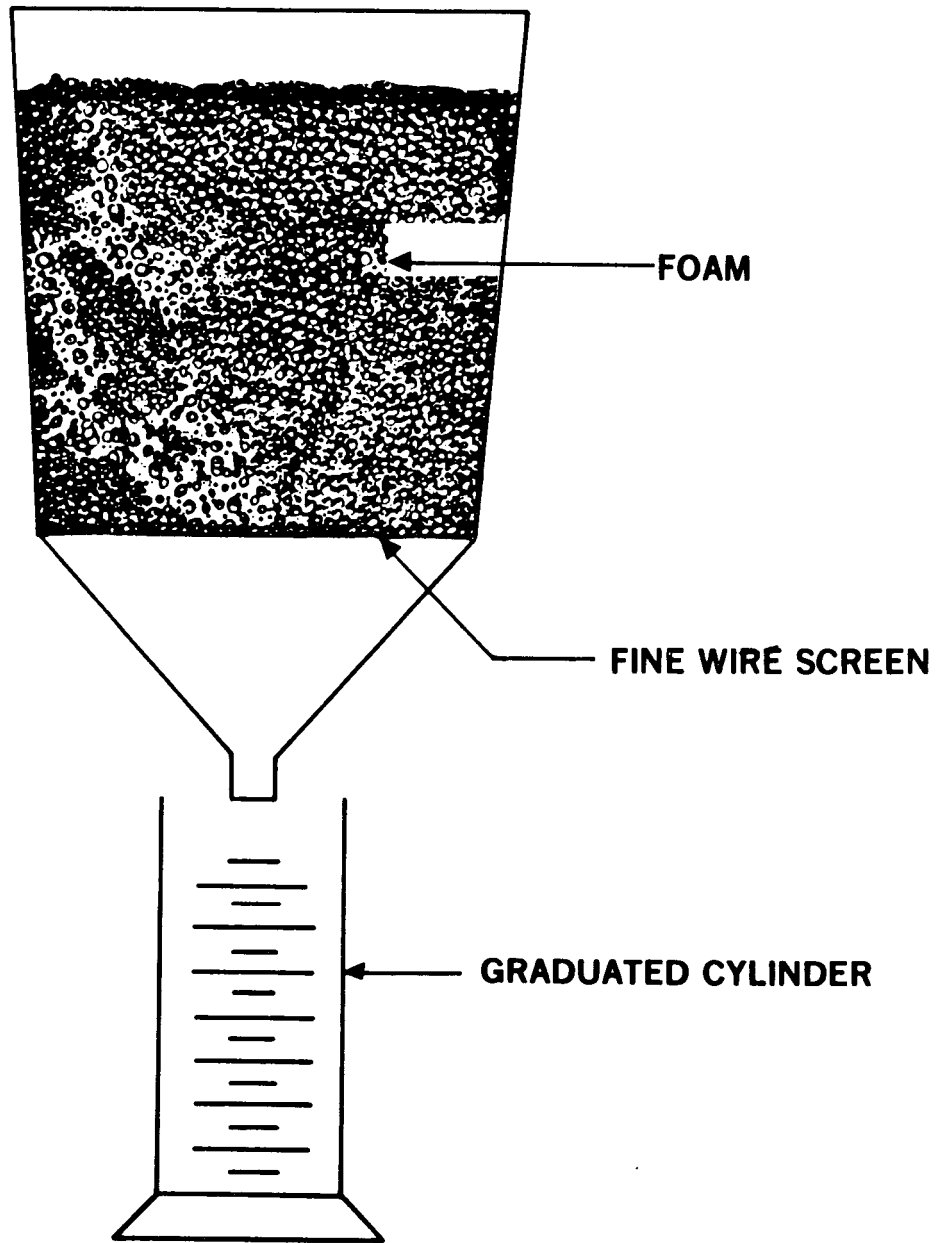


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