CRUDE OIL SEPARATOR FOAM PROBLEMS

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ABSTRACT

Separator design and sizing is often done without full appreciation or understanding of the problem of foam. Many field and lab tests using probes and windows have shown that foam is often the major problem for the typical crude oil degassing, flash, separator. Often more than 50% of a separator's volume is occupied by foam. All crude oils should be considered foamy because any oil can create large foam volumes under certain conditions. The size of the separator foam volume depends on many interrelated factors. There is no single magic key to determining foam volume. Derating of the allowable gas velocity to account for foam is a grossly inaccurate method of separator sizing. The K-factor in the allowable gas velocity equation correlates to none of the factors that affect foam volume. Fritted bubbler and pressure bomb indexers are a step in the right direction but are still inadequate. We have developed a pilot operation which with proper foam generation can produce meaningful oil foaminess measurements. To predict separator foam volumes, several adjusting factors must be applied. The heart of an accurate foam volume prediction is an abundance of field experience correlated with laboratory pilot data, which includes all pertinent variables.

STATEMENT OF PROBLEM

Many years of research have shown us that crude oil foam is a major problem in separator flash vessels. Many analytical methods and ideas relating to foam currently in use in the oil industry are of little real value. There has been a need for meaningful foaminess tests and an understanding of the dynamics of foam creation and decay. With current economic pressures and offshore platform requirements, separator sizes are being reduced, foam problems are becoming more frequent, and the need for knowledge is in demand.

Separators are like black boxes that keep their secrets well hidden. Crude oils are seldom considered foamy unless carryover occurs. However we have discovered that at high rates the foam layer in a separator often occupies 60% of the separator volume. This has been seen in an actual high pressure test vessel equipped with 4" Lexan windows. Field tests on a 40° API oil, using a vessel with multiple probes, confirmed this fact.

Some industrial foams require hours or days to decay. By comparison crude oil foams are unstable (except where oil viscosity is quite high). However, foam problems exist for even 40° API oils because of the tremendous foam flow rate that crude oil separators must handle. Typical industrial plant foam problems involve relatively small production rates of very stable foam.

Measurements have been made by Natco to determine the foaminess of about 100 crude oils from around the world. Every oil investigated has the potential of creating foam carryover if proper sizing, internal design, or operation is neglected. Often a crude oil is only considered foamy if premature carryover occurs. It would be wise to consider every crude oil to be foamy, to seek an accurate method for predicting foam volume and to make a prediction of foam volume at the time of separator sizing.

FOAM LAYER DYNAMICS

The creation of foam starts in the reservoir or well bore as the oil experiences pressure reduction. Evolved flash gas forms bubbles by nucleation. Foam is also created by pipeline turbulence, Figure 1. Foam will partially decay in pipelines by natural processes. Flashing equilibrium is attained almost instantly after a pressure drop due to turbulence. Thus fluids enter a separator as foam, free oil and free gas. Foam bubbles come in a spectrum of sizes, mostly greater than 250 microns.

At a constant flow rate, temperature and pressure the separator foam volume is constant. The separator foam volume stops growing when it is large enough that the rate of foam decay equals the inlet rate of foam (dynamic equilibrium).

Within the foam layer a three step decay process occurs. Bubbles grow by coalescence and diffusion of gas across common bubble walls. Diffusion occurs from small high pressure bubbles to large lower pressure bubbles, Figure 2. The smallest bubbles decrease in size until their internal pressure is so large that they collapse. Oil drainage through the foam is the second step. Bubble rupture at the foam-gas interface is the third step. Small, wet bubbles are the most stable. Rupture of young, small bubbles releases very little gas. Thus differential gas transfer and drainage must occur before the rate of rupture is significant. All three processes slow down as oil viscosity increases. All three processes can be readily observed in the laboratory.

It is tempting to blame foam problems on a single parameter. Abnormally large foam volumes can be created by asphaltic or paraffinic particles, stable emulsions, high viscosity, or poor vessel internals that inhibit decay, but normally there is no single magic key. Surface tension doesn't correlate well to foam volume, as some believe. Many factors are important. Figure 3 is one of our early attempts to illustrate the major interrelating factors.

CURRENT STATE OF THE ART OF SIZING

The most common method of separator sizing is to use retention time for the oil layer and the K-factor formula for the gas layer.

$$V = K\sqrt{\frac{P_l - P_g}{P_g}}$$

where:

V = maximum allowable gas velocity; fps (above which the gas flow has the aerodynamic force to pick up foam or liquid and carry it out; re-entrainment)

K = empirical value depending on type of separator and several other variables; typical values are .05 to .4 for vertical vessels and .4 to .6 for horizontal vessels (these are not equilibrium flash K's or velocity head pressure drop K's)

P_l = density of liquid, lb/cu ft

P_g = density of gas, lb/cu ft

The above formula is adequate for gas well streams where flows of non-foamy condensate are handled. For this application the maximum allowable K-factor may be derated slightly to account for small amounts of foam and other minor variables. The second type of separator application is that of crude oil streams. The oil rate and foaminess are typically much greater. The greater foam volumes are commonly accounted for by further derating of the K-factor. The K-factor is often reduced by a factor of 2 to 15. This is excessive extrapolation of the derating procedure. The foam layer is often 6 times larger than the gas layer; and yet, foam is supposed to be accounted for in the safety margin of the gas layer. With generous derating and a lot of luck, this procedure may succeed. However, K-factors only correlate to the aerodynamic force of the gas flow; they don't correlate to any of the pertinent foam volume factors, Figure 3. For example, in a particular separator field test the rate was increased until the point of carryover was reached at the gas outlet. The liquid level was then dropped two inches for operation at the verge of carryover. Gas was then added to the separator inlet from a separate source, doubling the gas rate, GOR, and superficial K-factor without causing carryover. In another test the K-factor was doubled by dropping the separator pressure and the same results were observed. Thus it becomes obvious from both theory and experience that K-factor formula methods are not accurate predictors of the point of separator failure in the presence of large amounts of foam.

Complicating the issue is the problem of interface location prediction and detection. The foam-gas interface typically can't be detected during operation, so superficial K-factors are calculated based on the oil-foam interface. Gauge glasses often give false indications of liquid level because the gauge is a stagnant, foam-free volume on which the weight of separator foam acts as oil head, Figure 4.

To make the derating of K-factors less arbitrary, the use of fritted bubbler or pressure bomb tests have been used; Figures 5 and 6. It is said that these give rules of thumb for foaminess. Even though they are useful for qualitatively screening defoamers, they are not totally adequate for determining oil foaminess. Figure 7 indicates that different results can be obtained from different test methods. The bubbler creates different bubble sizes than nucleation, especially at higher oil viscosities where large bubbles are usually formed. The bomb test would appear to produce better results. However a significant difference can still be found between pressure bomb foaminess indexing and true separator foaminess.

RECENT DEVELOPMENTS IN SEPARATOR SIZING

Only a complete pilot system properly operated can accurately predict actual field foam volumes. Figure 8 is an early Natco schematic of such a pilot system. Special pressure reduction equipment is required to duplicate field nucleation. The basic foaminess number, found from the pilot, was expected to account for the majority of factors in Figure 3. However, it was discovered that several additional factors must be applied to predict actual foam volume. Foam decays in the pipeline, chemical defoamers increase rupture rate; and various internals create, destroy, or aid natural foam decay. Decay rate is a function of the hydrocarbon molecular weight of the gas. Other factors are lab-to-field data correlations, foam height, and GOR.

The foam height factor is quite interesting. The taller the foam height is, the longer the drainage path is. Oil from a bubble that breaks at the top of the foam layer must drain through the entire height of foam. Mexican field tests show that a 6' x 20' horizontal separator has a capacity 75% greater than a 6' x 20' vertical. These tests were on the same oil, at the same conditions, and with the same volume available for foam layer decay. Stated another way, the vertical separator accumulated 75% more foam volume per barrel of oil than the horizontal separator did.

Very little gas volume can create very little foam. But a large GOR can produce a dry, thin wall, unstable foam that decays rapidly. GOR factor curves can take many forms depending on several variables; Figure 9.

To size a separator scientifically, the designer needs to provide enough liquid retention time for degassing and oil-water separation and enough volume for foam decay. Also enough flow area above the foam must be provided so that the gas velocity is low enough to prevent pick-up of foam. The designer should have a valid method for calculating the volume required for each layer of fluid; water, oil, foam, and gas.

SEPARATOR INTERNALS DEVELOPMENT

We have tested hundreds of internal designs for reducing foam volume. Many of the designs were shown to be at best neutral to performance.

Inlet momentum absorbers should reduce inlet velocity with the least amount of shear. Shear forces create additional foam and break up inlet bubbles into smaller, more stable, bubbles.

Internal baffles and their proper placement are also very important. They can confine the inlet turbulence to a small section of the vessel. Without baffles the eddying of the oil and foam layers reduces the rate of all three steps of foam decay. Token baffle sections with spacing greater than 1" have been shown to be inadequate, even when properly placed. Several side-by-side field comparisons have shown that the use of proper baffles can more than double the capacity of a given size separator.

We have tested ultrasonics, electrostatics, and other exotic schemes for destroying large quantities of wet foam. However, to date the most inexpensive, reliable method is to provide adequate retention volume, quieted by proper internals, for the foam to decay by natural processes. Application of chemical antifoam agents and heat can also enhance the foam decay process.

CONCLUSION

Foam has emerged as one of the major problems of crude oil depressuring separators. The complexity of multiple interrelated variables should prompt us to consider all oils as potentially foamy. Derated K-factor sizing should be phased out since it can result in missizing and has been shown to be inadequate. Sizing based on bubbler or pressure bomb foam indexing can result in significant sizing errors. Many attempts have been made to correlate lab-to-field data for narrow ranges of operating conditions and crude oil types with the bubbler and pressure bomb. Results have been inadequate for today's demands. The only acceptable method found to date is a detailed pilot simulation of the reservoir, pipeline, and separation system. Even then, pilot data only becomes meaningful when it is adjusted by several factors and correlated to accurate field data. Accurate field data can't be collected by hearsay. It requires experienced operators, planning, internals inspection, pre-calibration, ample instrumentation, operation to the failure point, and proper analysis.

	Pipeline A	Choke B	Pipeline C	Inlet D & G	Choke F	Foam Volume E & H
Bubble creation by gas nucleation of super saturated oil	X	X			X	
Bubble growth by coalescence and gas transfer	X		X			X
Two or more bubbles created from one bubble by turbulent shearing forces	X	X	X	X		
Destruction of large bubbles				X		
Natural foam drainage and decay	Sometimes		Sometimes			X

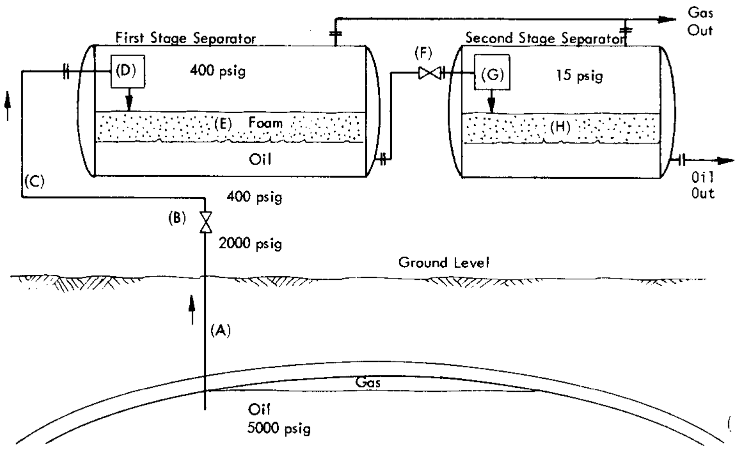
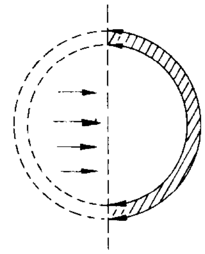


FIGURE 1 — HISTORY OF BUBBLE CREATION, GROWTH, AND DESTRUCTION



$$(\text{PRESSURE})\left(\text{CROSS SECTIONAL AREA}\right) = \left(\text{SURFACE TENSION FORCE}\right)$$

$$P = \frac{(2T)(\pi D)}{\frac{\pi D^2}{4}} = \frac{8T}{D}$$

(D) DIAMETER (INCHES)	$V = \frac{\pi}{6} D^3$ VOLUME (INCHES)^3	$P = \frac{8T}{D}$ $\left(T = 35 \frac{\text{dyne}}{\text{cm}}\right)$ PRESSURE (PSI)
.001	5.2×10^{-10}	1.6
.01	5.2×10^{-7}	0.16
.1	5.2×10^{-4}	0.016
1.0	0.52	0.0016
10.	524.0	0.00016

Foam Decay Processes

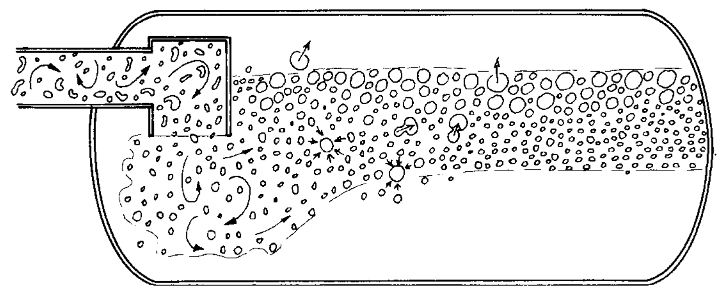


FIGURE 2 — PARAMETERS OF A FREE BUBBLE

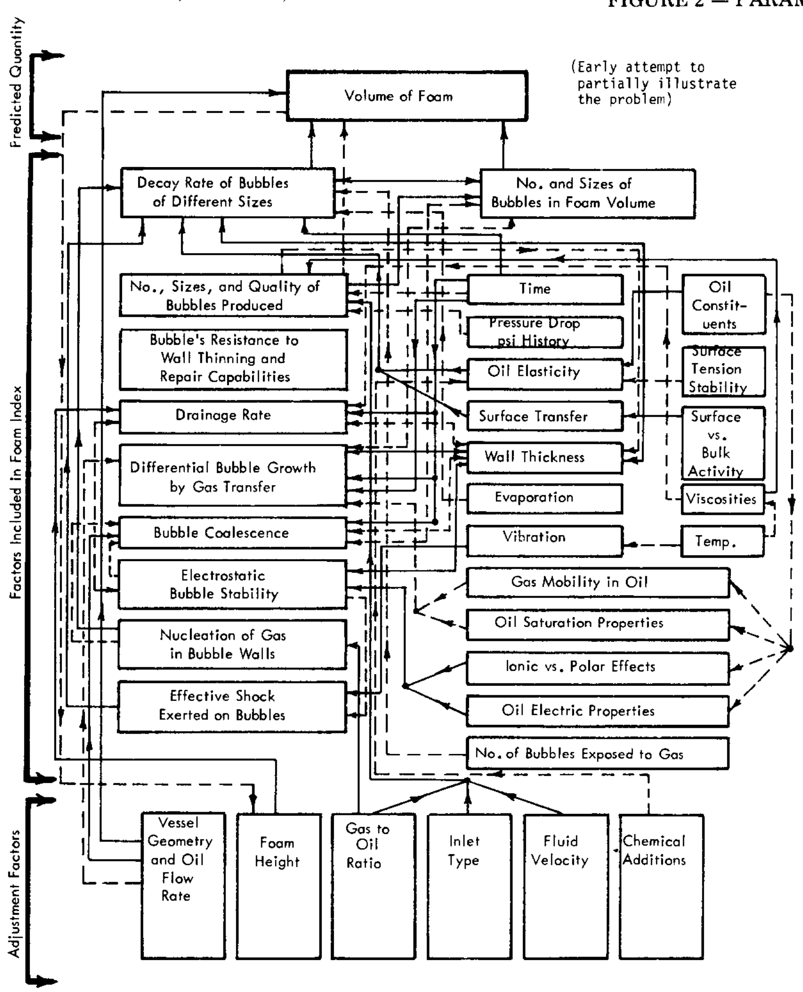
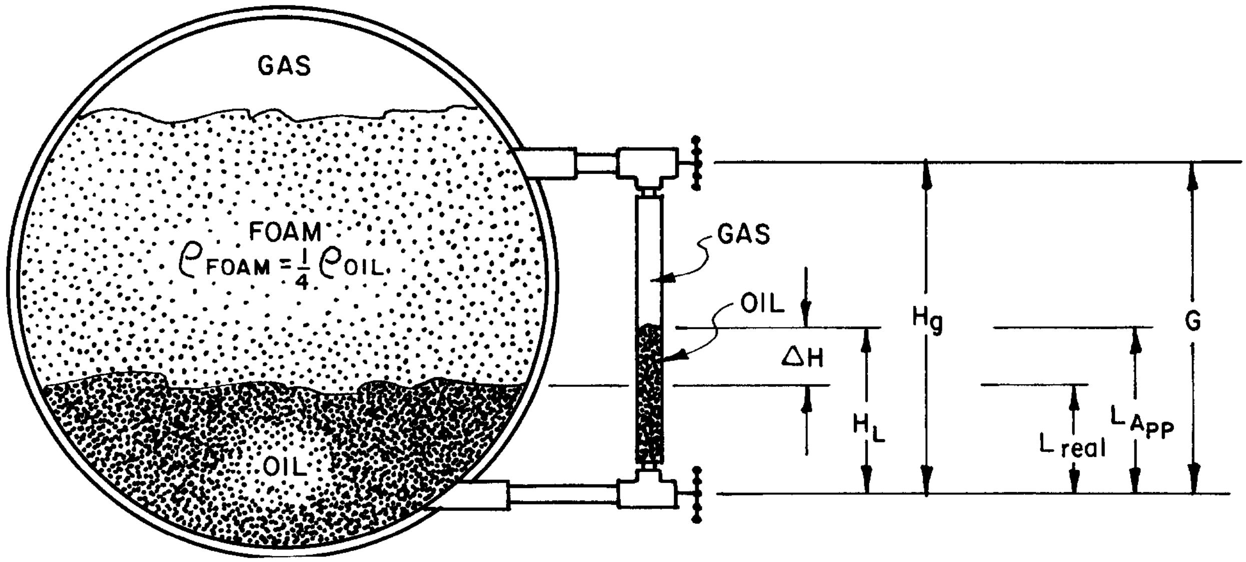


FIGURE 3 — SEPARATOR FOAM VOLUME PARAMETERS AND RELATIONSHIPS



$$\Delta H = \frac{H_g - (H_L - \Delta H)}{4} \qquad L_{real} = \frac{4\,L_{App} - G}{3}$$

$$\Delta H = \frac{H_g - H_L}{3} \qquad L_{App} = \frac{3\,L_{real} + G}{4}$$

FIGURE 4 — LOCATING THE REAL LIQUID LEVEL

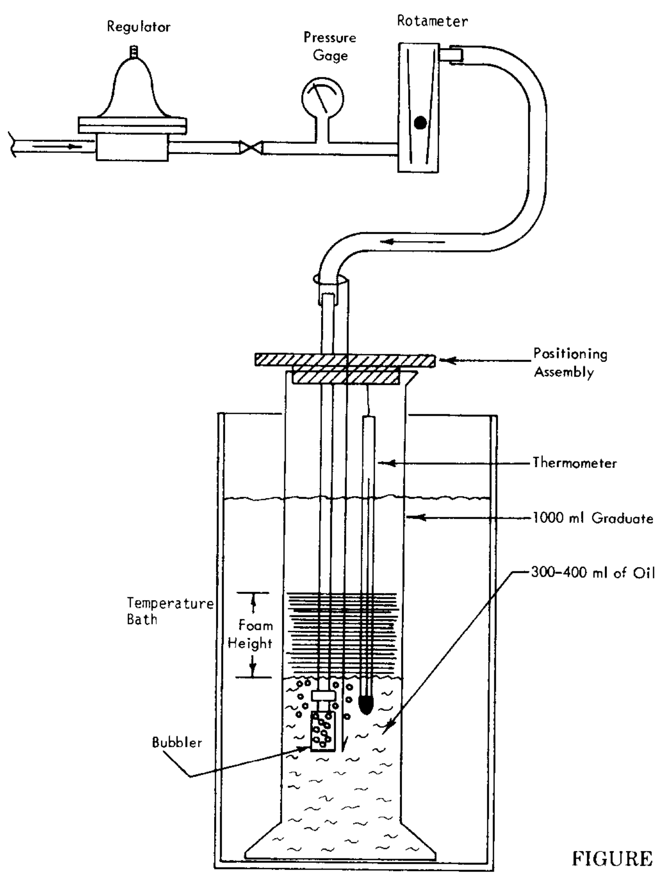


FIGURE 5 — AIR BUBBLE FOAM TEST APPARATUS

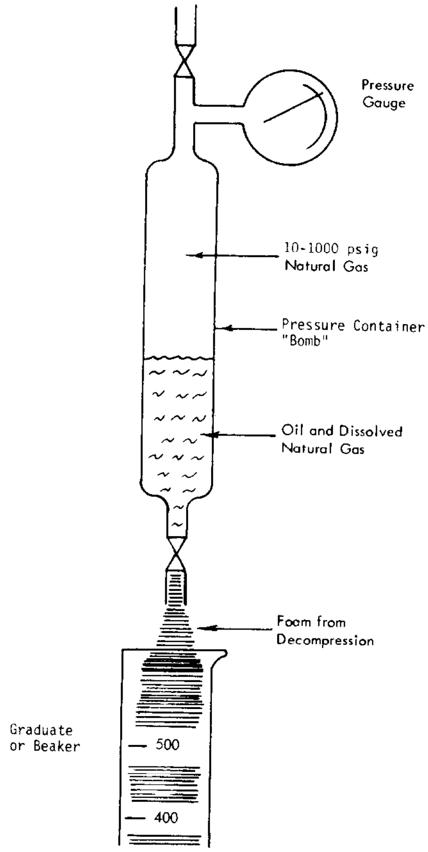


FIGURE 6 — PRESSURE BOMB FOAM TEST APPARATUS

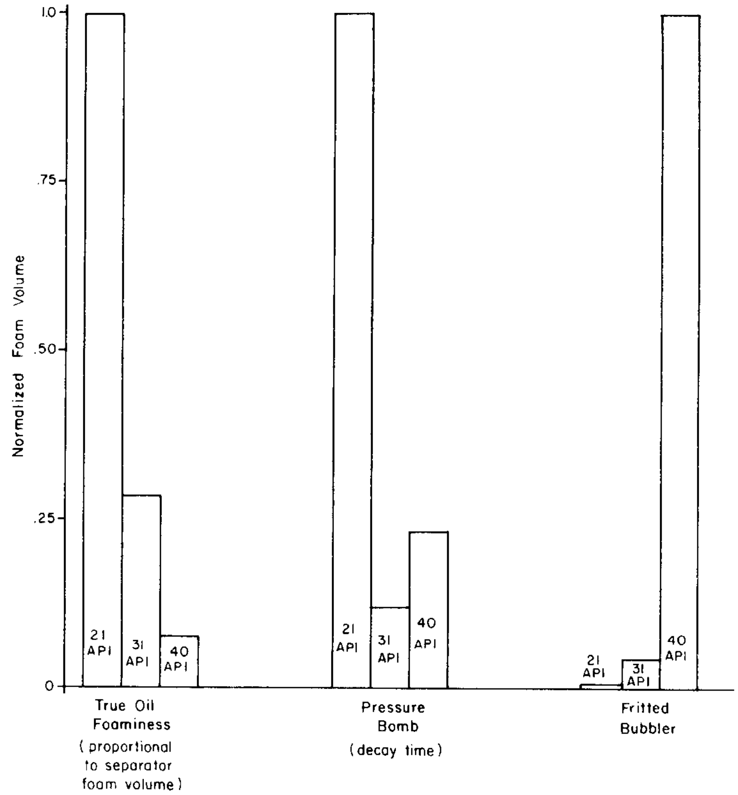


FIGURE 7 — FOAMINESS OF THREE OILS AS MEASURED BY PRESSURE BOMB AND FRITTED BUBBLER

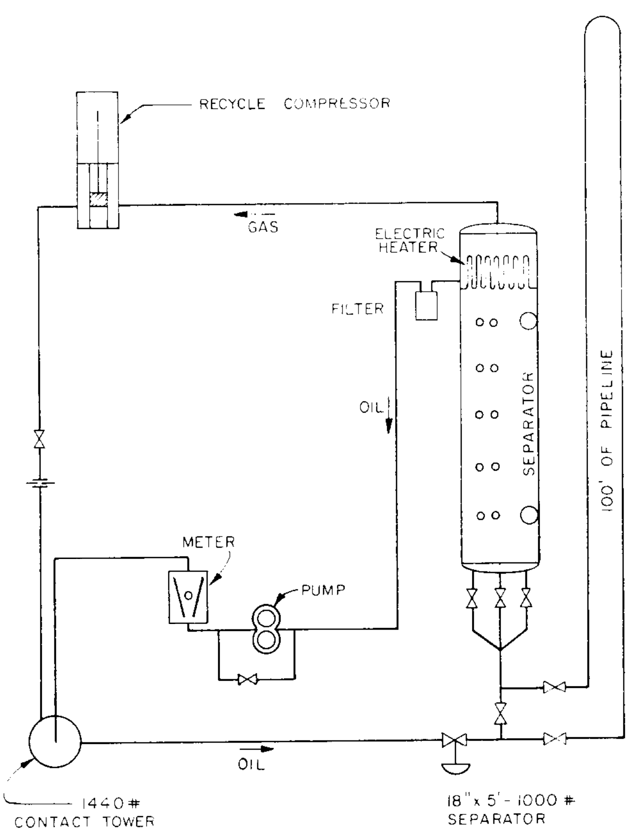


FIGURE 8 — PILOT TEST LOOP

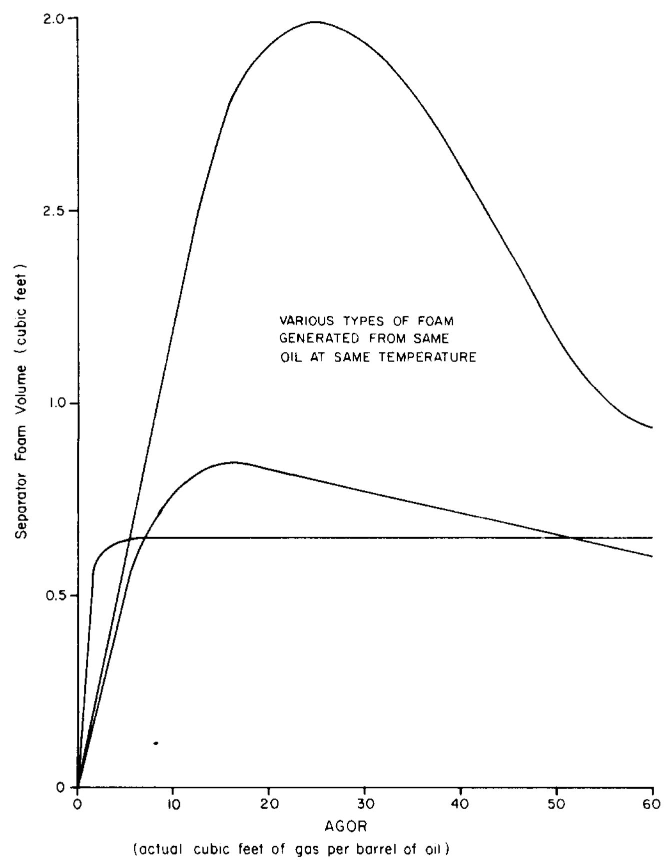


FIGURE 9 — FOAM VOLUME VS GOR