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DETERMINATION OF MISCIBILITY PRESSURE BY DIRECT OBSERVATION METHOD

Quarterly Report for the Period

January 1 to March 31, 1982

George C. Wang

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Background

The objective of the project is to conduct laboratory tests to:

1. develop a method for determining MMP through direct observation using a high pressure cell;

2. determine feasibility of in-situ foam generation by visual observation and microphotographic technique.

The project is presently organized and carried out in three major fronts, i.e., (1) MMP test; (2) high pressure sampling and chemical analysis; and (3) foam study and displacement test. The technical progress in each of these areas is discussed as follows:

(A) MMP test

SACROC Crude Oil

Investigation of miscibility development for SACROC crude was continued at 72°F and 140°F. Volumetric and phase behavior at 140°F were very similar to that at 120°F as described in the last quartely report. The principal difference is the higher pressures at which the CO_2-rich liquid emerged and became miscible with the vapor phase. Again, we have observed that the emergence of a CO_2-rich liquid phase was the key to the development of a transition zone miscible with both fresh crude oil and the driving CO_2. At the forward contacts, the CO_2-rich liquid becomes enriched through multiple contact until it becomes miscible with fresh crude. At the rear of the transition zone, the CO_2-rich liquid phase becomes miscible with the driving CO_2 at a pressure equivalent to MMP. It is also clear that the regeneration of the CO_2-rich phase is necessary to maintain a miscible displacement and the absence of CO_2-rich phase would result in an immiscible type displacement.

For the 72°F experiment, there was no distinguished CO_2-rich phase as was observed at 120°F and 140°F runs. This is because that as soon as the CO_2-rich phase was formed, it immediately mixed with the liquid CO_2. This enriched lqiuid CO_2 was observed to be miscible with fresh CO_2 but immiscible with the stripped crude. In the later multiple contact experiment, the liquid CO_2 was continuously enriched through contact with drops of fresh crude and finally became completely miscible with crude oil.

This experiment tends to show that for low temperature reservoirs, miscibility could be developed between the liquid CO_2 and crude oil through multiple contact process. The CO_2-rich liquid phase may be obscured as opposed to those at higher temperatures.

Penn-Grade Oil

MMP experiments were conducted on Penn-Grade oil at 84°F, 120°, and 140°F. The CO_2-rich liquid appeared at 1157 psig and became miscible with vapor phase at 1400 psig in the experiment at 120°F. At 140°F, the pressure at which CO_2-rich phase emerged and became miscible with the vapor phase were 1300 psig and 1481 psig, respectively.

Slaughter Estate Crude Oil

Experiments conducted on Slaughter Estate at 72°F, 120°F, and 140°F produced volumetric behavior similar to that exhibited by SACROC oil. The key difference was that the pressures at which the CO_2-rich phase emerged and became miscible with CO_2 vapor were higher. Also, the amount of asphaltic precipitation that fell out of this oil were so great that a large part of the sight glass was obscured.

Rock Creek Oil

Experiments conducted on Rock Creek oil at 70°F, 120°F, and 140°F produced results very similar to those of Penn-Grade crude oil. Both crudes exhibited large swelling factors from 1.7 to 1.8 at 120°F and 140°F. The amount of CO_2-rich liquid generated was much greater in the experiments at 120°F and 140°F.

Special attention was given to the experiment conducted on Rock Creek oil at 70°F, its true reservoir temperature. Swelling of the crude oil phase began at approximately 515 psig and continued up to 880 psig to reach its maximum swelling factor of 1.4. At this point, the CO_2 began to enter the system in liquid phase and the crude oil phase was observed to shrink, indicating that the major extraction of hydrocarbons by liquid CO_2 had begun. As described earlier in the SACROC experiment, it was almost impossible to identify a distinct CO_2-rich liquid column due to the mixing nature of CO_2-rich phase and liquid CO_2. When fresh crude oil was charged, it liquid CO_2 was further enriched and changed its color from misty-white to yellow and then became miscible with crude oil.

Gilbertown Crude Oil

Gilbertown crude oil is a 17° API from southwest Alabama. A swelling factor of 1.3 was observed at 120°F as compared to 1.13 and 1.1 at 140°F and 74°F.

In the experiment at 120°F and 140°F, only a thin layer of CO_2-rich liquid was generated at approximately 1250 psi and became miscible with vapor at 1400 psi and 1550 psi in the 120°F and 140°F experiments, respectively. Because of the scanty amount of CO_2-rich liquid, miscible condition with the crude oil was never observed.

The effects of temperature on MMP and appearance of CO_2-rich phase for each of the four crude oils tested are plotted on Figures 1-5. The MMP is the pressure at which the CO_2-rich phase becomes miscible with CO_2 vapor.

Comparison with Other MMP Techniques

In order to verify the results from the study, comparisons have been made with published Yellig and Metcalf correlations. In Figure 6 , the observed MMP are superimposed on the correlation curve. While the majority of MMPs determined by direct observation fall within the limits of the correlation, our data appear to show slightly low MMP at higher temperatures. This would be expected since they used recombined reservoir oil rather than stock tank oil in their displacement tests. The MMP would be higher to obtain a comparable recovery for a recombined reservoir oil than for a stock tank oil because of methane content.

Comparison of MMP was also made with Maljamar crude oil. The MMP of stock tank Maljamar crude determined by slim tube displacement tests at the New Mexico Petroleum Recovery Research Center (NMPRRC) was 1200 psi at 90°F. The direct observation study at our laboratory indicates that an upper CO_2-rich liquid phase emerged at 1025 psi and became miscible with CO_2 vapor at 1181 psi. This compares favorably with NMPRRC's results.

(B) Sampling and Chemical Analysis

The Hewlet-Packard 5880-A gas chromatograph has been tested and a BASIC program has been incorporated with the unit to determine C_5 to C_{36}. The results of analysis for the four crude oils tested are shown in Figure 7. It is obvious that the SACROC crude oil is the richest in C_5 to C_{20} components, followed by Penn-Grade, Slaughter Estate and Gilbertown crude oils. The deficiency of C_5 to C_{20} in the Gilbertown oil may explain why no miscibility between the CO_2-rich liquid and crude oil was observed. As previously stated that the richness of C_5 to C_{20} components is the key factor for determining the quality and stability of the miscible transition zone.

(C) Foam Displacement Test

Apparatus and Procedure

The high pressure foam testing unit has been revised as shown in Figure 8. The system has a working pressure of 3000 psi at 140°F. The foam generator was constructed using a 3-inch piece of 1/8-inch stainless tubing for the body, and glass wool as the packing material; two small metal screens were placed at the two ends to prevent glass wool being flushed out. Preliminary testing of the packing materials indicated that the glass wool is more effective in generating foam than glass beads for a practical CO_2 injection rate of approximately 8 cc/hr; this can be explained as glass wool's greater surface area promotes more mixing between CO_2 and surfactant solution. The generator has porosity and permeability of approximately 70% and 8 darcies respectively.

The observation cell is a Jerguson liquid level indicator with a linear scale attached to the outside of the glass window. A conversion factor of 3.79 cc/cm was calculated for this cell to convert from height into volume.

Surfactant solution is supplied by an adjustable rate pump made by Milton Roy Co.. Carbon dioxide is supplied by a cuctom made rod-cell; the CO_2 rate is controlled by a Ruska positive displacement pump pumping water into the lower part of the cell to move a rod connected piston separating the two fluid chambers, the upward moving piston displaces CO_2 into the foam generator, and the rod indicates the relative position of the piston.

The surfactant solution used in the test was prepared by adding Alipal CD-128 into distilled water to a concentration of 0.5% by volume.

The system is first charged with liquid CO_2, and the heater is then turned on to bring it to the desired temperature. After the temperature is stabilized, the outlet pressure is set by adjesting the CO_2 pressure and the back pressure regulator. The CO_2 pump and the surfactant pump are then turned on to begin the injection of these two fluids into the foam generator. It will take approximately one hour before the foam first appears in the observation cell. The foam level in the observation cell, CO_2 and surfactant injection pressure, system pressure and the surfactant level in the reservoir are recorded at this instant. The system is left to continue without altering the running condition and readings are taking again after one hour interval. The increase in foam level and the surfactant level are determined which are then used to calculate foam quality.

The CO_2 rate was kept constant at 8.1 cc/hr for every run. Different surfactant rates were tested to study the effect on foam quality and foam quantity at a particular temperatur-pressure condition. The process was repeated to study the effect of pressure on foam properties by generating foam at different system pressures:1000, 1500 and 2000 psi. Tests at different temperatures of 75, 120 and 140^{o}F were also performed.

Results and Discussion

Because the densities of carbon dioxide are changed with temperatures and pressures, CO_2 mass flow rates were calculated to provide the basis for analysis. The surfactant/CO_2 ratio relative to foam quality and foam quantity are presented in Table 1 and plotted in Figures 9 to 14.

Figures 9, 10 and 11 show the foam qualities increased as the surfactant rates are decreased. At 75^{o}F, the foam quality increases as the pressure is decreased whereas the reverse is true for temperature at 120^{o}F. The reversal in behavior could be true since CO_2 is existed at 75^{o}F in liquid phase and in gas phase at 120^{o}F. For CO_2 injection rate of 8.1 cc/hr, foam did not appear at 1000 psi-120^{o}F, 1000 psi-140^{o}F and 1500 psi-140^{o}F.

Figures 12,13 and 14 show foam generating rate increase with increasing surfactant/CO_2 ratio. High temperatures tend to lower the rate and high pressures tend to increase the rate at 120^{o}F but to decrease at 75^{o}F. Foam quality was found to be affected more by surfactant/CO_2 ratio, and to a lesser degree by pressures and temperatures. For a specific foam quality and gaseous CO_2, more foam would be generated at higher pressures, however, the reverse is true whereas the CO_2 is liquid.

More testings are being planned to study the effects of foam properties in relation to brine and crude oil before conclusions can be drawn to which surfactant /CO_2 ratio is the best for later uses in foam flooding tests.

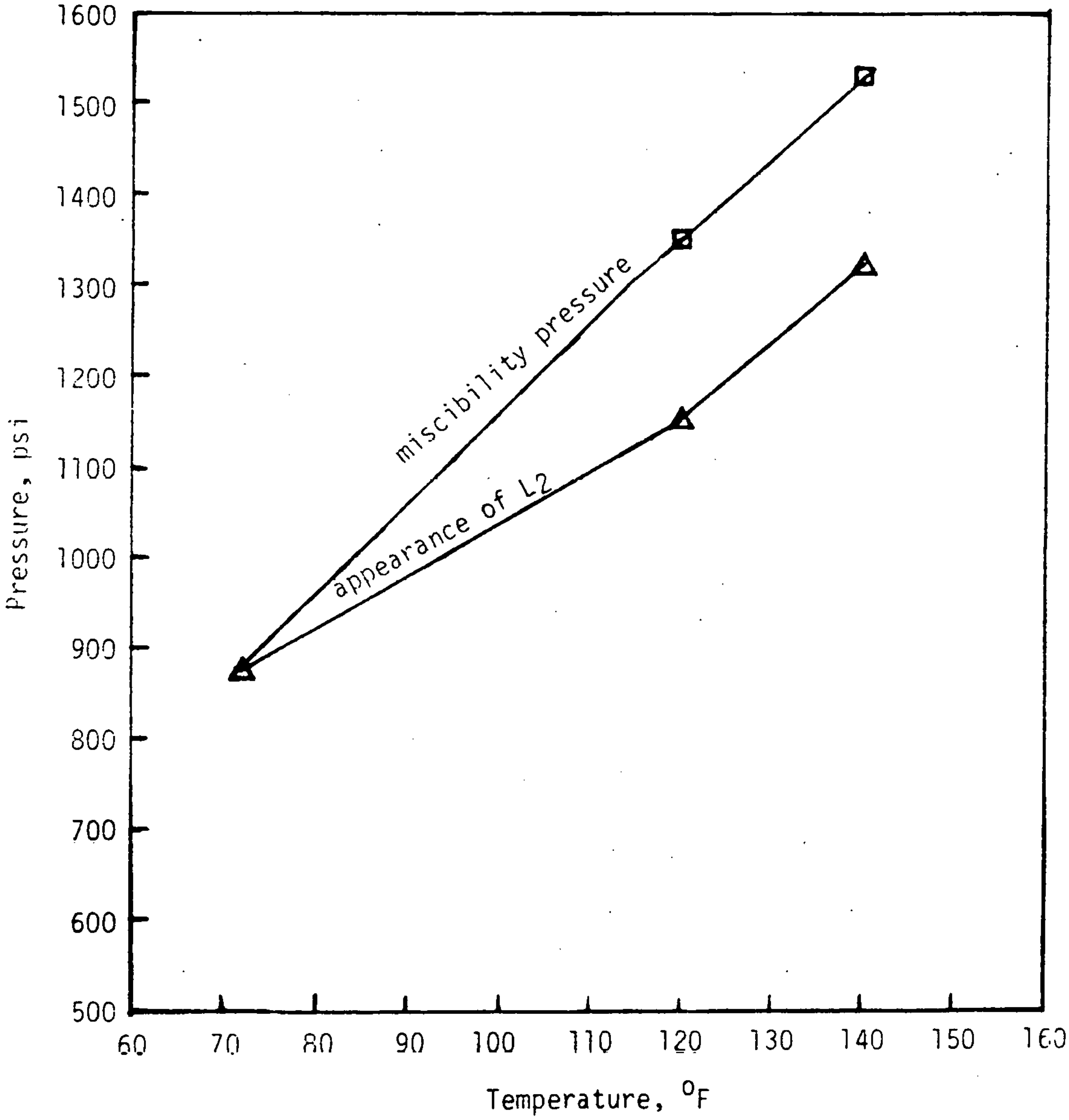


Figure 1. SACROC Crude Oil-CO_2
MMP vs. Temperature

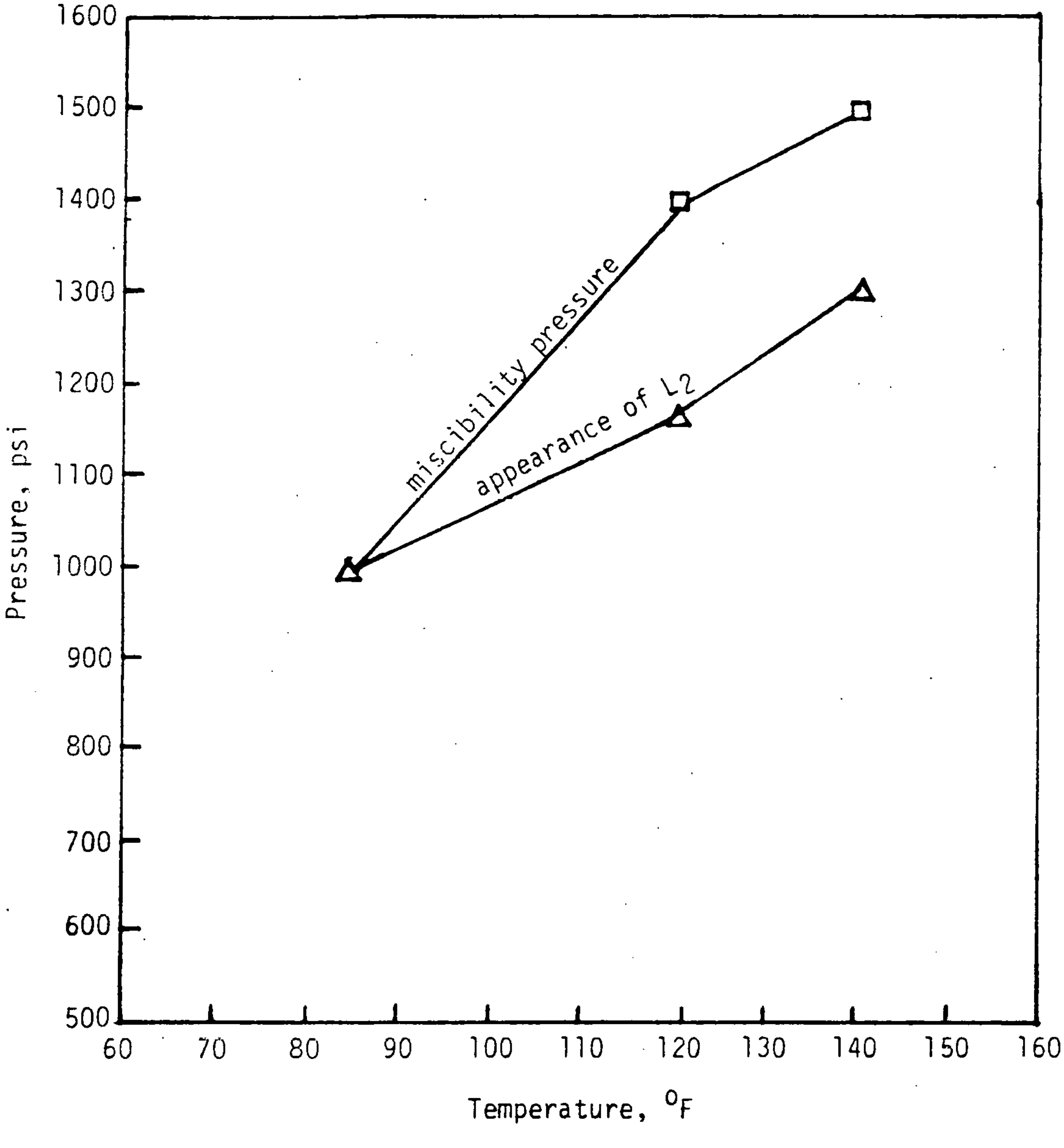


Figure 2 . Penn-Grade Crude Oil MMP vs. Temperature

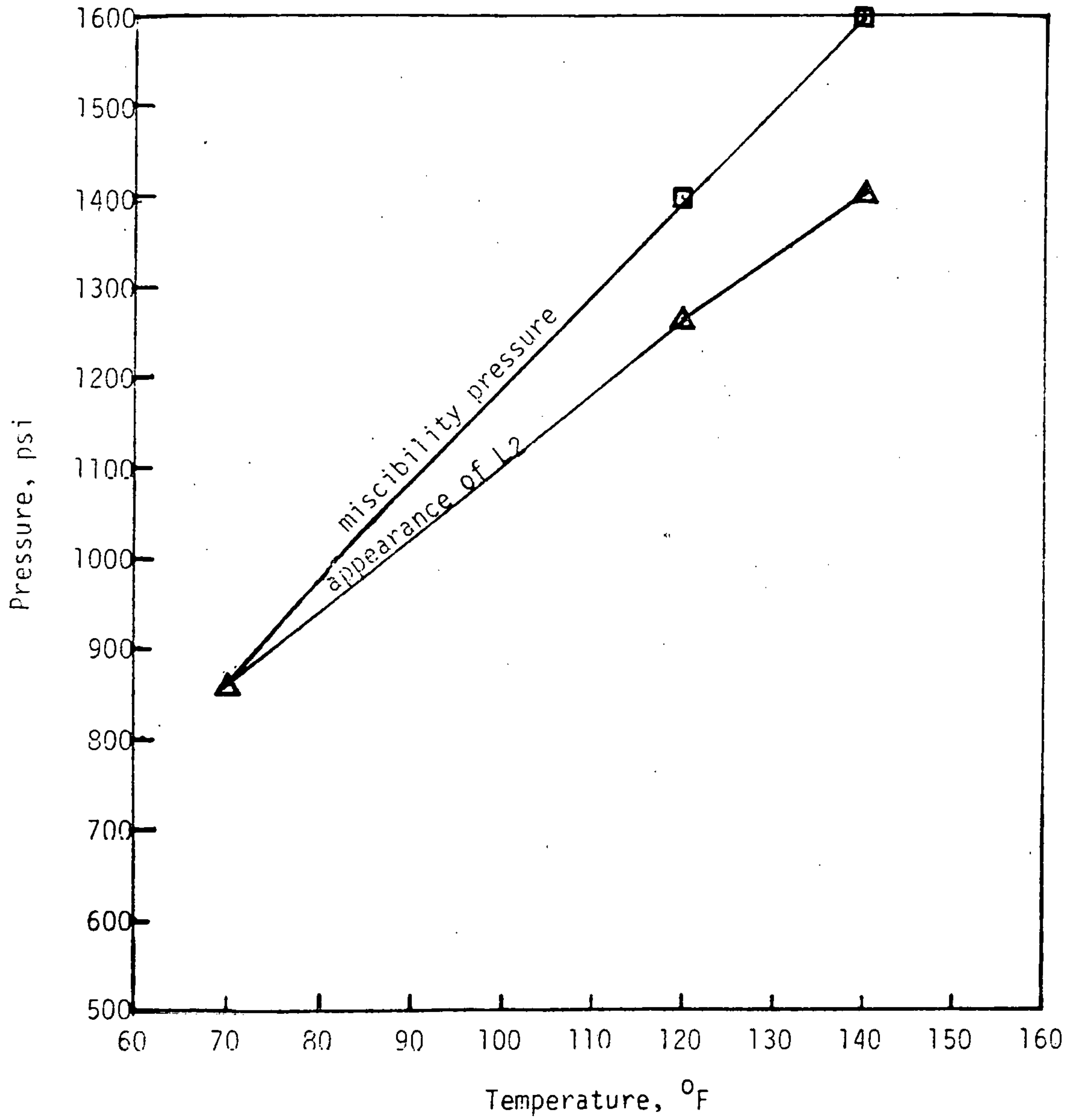


Figure 3 . Slaughter Estate Crude Oil
MMP vs. Temperature

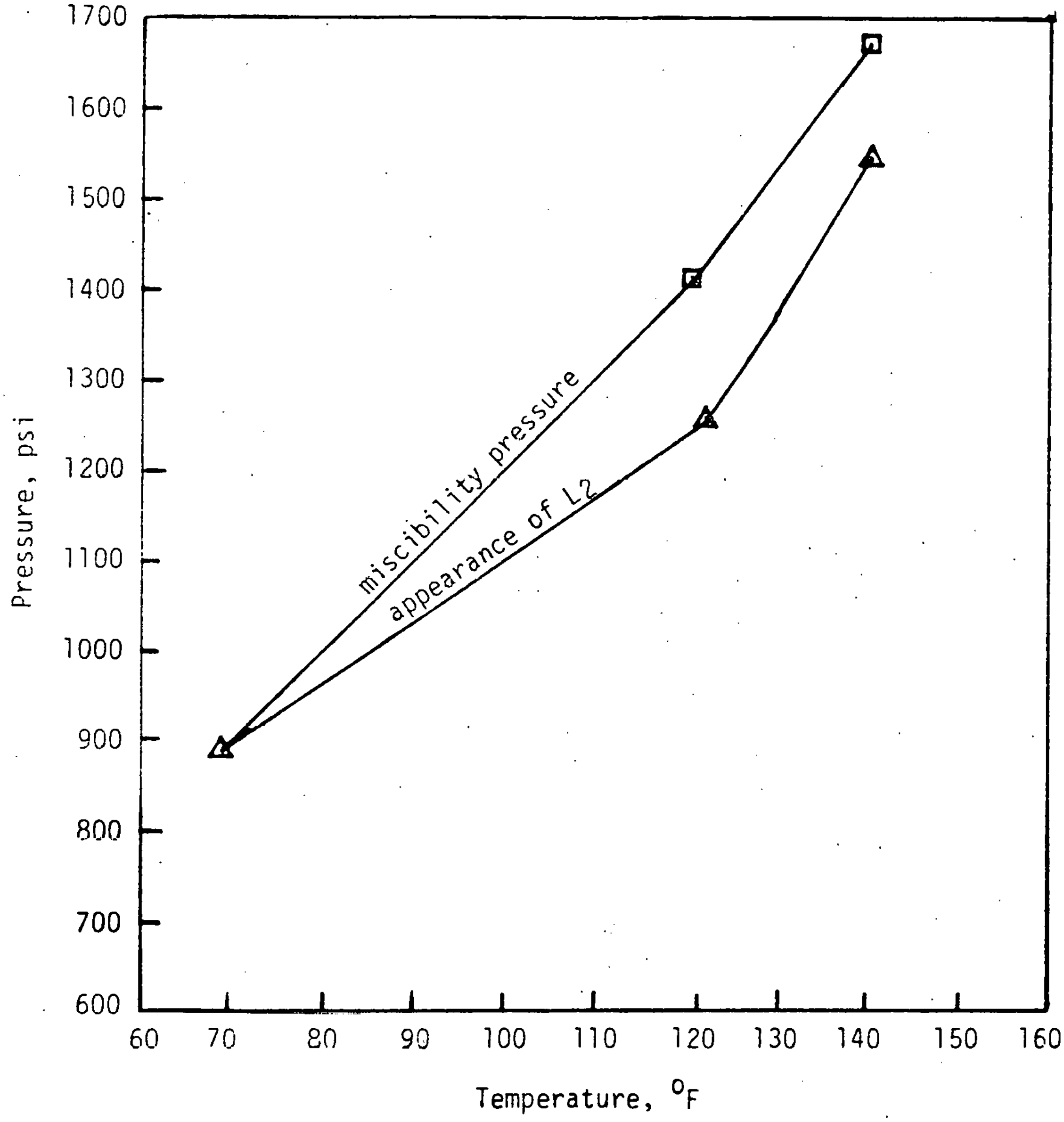


Figure 4 . Rock Creek Crude Oil MMP vs. Temperature

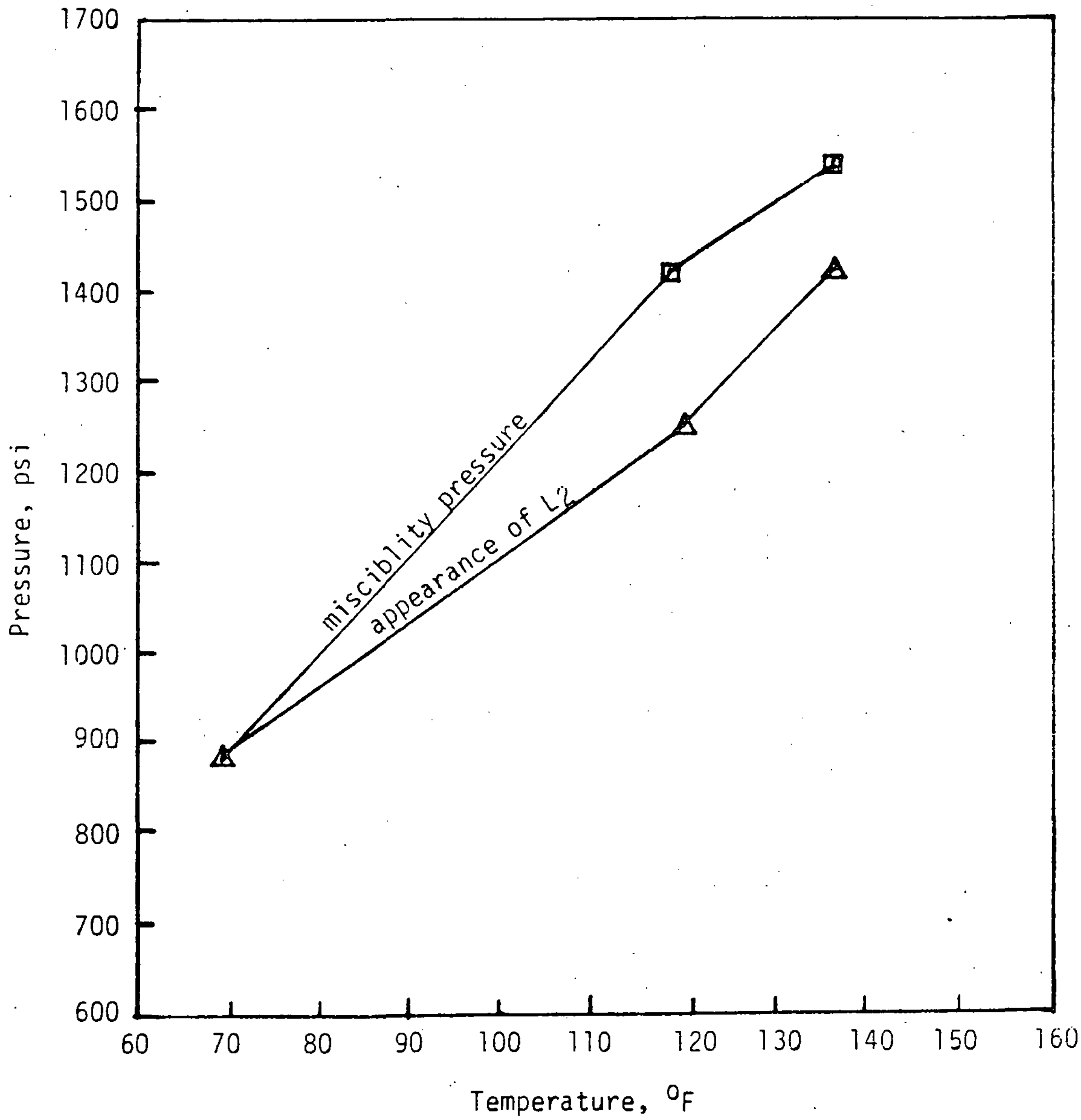


Figure 5 . Gilbertown Crude Oil MMP vs. Temperature

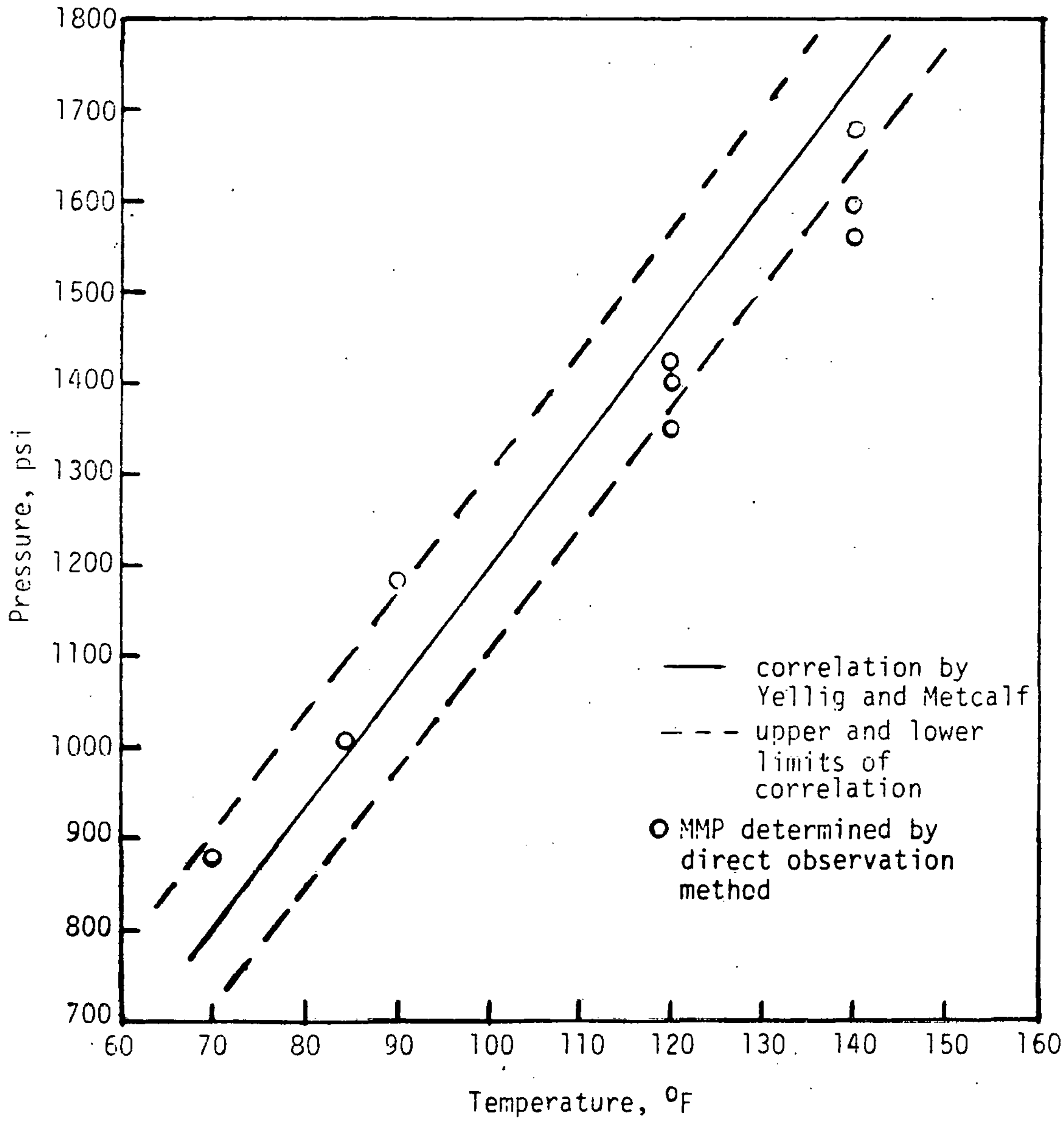


Figure 6 . CO_2-Crude Oil MMP Correlation Developed by Yellig and Metcalf

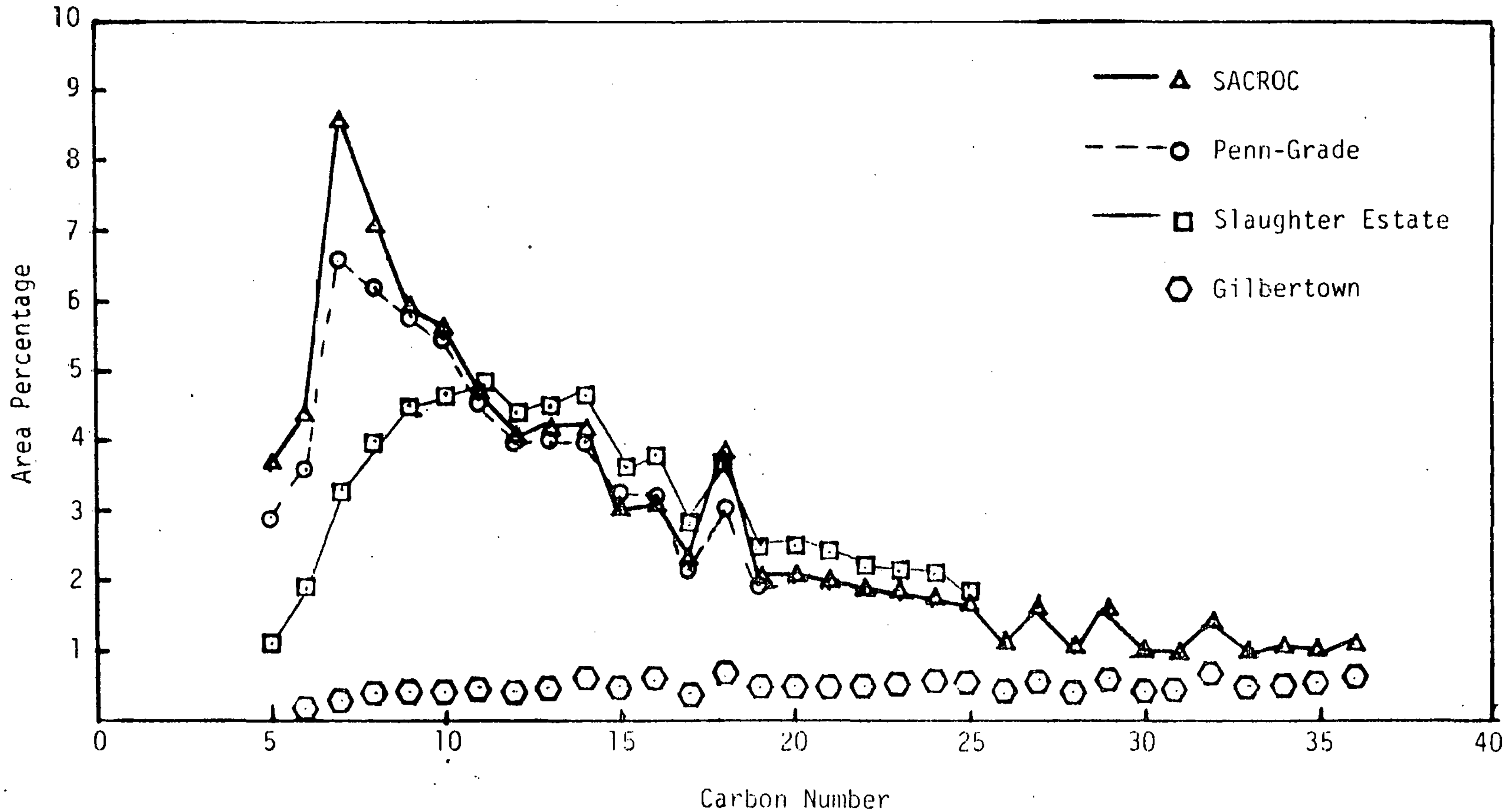
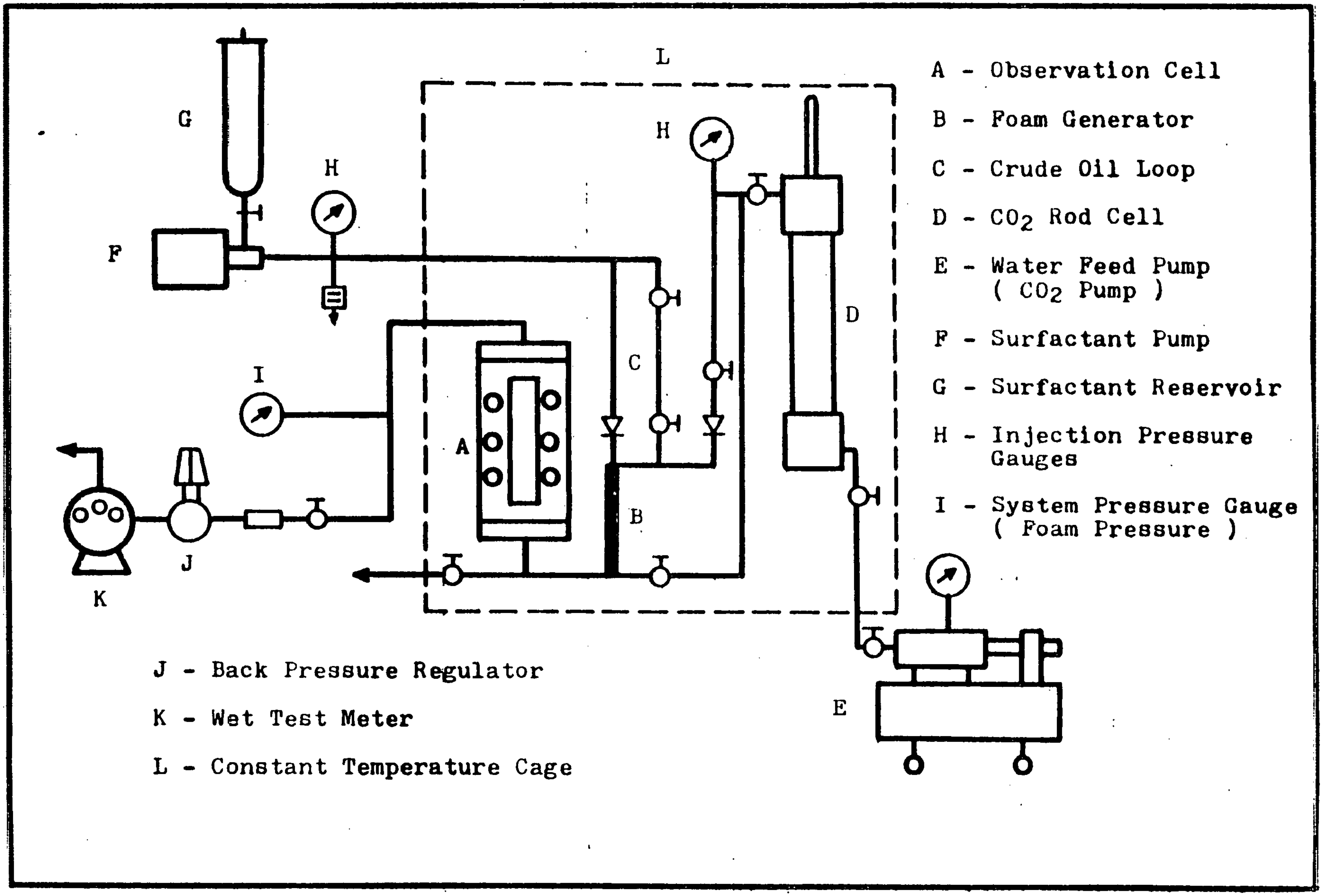


Figure 7 . Component Area Percentage vs. Carbon Number for Crude Oils Studied

Figure 8 - **Laboratory Set-Up for CO_2-Surfactant Foam Generating.**



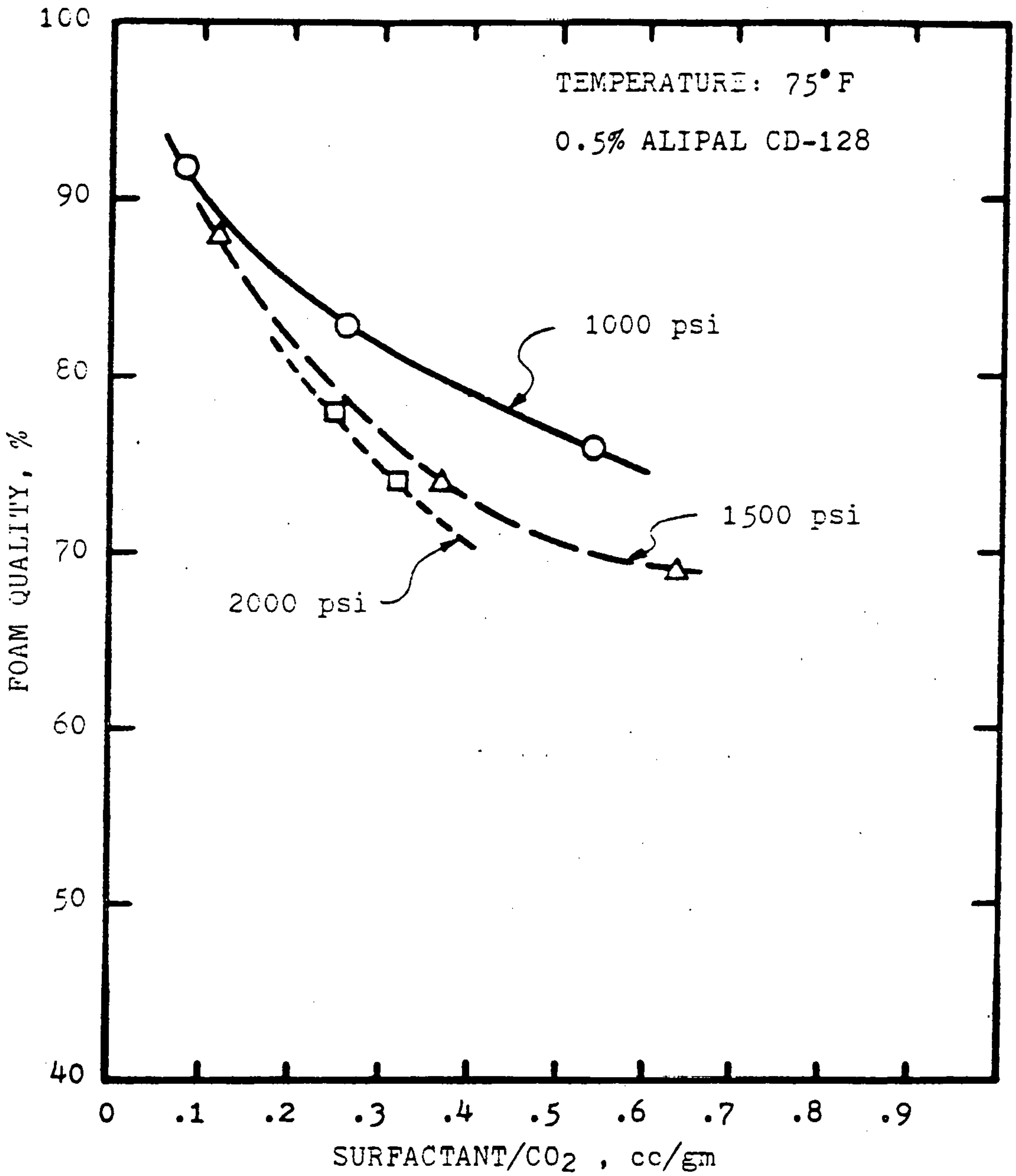


Figure 9 - Effect of Surfactant/CO_2 ratio on Foam Quality at 75°F.

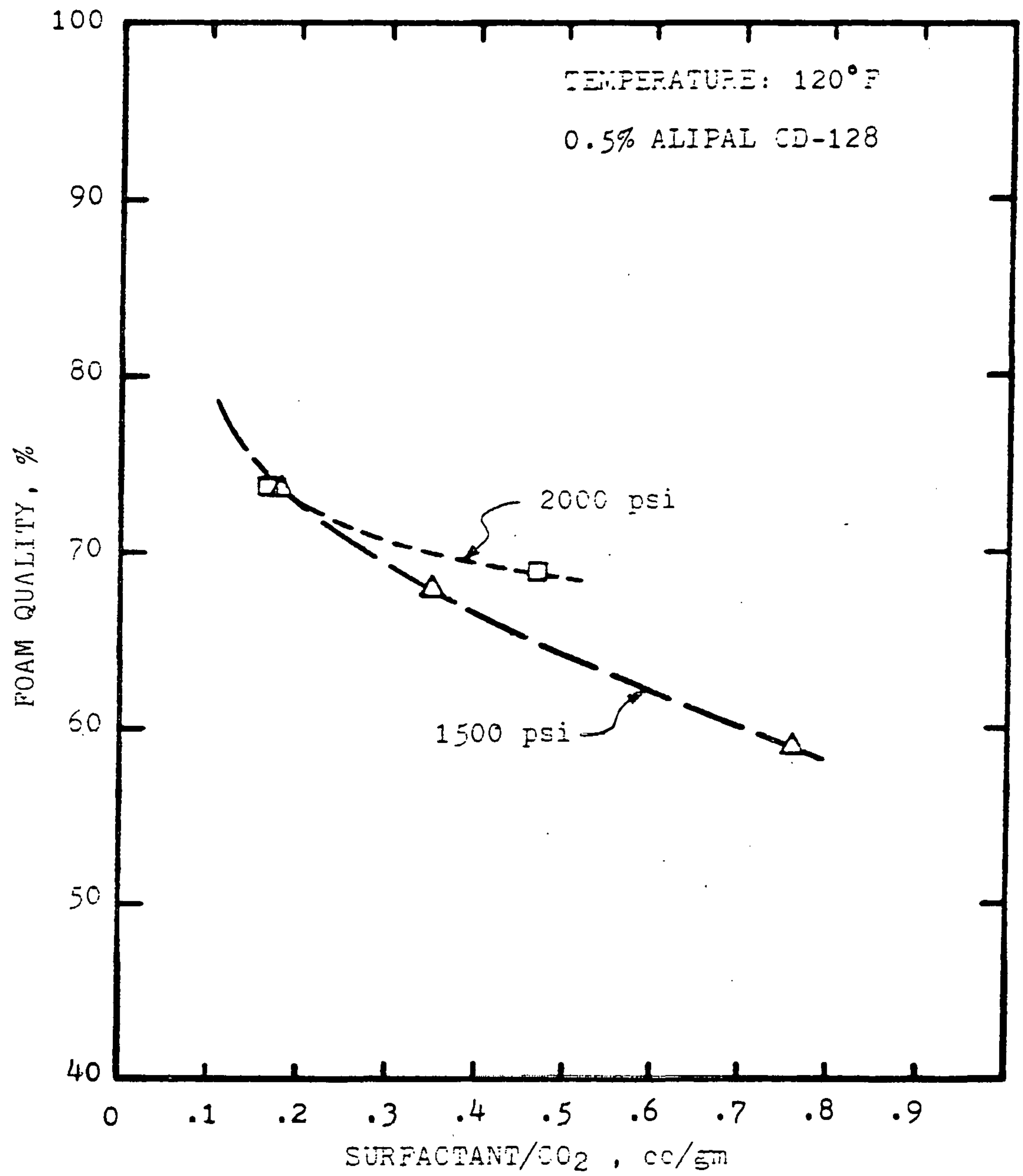


Figure 10 - Effect of Surfactant/CO_2 ratio on Foam Quality at 120° F.

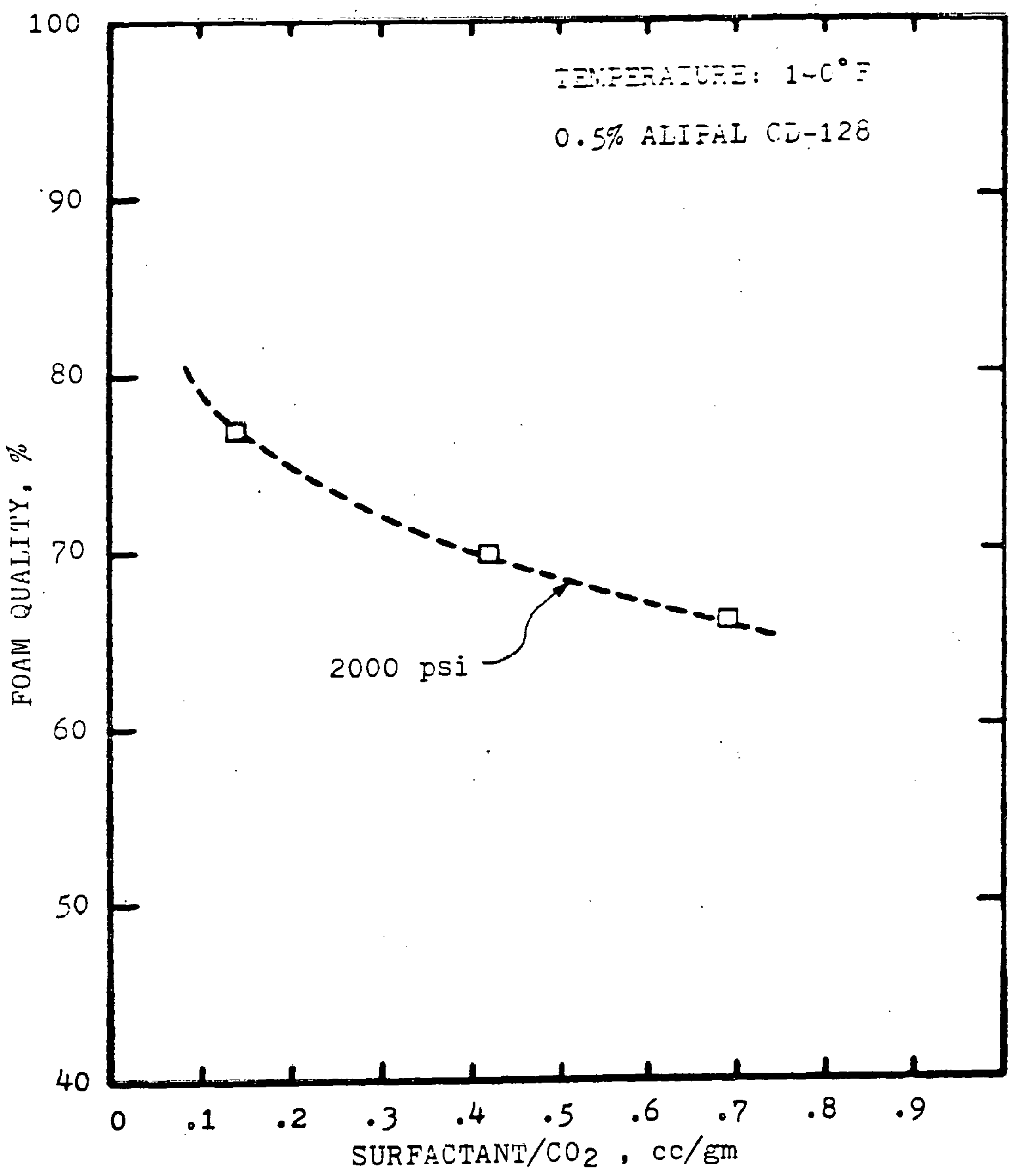


Figure 11 - Effect of Surfactant/CO_2 ratio on Foam Quality at 140°F.

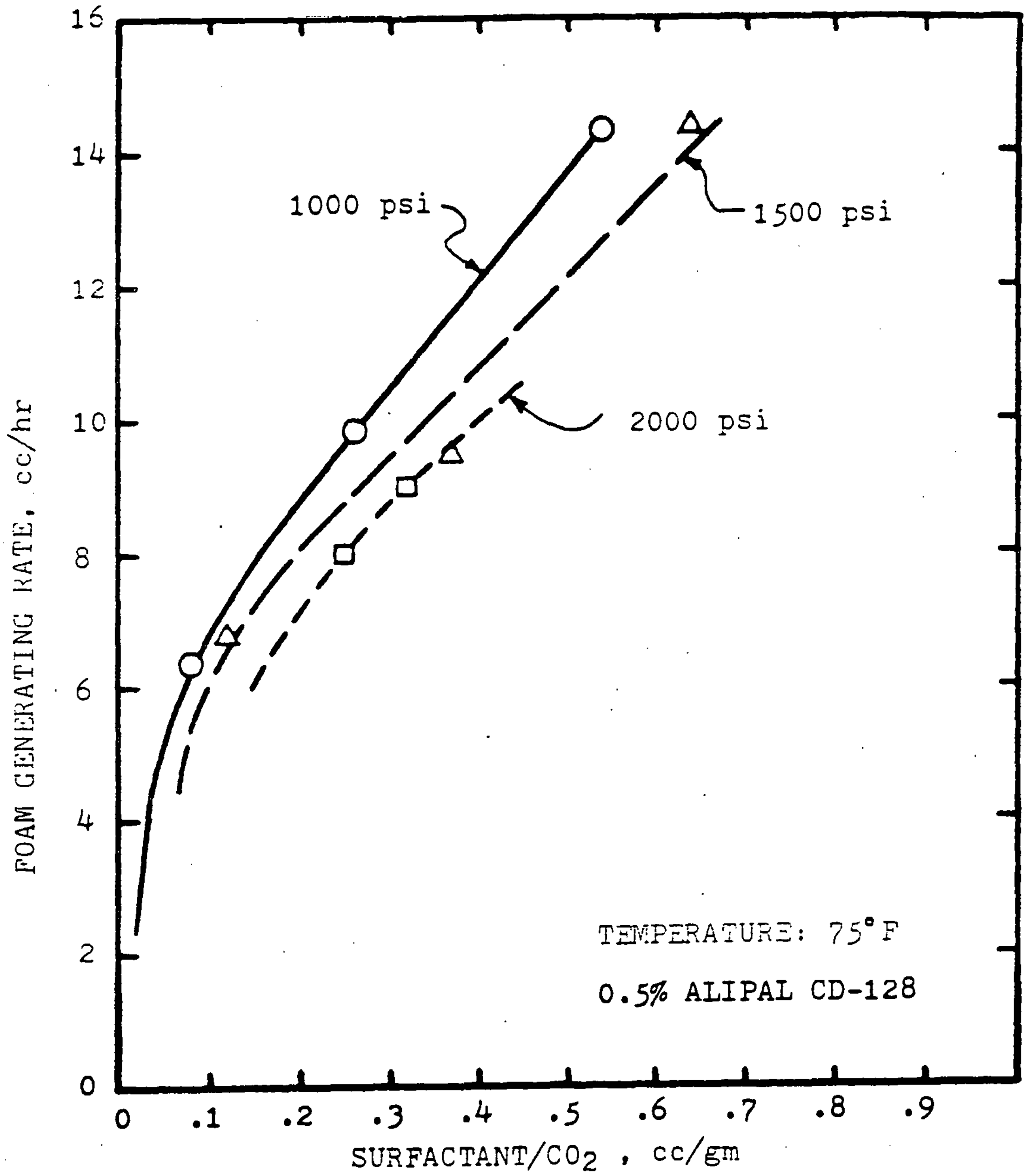


Figure 12 - Effect of Surfactant/CO_2 ratio on Foam Quantity at 75°F.

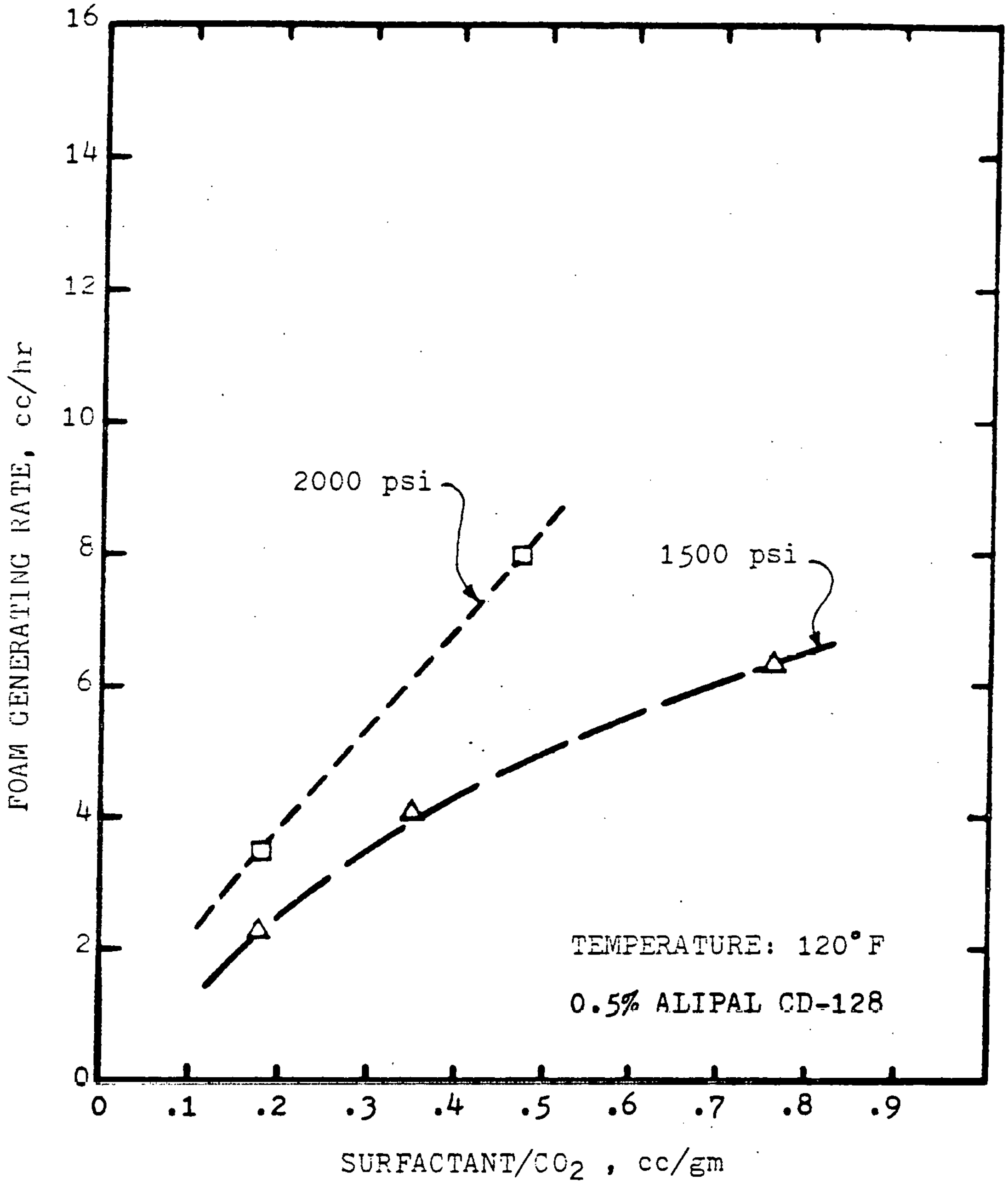


Figure 13 - Effect of Surfactant/CO_2 ratio on Foam Quantity at 120°F.

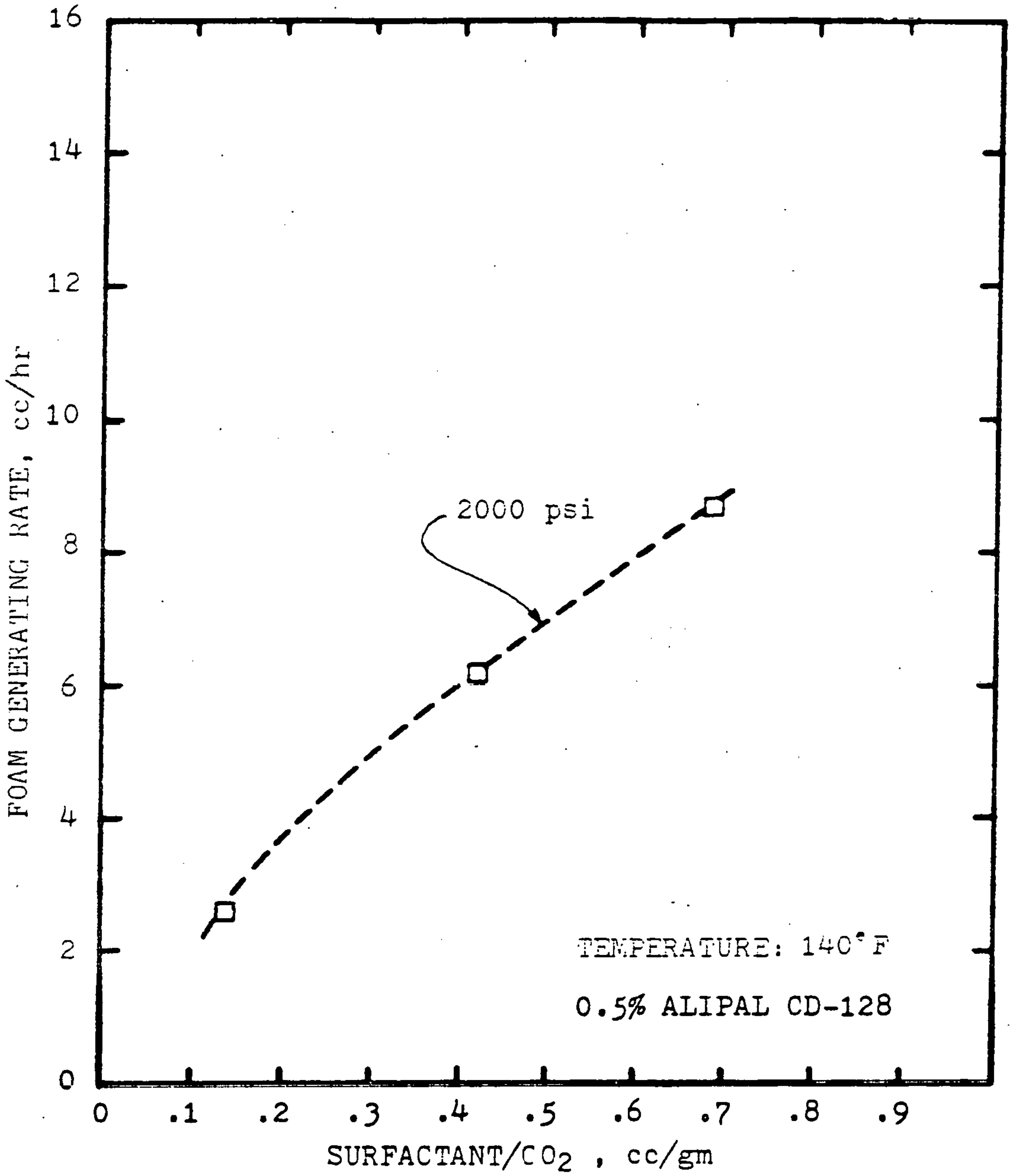


Figure 14 - Effect of Surfactant/CO_2 ratio on Foam Quantity at 140°F.

Run #	Foam Pressure (psi)	Foam Temperature (°F)	Injection Pressure (psi)	CO_2 Inj. Rate (cc/hr)	Surfactant Inj. Rate (cc/hr)	Foam Gen. Rate (cc/hr)	Foam Quality (%)	CO_2 Mass Flow Rate (gm/hr)	Surfactant/ CO_2 (cc/gm)
0308M	1000	75	1200	8.1	1.7	9.8	83	6.49	0.26
0309A	990	75	1235	8.1	3.5	14.4	76	6.51	0.54
0310M	1000	76	1090	8.1	0.5	6.4	92	6.35	0.08
0304P	1500	75	1620	8.1	2.5	9.5	74	6.83	0.37
0305A	1490	75	1590	8.1	0.8	6.8	88	6.81	0.12
0310P	1465	75	1640	8.1	4.4	14.4	69	6.84	0.64
0225M	2000	76	2190	8.1	2.3	8.8	74	7.14	0.32
0302P	2005	75	2115	8.1	1.8	8.0	78	7.09	0.25
0311A	1500	121	1645	8.1	1.3	4.1	68	3.68	0.35
0315A	1480	121	1575	8.1	2.6	6.4	59	3.44	0.76
0315P	1495	121	1570	8.1	0.6	2.3	74	3.43	0.18
0316A	2000	120	2135	8.1	2.5	8.0	69	5.28	0.47
0316P	1980	120	2100	8.1	0.9	3.4	74	5.26	0.17
0319M	2005	139	2095	8.1	1.8	6.1	70	4.28	0.42
0322A	2000	140	2080	8.1	0.6	2.6	77	4.26	0.14
0322P	2030	140	2150	8.1	3.0	8.7	66	4.35	0.69

Table 1 - Summary of Test Results for CO_2-Surfactant Foam Generating.