

**THE EFFECTIVENESS OF FOAM AS A BLOCKING AGENT AT
ELEVATED TEMPERATURES OVER EXTENDED PERIODS OF TIME**

Work Performed for the Department of Energy
Under Contract No. DE-AC03-76ET12056

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Stanford University Petroleum Research Institute
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FOSSIL FUELS

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**THE EFFECTIVENESS OF FOAM AS A BLOCKING AGENT AT
ELEVATED TEMPERATURES OVER EXTENDED PERIODS OF TIME**

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TABLE OF CONTENTS

LIST OF FIGURES	iii
LIST OF TABLES	iv
ABSTRACT	v
INTRODUCTION	1
STATEMENT OF PROBLEM	4
LITERATURE SURVEY	5
APPARATUS AND PROCEDURE	10
RESULTS AND DISCUSSION	12
RECOMMENDATIONS FOR ADDITIONAL WORK	15
CONCLUSIONS	17
REFERENCES	18
TABLES	20
FIGURES	24
APPENDICES	34

LIST OF FIGURES

	<u>Page</u>
1. Equipment for Screening Foamers at the Boiling Point of Water.	24
2. Schematic Diagram for Testing Foamability in Porous Media at Elevated Temperatures.	25
3. Performance of Various Foamers at the Boiling Point of Water.	26
4. Performance of Three Foamers at the Boiling Point of Water with Oil Present.	28
5. Flow Rate for Gas in Ottawa Sand after Water or Foamer Solution had been Injected.	29
6. Flow Rate for Gas in Ottawa Sand after Water or Foamer Solution had been Injected. Temperature Range for each Injection is Included.	30
7. Flow Rate for Gas in Ottawa Sand after Water or Foamer Solution had been Injected. Measurements Made at Room Temperature.	31
8. Flow Rate for Gas in Ottawa Sand after Water or Foamer Solution had been Injected. Temperature Range is Included.	32
9. Flow Rate for Gas in Ottawa Sand after Water or Foamer Solution had been Injected. Temperature Range is Included.	33

LIST OF TABLES

		<u>Page</u>
Table 1	Results of Surfactant Screening at the Boiling Point of Water.	20
<u>APPENDIX 1</u>		
1.1.1	Ampli Foam, Run 1.	34
1.1.2	Ampli Foam, Run 2.	35
1.1.3	Ampli Foam, Run 3.	36
1.2.1	Suntech Sample Code I, Run 1.	37
1.2.2	Suntech Sample Code I, Run 2.	38
1.2.3	Suntech Sample Code I, Run 3.	39

ABSTRACT

The ability of foaming agents to withstand elevated temperatures over extended periods of time has been studied for their potential use in thermal recovery operations.

Thirty-four samples were studied in a preliminary screening apparatus in which foaming ability was observed at the boiling point of water over a one week period. The sulfonate samples and some of the cations showed the best results while the nonionics showed the poorest.

A second study involved the injection of slugs of water or foamer solution into an unconsolidated sandpack followed by continuous gas injection. Temperatures ranged from room temperature to 360⁰F. The slug containing foamer solution decreased gas flow rate through the sandpack significantly more than the water slug. In time the gas flow rate would increase again, but injection of more foamer would cause it to decrease to even lower levels than the previous injection.

INTRODUCTION

In enhanced oil recovery a significant area of interest is in the improvement of sweep efficiency for thermal drives. This report deals with the effectiveness of foam as a plugging agent for high permeability zones often found in oil reservoirs.

The literature contains much information about the uses of polymers, suspensions, and emulsions to improve sweep efficiency. In recent years foam has also been a topic of research relating to this subject. Since all of these deal with the same problem, it is useful to be familiar with the successes and failures of each.

A great deal of effort has been put into the area of polymer applications. Cross-linking polymers capable of forming gels have been used to plug porous media. Using two cores of different permeabilities in parallel, Routson et al. (1) showed that a solution of cross-linking polymers would gel and selectively plug the core of higher permeability.

In another study, Gogarty (2) investigated the use of polymer solutions for mobility control. He suggested permeability reduction mechanisms of adsorption and mechanical entrapment.

It has been pointed out in one study (3) that in situ

filtration prevents deep penetration of polymer solutions in reservoir rock. Fluid segregation and economics can also limit the application of polymers in enhanced recovery operations (4).

An example of the use of emulsions is the work done by McAuliffe (5). He used cores in parallel to show that an oil-in-water emulsion would selectively plug the more permeable one. It was seen that the emulsion would maintain its permeability reduction characteristics even after many pore volumes of water had passed through.

The patent literature contains many methods of plugging formations using inorganic as well as organic materials. Reactions that form precipitates or increase viscosity have been considered. Everything from powdered CaCO_3 to bovine blood and molasses appear as methods of improving sweep efficiency in the formation. A recent literature review by Marsden et al. (6) describes a large number of these methods.

An area of increasing interest is the use of foam as a fluid blocking agent. Foam has been described as a completely immiscible dispersion in which the dispersed phase is a gas. The term foamer solution is one that the oil industry is becoming familiar with. In general, it is simply a dilute aqueous solution containing a surface active agent. It has the property that when agitated, such as through rigorous shaking, it becomes foam. A porous medium saturated with a foaming agent represents an excellent foam generating device when gas is flowed through it.

Surface active agents are familiar to the world in the form of soaps, sulfonated oils and many other materials. In dilute

aqueous solutions they wet surfaces, remove dirt, penetrate porous materials, disperse solid particles, emulsify oil and grease, and foam. All agents exhibit this general behavior though usually each will often show one predominant characteristic.

There are two broad groups of surface active agents, the ionics and the nonionics. The ionics form ions in solution and are also known as colloidal electrolytes. Nonionics do not form ions but dissolve through the effect of a number of weak solubilizing groups.

A molecule is characterized by an elongated hydrophobic end and a relatively small, solubilizing, polar, hydrophilic end. The characteristic surface activity of a particular agent is directly due to its chemical constitution.

Foaming ability is one property of surface active agents. Not only must the foaming agent exhibit low surface tension but it must also generate a bubble that can contract and expand without bursting. This is particularly important in oil recovery applications.

Finding a suitable foaming agent for application in an EOR operation is an important area of research. Once one is found that can meet certain preliminary requirements, such as those dealing with conditions of temperature, pressure, and time, it will be necessary to simulate the actual process, that is, the plugging of a porous medium with foam.

STATEMENT OF PROBLEM

It is desired to show that foaming agents can be used in thermal recovery to help solve gravity override and channeling problems. The laboratory work is aimed at demonstrating the blocking ability of foam to gas in a porous medium at elevated temperatures. A necessary part of accomplishing this will be to find one or more foaming agents that will function at the desired temperatures. Foam stability with time will be the other main property considered.

LITERATURE SURVEY

Many studies have suggested the use of foam as displacing and diverting agents to improve sweep efficiency and thus oil recovery. Most of this research involving foam falls into a few specific areas.

First, some work has been directed to determining the physical properties of foam such as film resiliency and stability and how they are related to type and concentration of foaming agent. Many studies use a term known as foam quality, which is the ratio of gas volume to the bulk volume, to describe foam. It is believed to be related to type and concentration of foaming agent, the characteristics of the porous media, pressure levels and gradients, and the saturations of fluids originally in place.

Another subject of investigation deals with classifying and comparing different surfactant solutions for the preparation of foams. Some important parameters used in characterizing these solutions are surface tension, wetting ability, foaming ability and stability, and viscosity. For example, Raza (7) observed that a combination of nonionic and anionic foaming agents produce a high quality, high resiliency foam.

Still another area of research has been studies of flow mechanisms of foam in porous media.

Marsden and Khan (8) described foam as flowing as a contin-

uous fluid through short porous media. They applied Darcy's law to describe the flow using an apparent foam viscosity, μ_a , which they measured with three different viscometers. They saw that the ratio of effective permeability, k_e , to viscosity decreased linearly with foam quality in high permeability porous media. They also noted that k_e/μ_a reductions are greater for high permeability porous media than for low permeability porous media.

In another study, Minssieux (9) also measured μ_a of foam and by applying Darcy's law, he wrote this quantity as a function of quality, pressure gradient, and permeability.

Some researchers have not considered foam flowing as a continuous fluid in porous media but instead have described the flow of liquid and gas in the presence of foam versus flow in its absence.

Holm (10) suggested four possible mechanisms of flow of gas and liquid with foam present. They are: 1) a small amount of free gas flowing with a greater amount remaining as trapped gas, 2) the foam structure flowing as a body, 3) gas flowing as a discontinuous phase, breaking and reforming films, while liquid is flowing as a free phase, and 4) the combination of foam body movement and surfactant solution flowing as a free phase. Holm's laboratory studies indicated to him that foam moves through a porous medium as a discontinuous phase in which bubbles are breaking and reforming. As others have, he observed that gas permeability is significantly reduced in the presence of foam.

The reduction of aqueous permeability, k_w , was investigated by Bernard et al. (11) as a function of foaming agent, concentration of foaming agent, pressure gradient, length of porous media, and oil saturation. Their study concluded that foam indirectly reduces k_w by developing a higher trapped gas saturation. In their laboratory experiments they saw that foam persisted up to at least 140°F even after 10-25 pore volumes of surfactant-free water had passed through a core. Another important observation, also pointed out in other studies, was that oil decreased most foaming agents' ability to lower k_w as foams were less resilient and fewer bubbles formed.

For gas drives, Bernard (12) showed that foam is a good displacing agent as its mobility is much less than that of free gas.

Experiments by Albrecht and Marsden (13), point out a direct application of foam in solving gas leakage problems in underground storage operations. Gas was injected into a porous medium saturated with foamer solution until a steady flow of foam appeared at the downstream end. Then the injection pressure was lowered until no foam appeared downstream. They called this the blocking pressure, P_b . The injection pressure was then increased to a level greater than the initial pressure and upon lowering it again they observed that P_b occurred at a higher level than before.

Foam is described as a semicompressible fluid owing to the essentially incompressible nature of the liquid component and the high compressibility of the gas component. Under a pressure

gradient the gas component expands along the flow path. In a porous medium, blocking may occur if a bubble expands to the point that it cannot be forced through a pore opening under the existing pressure gradient. Many factors will affect this blocking or plugging ability. The surfactant type, pore size, and pore size distribution, pressure gradient, and foam quality, are a few of the factors.

Most controversy over the flow mechanism of foam may be resolved by simply examining the differences in experimental procedure. For instance, it has been observed that foam will flow as a single body fluid through a porous medium. On the other hand, it is argued that the gas and liquid components will move at different rates through the porous medium. Considering these two points, one can conclude that one group is wrong, but this may not be so. In short porous media, fine textured foam may indeed pass through pore channels without constriction or rupturing of bubbles, i.e. just as a single body fluid would. In longer porous media under larger pressure drops pore openings may offer significant resistance to foam flow. The result can be a mechanism in which bubbles rupture and reform in a nonuniform manner. Indeed, this is what is usually observed.

Perhaps the most conspicuous aspect of a literature survey of foam application in the petroleum industry is the lack of information regarding foam flow or stability at elevated temperatures. One study (14) noted that foam would persist up to 180°F and a field test (15) described selective plugging by in situ

foam generation at temperatures up to 600°F. But neither study is comprehensive or conclusive so that direct application to reservoirs at elevated temperatures is yet to be proven.

APPARATUS AND PROCEDURE

A simple glass apparatus was constructed for screening foaming agents that would not foam at a temperature of approximately 212°F. This preliminary experiment would also show foaming ability over an extended period of time.

The apparatus, shown in Fig. 1, consists of twelve 250 ml Erlenmeyer flasks, each heated on electrical hot plates and topped first by clear, vacuum-jacketed tubes 40 cm high and then by small water-cooled condensers. The three components are connected with non-lubricated, standard-taper, and ball-and socket joints.

Foam is generated in each flask by boiling 100 ml of 1.0% solutions of foamer. To reduce the possibility of O_2 from the air reacting with the mixtures, N_2 is slowly bubbled through the solutions by means of stainless steel capillary tubing which runs down the inside of the condenser and jacketed tube and into the flask.

If foam is in fact generated, it is observed for one week. The height that it reaches in the tube is recorded as well as a brief description of the foam characteristics, such as size of bubbles and how rigorously they are regenerated.

The screening apparatus is empirical in nature but it does allow a basis for selecting a foaming agent for use in other studies requiring foamability and stability at 212°F or above.

The apparatus used to study the blocking ability of foam to gas at elevated temperatures is shown in Fig. 2. A 1 in. stainless steel tube 24 in. high is in a vertical tube furnace capable of heating it to temperatures above 600°F. The tube is packed with Ottawa sand (20-40 mesh) in which temperature is monitored with a J-type thermocouple and recorder. Water, N₂, or foamer solution can be injected at the top of the sandpack and collected at the bottom in a gas/liquid separator. The liquids can be preheated in the liquid reservoir with heating tape.

The procedure to study gas blockage with foam uses the natural foam generating capabilities of a porous medium. Slugs of water or foamer solution are injected and followed by continuous gas. Liquid is collected with a graduated cylinder and gas flow measured with a wet test meter. For a given pressure drop, decreased flow rates after foamer solution is passed through the sandpack compared to that for water is taken as being indicative of foam generation.

RESULTS AND DISCUSSION

The results collected in the preliminary screening experiment are listed in Table 1 with the foaming agents ranked in the order of decreasing foaming ability. The second column gives data on chemical constitution if any could be obtained because often such information is proprietary. The third column gives a brief description of foaming action in terms of foam column height and bubble size. Any foaming action change with time is shown in the fourth column.

The data in Table 1 is graphically presented in Fig. 3. The length of a bar is proportional to each sample's performance at the end of 0, 3, and 7 days. A good foam is described as one with a rigorous generation of bubbles that reach a significant height in the glass column.

From the information presented in Table 1, some generalizations can be made about foaming ability at 212°F for various foaming agent types. Almost all of the sulfonates showed outstanding results in the experiment. It has been suggested that perhaps all might show these results with better elimination of O₂ from the system (16). Cationics and amphotericics showed better results on the whole than did nonionics. Some nonionics that would foam well at room temperatures showed no foaming ability at 212°F. Some samples showed good foaming ability initially but decreasing ability with time.

Three samples were also tested with a few drops of oil present to see if this would affect the results already obtained, and Fig. 4 shows the bar graphs for these samples. Comparing them with the corresponding bars in Fig. 3, it is seen that two samples showed no change while the third demonstrated decreasing performance over the one week period. Further tests with crude oil plus reservoir sand and brines would be useful for planning field application.

The results of experiments run with the sandpack are graphically presented in Figs. 5-9. Figs. 5 and 6 represent data collected using the foamer Ampli Foam while Figs. 7-9 are runs made using the sulfonate Suntech Sample Code I.

In Fig. 4 results of the first two runs are shown on a cumulative time basis. Foamer solution was introduced into the system after the flow rate was measured with only water present. Before the temperature was increased for the next run, the sandpack was carefully flushed clean of foamer solution. It can be seen that at ambient temperature flow rates declined on the order of 80% after the foamer solution was introduced. The reduced flow rate (and thus the permeability, since ΔP was constant) remained relatively constant for a 20 minute observation period. At the next temperature (120°F for the foamer solution) flow rates declined again, this time on the order of 85%. The reduction was constant for the 20 minute observation period.

Fig. 5 is an extension of the previous figure but includes a temperature scale for temperature was not constant during the run. After gas injection in the sandpack saturated with water

only, foamer solution was injected at three different times as indicated in Fig. 5. At each of these times a decline in gas flow rate was observed; however, this was not constant over the 20-min. period as was the case with runs at both ambient temperature and 120°F.

Flow rates declined on the order of 90-95% and in fact, to lower levels after each successive injection of foamer solution. It was also observed that although flow rates would increase again, the time at which this occurred, around 10 minutes, was longer after each injection.

The second set of data using the Suntech sulfonate are presented in a different manner than the previous runs with Ampli Foam. Blockage at times was complete even under large pressure drops. Since pressure drops varied, the ratio of gas flow rate to pressure drop, $Q/\Delta P$, is plotted versus cumulative time, t .

Fig. 7 is a run at room temperature, 65°F. It shows complete blockage until 30-min. after the foamer slug had passed through the sandpack. Even then, flow rate per psi of pressure drop increased only slightly. The same kind of results occurred at the next elevated temperature step shown in Fig. 8. A temperature scale is included and it shows that a maximum temperature of 210°F was reached. Here a flow rate could not be measured from the wet test meter until 46 minutes after the foamer slug had passed through. In each case though, some gas was indicated after 23 and 22 minutes, respectively, for each run.

Finally, Fig. 9 shows that in the range of 320-360°F blockage will occur though it increased rapidly to the gas flow rate level seen before the foamer slug was injected.

RECOMMENDATIONS FOR ADDITIONAL WORK

Though the nature of the runs indicated by Figs. 5-9 have allowed the observation of gas flowing through the sandpack with or without foaming agent present, there were some procedural problems that should be noted.

A major problem was the back pressure valve. At small pressure drops its lack of sensitivity made it difficult to obtain the same ΔP after foamer was injected compared to the previous water slug. Figs. 7-9 were drawn using $Q/\Delta P$ vs t as variables because ΔP was not constant in each run. Though it is not important that ΔP be constant, it would be better to have the same valve opening for each run; then the same conditions would prevail for both types of slug, water or foamer. A micrometer valve would improve this part of the procedure.

Another improvement that could be important to the goals of these experiments is in collecting and measuring the produced liquids. Though no conclusions were drawn relating to this, these measurements could indicate how a foaming agent affects irreducible liquid saturations.

Temperature control was seen to be difficult unless the injected liquid could be brought to the same temperature of the sandpack.

Since this study investigated some new ideas, scaling the sandpack dimensions and fluid flow rates to field conditions

was not considered as important. Thus, it should be noted while studying Figs. 5-9 that the gas flow rates represent many pore volumes of gas flowing per minute and the liquid slugs are almost two pore volumes of liquid each.

The data used to construct the graphs in Figs. 5-9 is contained in Appendix A.

CONCLUSIONS

As others have noted, foam can be used to impede fluid flow in porous media. The work done here presents some new data from which the following conclusions may be drawn:

1. Some foamers which work well at room temperature do not at the boiling point of water. These are usually the non-ionics.
2. Some foamers lose their ability to function after several days at the boiling point of water while others, notably the sulfonates, are still fully effective for at least a week.
3. Some foamers have excellent foamability but deteriorate rapidly with time while some have modest foaming ability but retain the ability over a longer time.
4. At temperatures of 212°F and higher, injection of foamer solution into unconsolidated porous media decreases gas flow much more than simply injection of water. The effect decreases with time but can be renewed by injection of more foamer solution.
5. Foamer solution may decrease the ability of gas to flow in a porous media or block it completely over a period of time.
6. Observation of the effluent indicates that foam is generated within and flows through these porous media at these temperatures.

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TABLE 1 RESULTS OF SURFACTANT SCREENING AT THE BOILING POINT WATER

<u>FOAMER</u>	<u>SURFACTANT DESCRIPTION</u>	<u>FOAMING ACTION</u>	<u>COMMENTS AND OBSERVATION PERIOD</u>
Sample Code I (Suntech)	Sulfonate (Mixed Xylenes + C ₁₂ Olefin)	Rigorous foaming action to 40 cm Height	Constant throughout 7 days
Sample Code II (Suntech)	Sulfonate (Mixed Xylenes + C ₁₅ Olefin-Narrow)	Same	Same
Sample Code IV (Suntech)	Sulfonate (Toluene + C ₁₅₋₁₈ Olefin)	Same	Same
Sample Code V (Suntech)	Sulfonate (Toluene + C ₁₅ Olefin-Narrow)	Same	Same
Sample Code VI (Suntech)	Sulfonate (Toluene + C ₁₅ Olefin-Broad)	Same	Same
Sample Code VII (Suntech)	Sulfonate (Benzene Tower Feed + C ₁₅ Olefin-Broad)	Same	Same
Sample Code VII (Suntech)	Sulfonate (Benzene Tower Feed + C ₁₅ Olefin-Narrow)	Same	Same
Sample Code IX (Suntech)	Sulfonate (Xylene Tower Bottoms + C ₁₂ Olefin)	Same	Same
Petrostep 450 (Stepan)	Sulfonate	Same	Same
Petrostep 420 (Stepan)	Sulfonate	Same	Same
Amplif Foam TM (MILCHEM)	Coco Amine Betaine	Reached height of 40 cm, vigorous action, bubbles in flask about 4 cm in diameter	Constant throughout 7 days.

TABLE I RESULTS OF SURFACTANT SCREENING AT THE BOILING POINT OF WATER (Cont'd)

<u>FOAMER</u>	<u>SURFACTANT DESCRIPTION</u>	<u>FOAMING ACTION</u>	<u>COMMENTS AND OBSERVATION PERIOD</u>
Magcofoamer 44 (MAGCOBAR)		Reached height of 40 cm	Constant throughout 7 days.
ARQUAD T-2C (Armour Ind. Chem. Co.)	Cationic; quaternary ammonium salt	Reached height of 40 cm, vigorous action, bubbles in flask 1-2 cm diameter	Constant throughout 7 days.
BCO (dupont)	Amphoteric; C-Alkyl betaine	Reached height of 35 cm, vigorous action	Constant throughout 7 days.
ALFOAM 3 (General Mills)		Reached height of 40 cm, vigorous action, bubbles in flask 1-2 cm diameter	After 7-day action had decreased so that foam reached 20 cm height in column.
Shell Foamer	Sulfonate (Probably no Benzene)	Rigorous action to 20 cm, bubbles 2-5 cm in diameter	Constant throughout 7 days
Thermophoam BW-D	Sulfonate (Probably no Benzene)	Rigorous action 20-25 cm	Mild decline in action, 15 cm height after 7 days.
ARMOMIST #1 (Armour Ind. Chem. Co.)	Cationic	Reached height of 40 cm, vigorous action, bubbles in flask about 2 cm in diameter	After 7 days the height of foam in the tube had fallen to zero but continued bubbling in flask.
HC-2 (Halliburton)		Reached height of 40 cm, bubbles in flask 5 cm in diameter	Decline in foaming action until none by 7 days.
TRITON QS-15 (Rohm & Haas)	Amphoteric; Oxyethylated sodium salt	Large bubbles to top of flask but no foam column	Constant throughout 7 days.

TABLE I RESULTS OF SURFACTANT SCREENING AT THE BOILING POINT OF WATER (Cont'd)

<u>FOAMER</u>	<u>SURFACTANT DESCRIPTION</u>	<u>FOAMING ACTION</u>	<u>COMMENTS AND OBSERVATION PERIOD</u>
Tret-o-liet J-9005 (PETROLITE CORP.)		Very rigorous foaming action, bubble with fine texture (0.5 - 1.0 cm diameter), 40 cm height	Decline until no foaming action after 3 days.
Hydro-pure	Sulfonate	Good foaming action to 25 cm	Decline until little action after 3 days
HOWCO SUDS (Halliburton)		Mild foaming action within the flask but no foam column	Stopped foaming by 7 days.
ADOFOAM (ADOMITE)	50% active anionic surfactant	Reached height of 40 cm 1-3 cm bubble diameter	Decline in foaming action until none after 3 days.
AEROSOL A-102 (CYANAMID)	Nonionic and anionic; disodium ethoxylated alcohol half ester of sulfosuccinic	Mild foaming action to top of flask	Stopped foaming after 5 days.
PEI 400 (DOW)	Cationic polymer; polyethylenimine	Mild foaming action to top of flask	Stopped foaming after 4 days.
ADOFOAM BF-1 (NALCO)	Anionic; alcohol ether sulfate	Mild foaming action within the flask but no foam column	Stopped foaming after 4 days.
Tret-o-lite TD-8 (PETROLITE CORP.)		Mild bubbling to top of flask	Decline until no action after 3 days.
TRITON GR-5 (Rohm & Haas)	Anionic; solium alkyl ester sulfonate	Large bubbles to top of flask but no foam column	Stopped foaming after 3 days.
PEI 1000 (DOW)	Cationic polymer; polyethylenimine	Mild foaming action within flask	Stopped foaming after 3 days
AEROSOL OT (75%AW) (Cyanamid)	Anionic; sodium dioctyl sulfosuccinic	Large bubbles to top of flask but no foam column	Stopped foaming after 3 days

TABLE I RESULTS OF SURFACTANT SCREENING AT THE BOILING POINT OF WATER (Cont'd)

<u>FOAMER</u>	<u>SURFACTANT DESCRIPTION</u>	<u>FOAMING ACTION</u>	<u>COMMENTS AND OBSERVATION PERIOD</u>
DRILLFOAM DMR (The mearl Corp.)	Protein base	Mild foaming action within flask but no foam column	Stopped foaming after 2 days.
IGEPAL CO-430 (GAF Corp.)	Nonylphenoxy (ethyleneoxy) ethanol	None	1 day
TRITON X-100 (Rohm & Haas)	Nonionic; octyl phenoxy polyethoxy ethanol	None	1 day

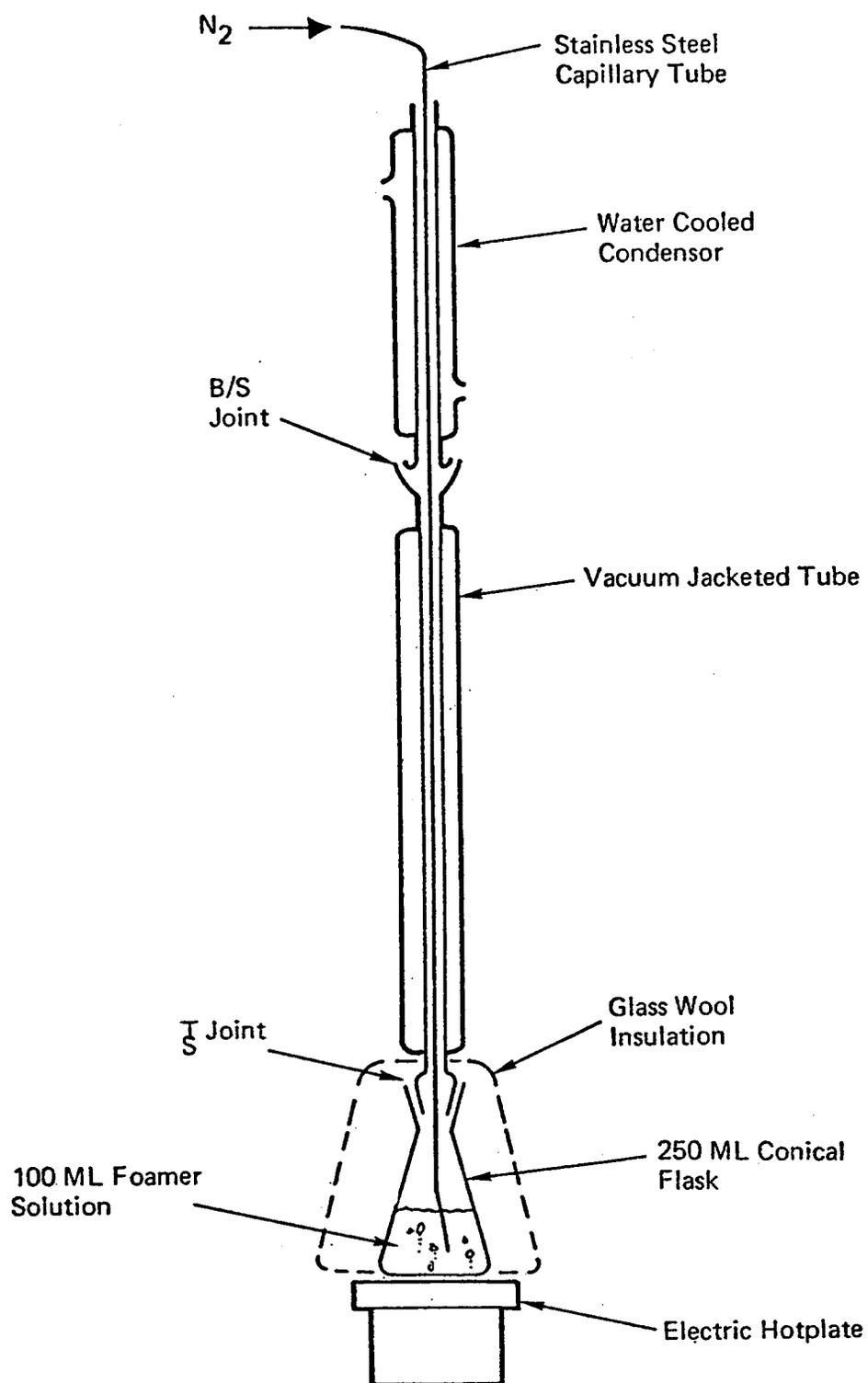


Figure 1
Equipment for Screening Foamers
at the Boiling Point of Water

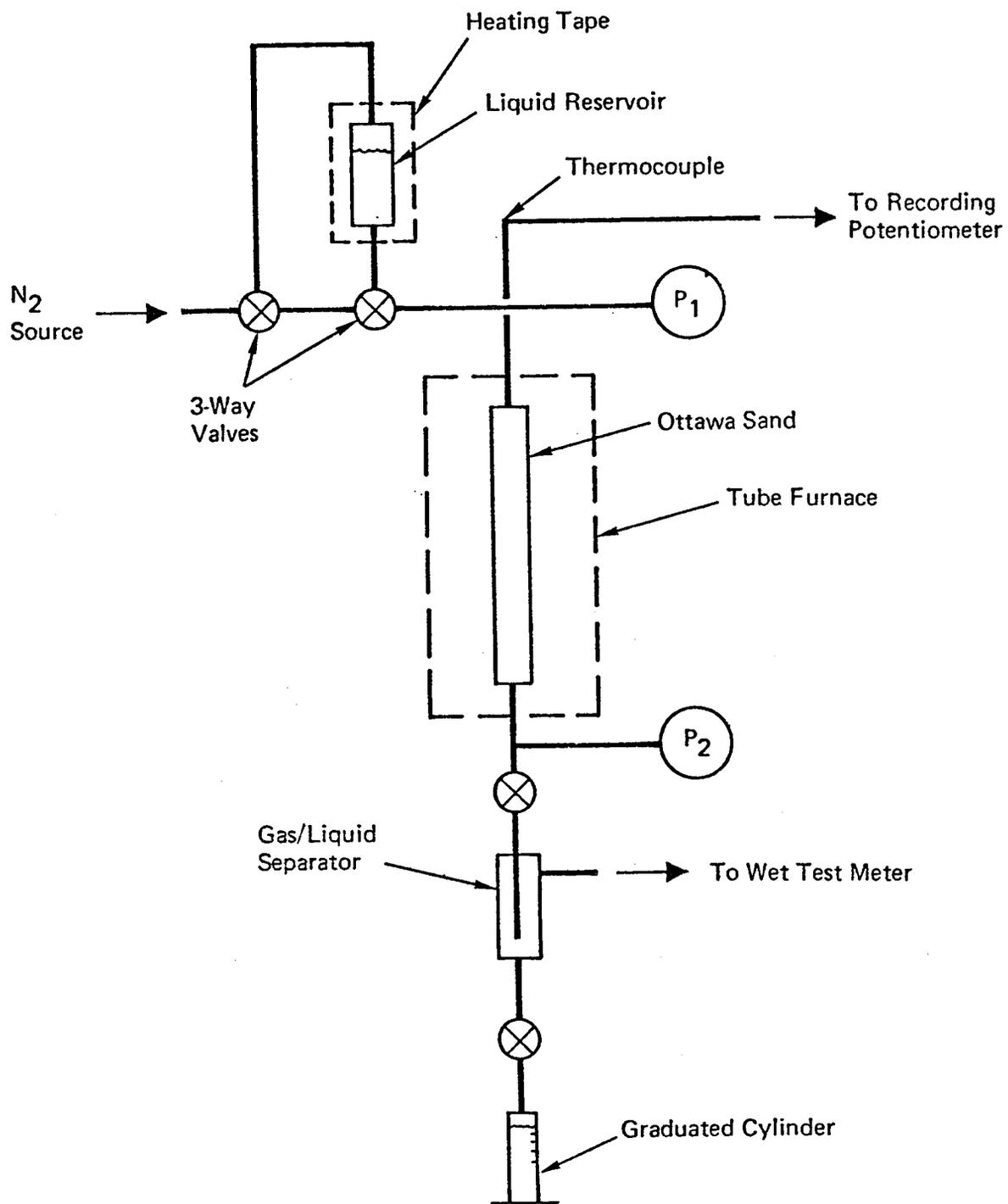


Figure 2
Schematic Diagram of Equipment for Testing
Foamability in Porous Media at Elevated Temperatures

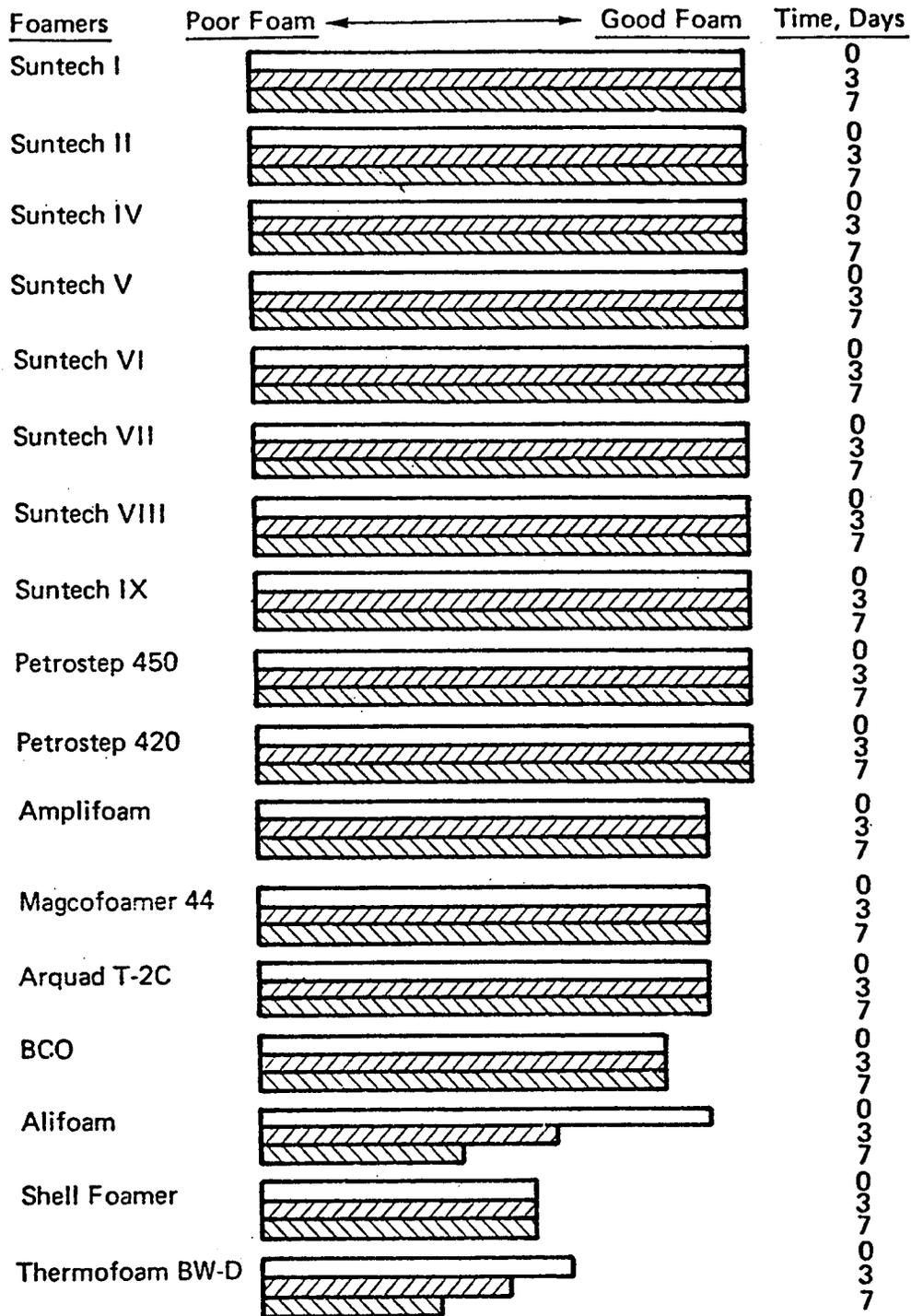


Figure 3
Performance of Various Foamers
at the Boiling Point of Water

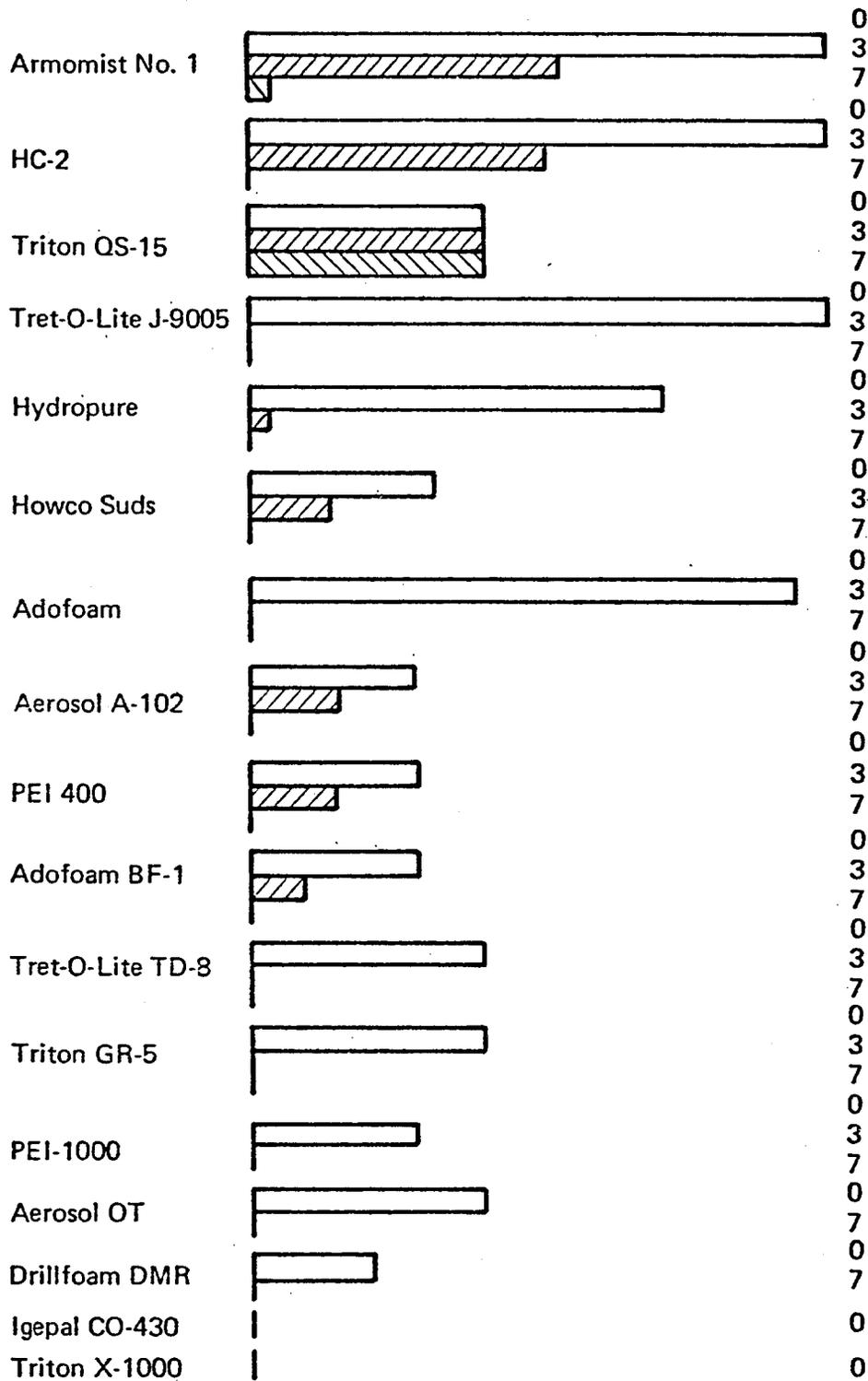


Figure 3
Performance of Various Foamers at the Boiling Point of Water (Cont'd)

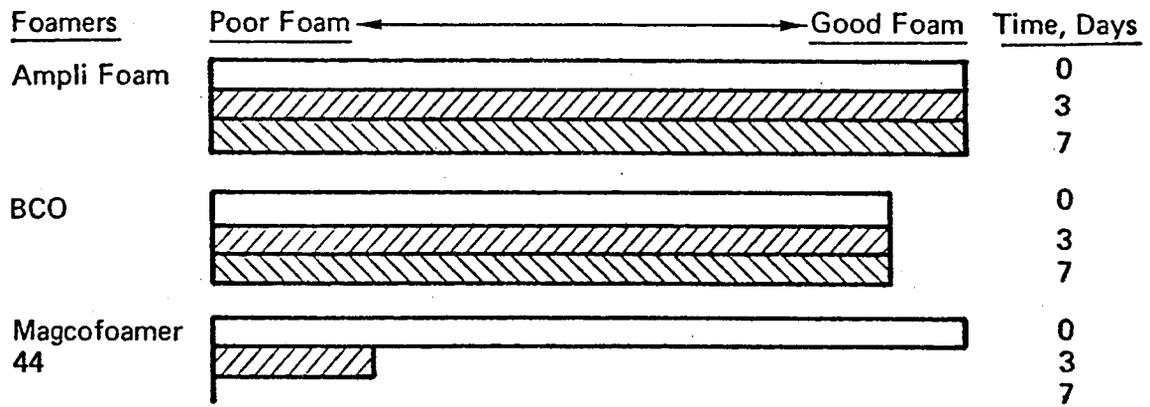


Figure 4
Performance of Three Foamers at
the Boiling Point of Water with Oil Present

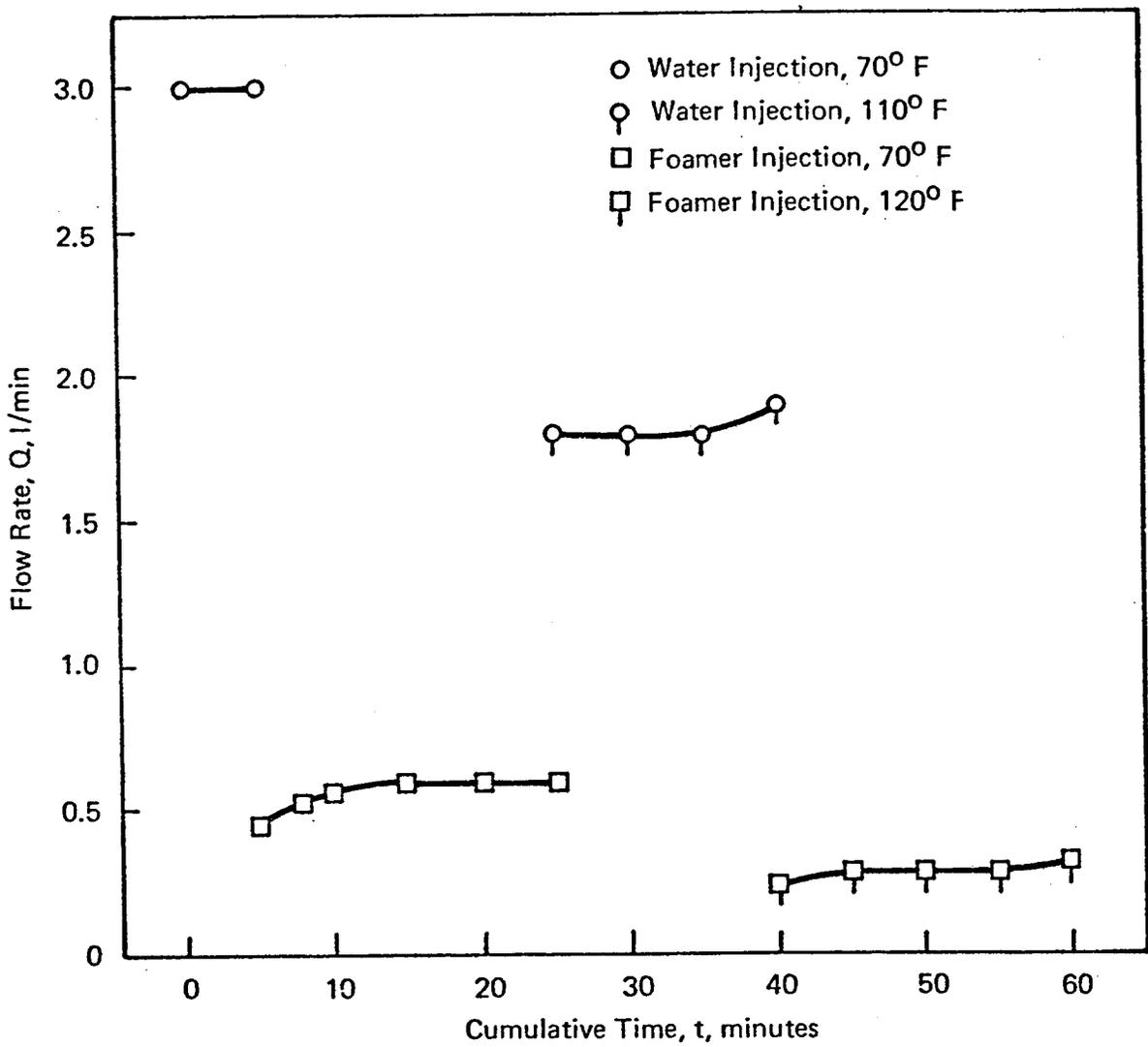


Figure 5
 Flow Rate for Gas in Ottawa Sand After
 Water or Foamer Solution had been Injected

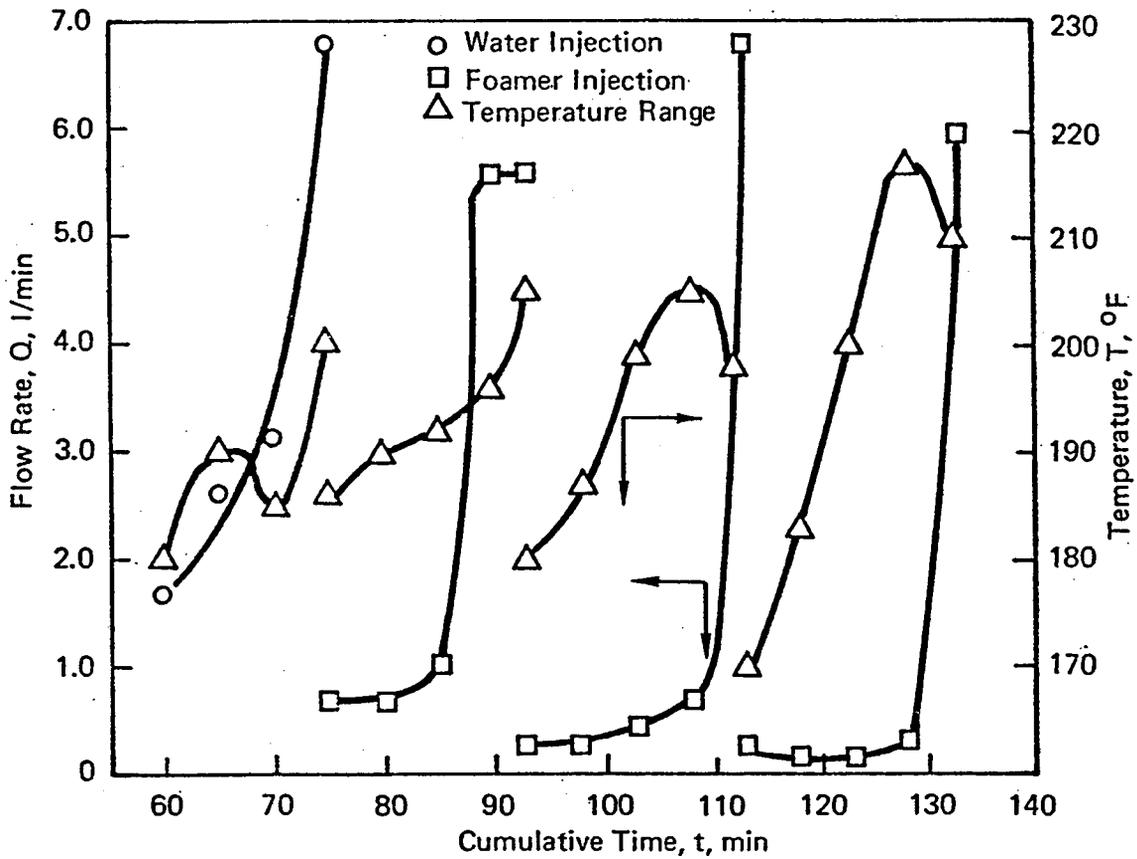


Figure 6
 Flow Rate for Gas in Ottawa Sand After
 Water or Foamer Solution had been Injected.
 Temperature Range for Each Injection is Included

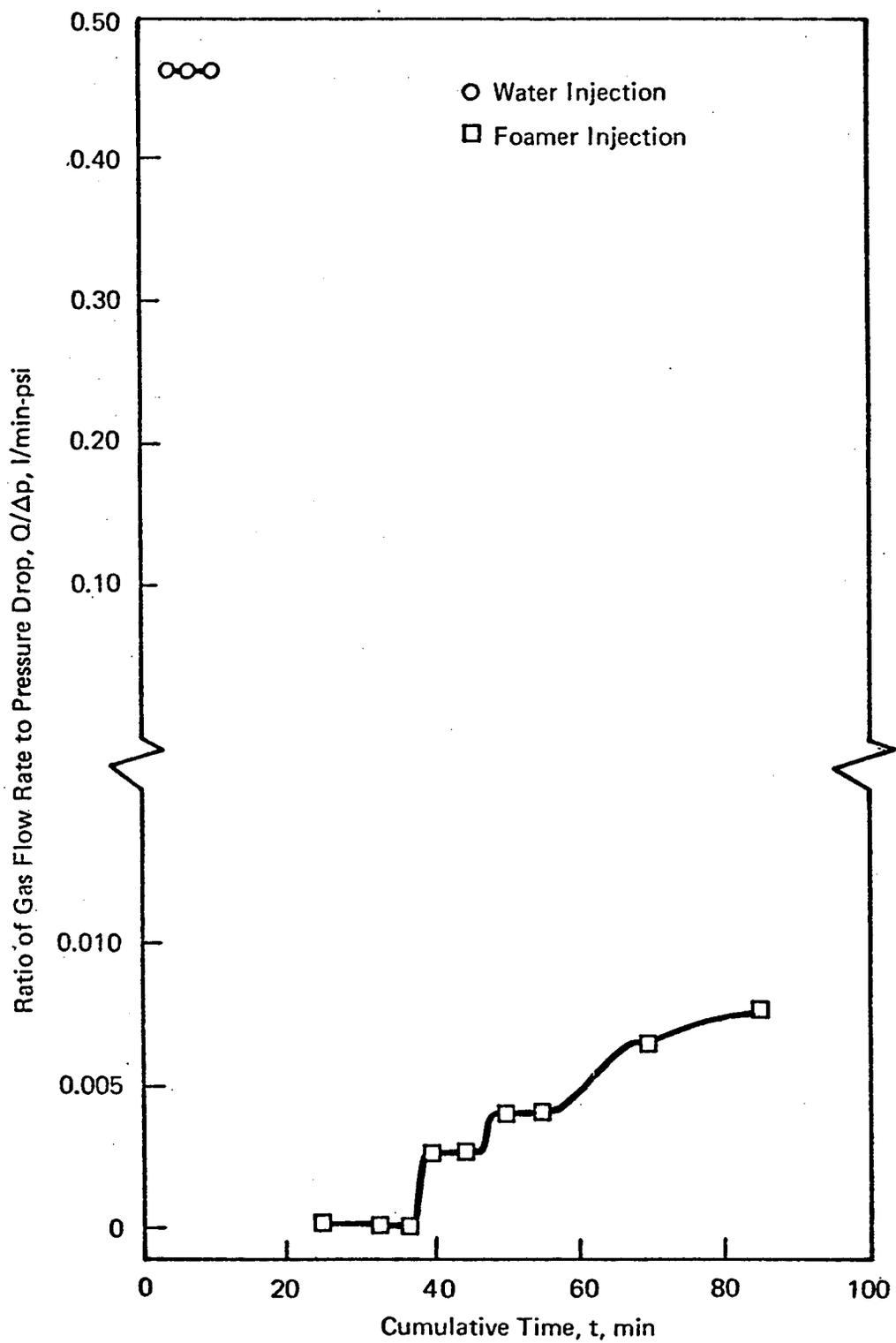


Figure 7
Flow Rate for Gas in Ottawa Sand After Water
or Foamer Solution had been Injected.
Measurements Made at Room Temperature

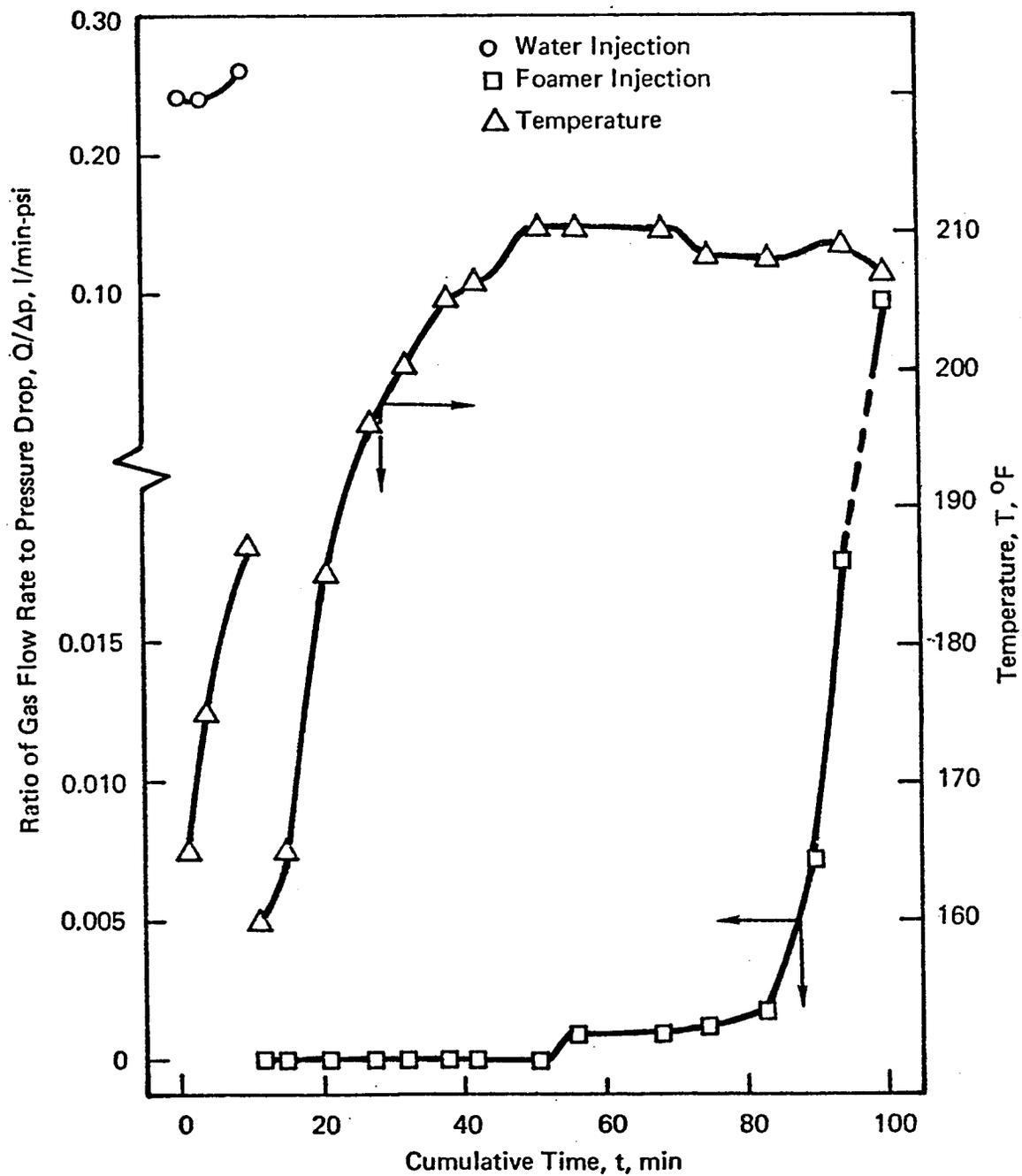


Figure 8
Flow Rate for Gas in Ottawa Sand After Water or Foamer Solution had been Injected. Temperature Range is Included

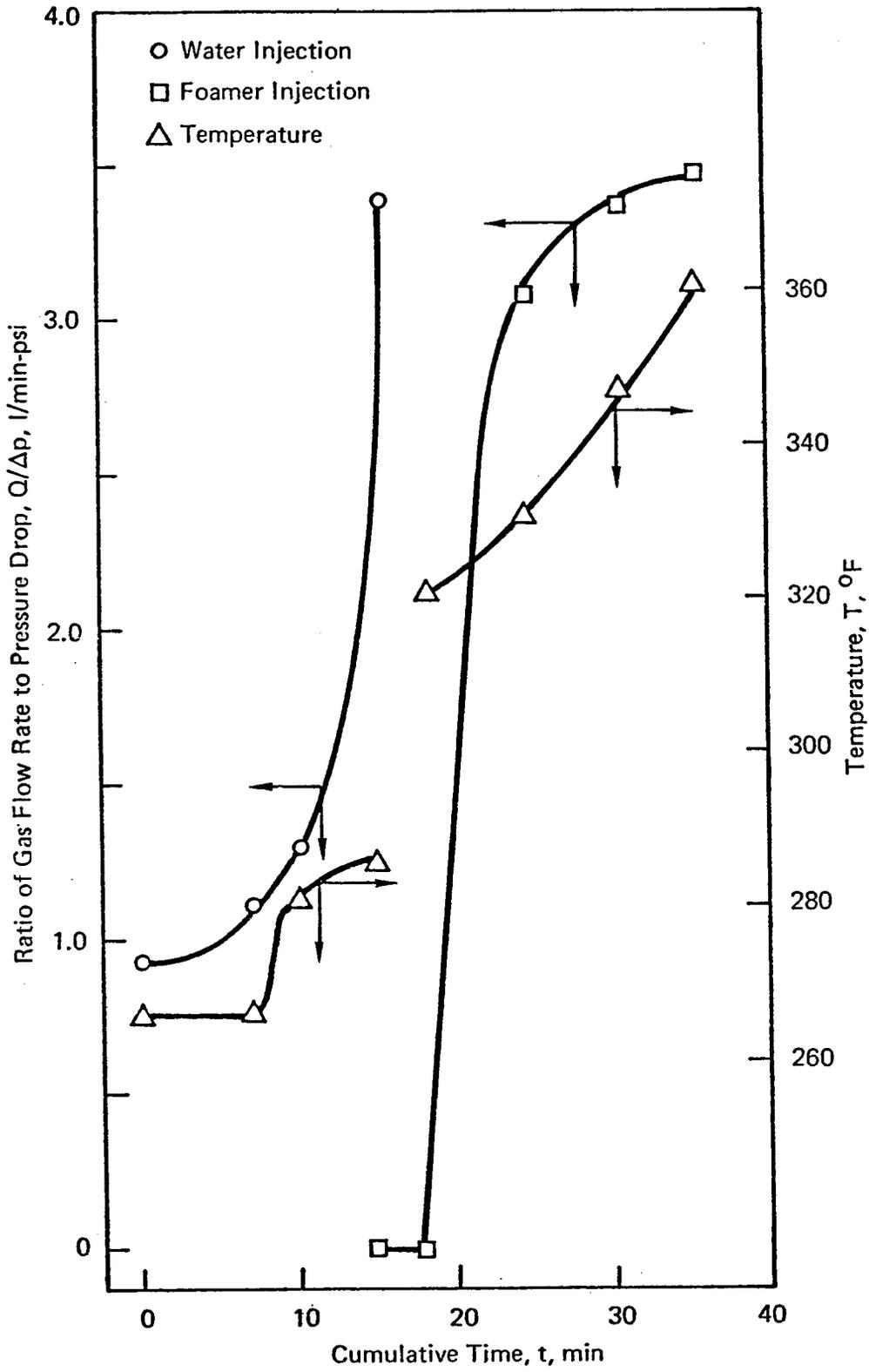


Figure 9
 Flow Rate for Gas in Ottawa Sand After Water or Foamer
 Solution had been Injected. Temperature Range is Included

APPENDIX 1

Table 1.1.1 - Ampli Foam, Run 1.

<u>FLUID INJECTED</u>	<u>PRESSURE DROP, ΔP, psi</u>	<u>GAS FLOW RATE, Q, l/min</u>	<u>TIME, t, min</u>	<u>CUM. REC., R, ml</u>	<u>TEMP., T, °F</u>
WATER SLUG	10	3.00	0	-	65
	10	3.00	5	-	"
FOAMER SLUG	10	0.44	0	0	65
(150 ml)	10	0.52	3	-	"
	10	0.56	5	-	"
	10	0.60	10	-	"
	10	0.60	15	-	"
	10	0.60	20	150	"

APPENDIX 1

Table 1.1.2 - Ampli Foam, Run 2.

<u>FLUID INJECTED</u>	<u>PRESSURE DROP, ΔP, psi</u>	<u>GAS FLOW RATE, Q, l/min</u>	<u>TIME, t, min</u>	<u>CUM. REC., R, ml</u>	<u>TEMP., T, °F</u>
WATER SLUG	10	1.80	0	-	100
(200 ml)	10	1.80	5	-	110
	10	1.80	10	-	110
	10	1.92	15	200	110
FOAMER SLUG	10	0.24	0	-	110
	10	0.28	5	-	120
	10	0.28	10	-	120
	10	0.28	15	-	120
	10	0.32	20	300	120

APPENDIX 1

Table 1.1.3 - Ampli Foam, Run 3.

<u>FLUID INJECTED</u>	<u>PRESSURE DROP, ΔP, psi</u>	<u>GAS FLOW RATE, Q, l/min</u>	<u>TIME, t, min</u>	<u>CUM. REC., R, ml</u>	<u>TEMP., T, °F</u>
WATER SLUG	10	1.68	0	170	180
(200 ml)	10	2.60	5	-	190
	10	3.12	10	-	185
	10	6.80	15	180	200
FOAMER SLUG	10	0.68	0	-	186
(100 ml)	10	0.68	5	-	190
	10	1.00	10	-	192
	10	5.60	15	-	196
	10	5.60	18	255	205
FOAMER SLUG	10	0.24	0	330	180
(100 ml)	10	0.28	5	-	187
	10	0.44	10	-	199
	10	0.68	15	345	205
	10	6.80	20	350	198
FOAMER SLUG	10	0.28	0	425	170
(100 ml)	10	0.16	5	-	183
	10	0.16	10	-	200
	10	0.32	15	440	217
	10	6.00	20	445	210

APPENDIX 1

Table 1.2.1 - Suntech Sample Code I, Run 1.

<u>FLUID INJECTED</u>	<u>PRESSURE DROP, ΔP, psi</u>	<u>GAS FLOW RATE, Q, l/min</u>	<u>TIME, t, min</u>	<u>CUM. REC., R, ml</u>	<u>TEMP., T, °F</u>
WATER SLUG	10	4.60	0	-	65
(100 ml)	10	4.60	4	61	"
	10	4.60	7	62	"
	10	4.60	10	62	"
FOAMER SLUG	32	0	0	-	65
(100 ml)	32	0	15	159	"
	32	0	23*	160	"
	32	0	27	160	"
	32	0.08	30	160	"
	32	0.08	35	160	"
	32	0.12	40	160	"
	32	0.12	45	160	"
	32	0.20	60	160	"
	32	0.24	75	160	"

* First indication of gas on wet test meter.

APPENDIX 1

Table 1.2.2 - Suntech Sample Code I, Run 2.

<u>FLUID INJECTED</u>	<u>PRESSURE DROP, ΔP, psi</u>	<u>GAS FLOW RATE, Q, l/min</u>	<u>TIME, t, min</u>	<u>CUM. REC., R, ml</u>	<u>TEMP., T, °F</u>
WATER SLUG	10	2.40	1	70	165
(100 ml)	10	2.40	4	75	175
	10	2.64	10	78	187
FOAMER SLUG	5-25	0	0	-	-
(100 ml)	5-25	0	2	120	160
	5-25	0	5	137	165
	5-25	0	11	138	185
	5-25	0	17	156	196
	5-25	0	22*	183	200
	5-25	0	28	185	205
	5-25	0	32	186	206
	5-25	0	41	187	210
	45	0.04	46	187	210
	45	0.04	58	188	210
	45	0.06	65	188	208
	45	0.08	73	191	208
	45	0.32	80	200	209
	10	0.80	84	202	207
	10	1.00	90	203	207

* First indication of gas on wet test meter.

APPENDIX 1

Table 1.2.3 - Suntech Sample Code I, Run 3.

<u>FLUID INJECTED</u>	<u>PRESSURE DROP, ΔP, psi</u>	<u>GAS FLOW RATE, Q, l/min</u>	<u>TIME, t, min</u>	<u>CUM. REC., R, ml</u>	<u>TEMP., T, °F</u>
WATER SLUG	8	7.40	0	105	265
(100 ml)	8	9.00	7	128	265
	9	12.0	10	131	280
	8	27.2	15	133	285
FOAMER SLUG	1.5	0	0	133	-
(100 ml)	1.5	0	3*	193	320
	2.6	8.00	9	198	330
	2.6	8.80	15	210	346
	2.6	9.20	20	211	360

* First indication of gas on wet test meter.

