EFFECT OF SAND CONCENTRATION IN FOAM FRACTURING

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ABSTRACT

Foams used as fracturing fluids for formation stimulation are mixtures of compressed nitrogen gas and a base liquid. The quality of a fracturing foam refers to the volumetric gas content of the foam and is usually in the range of 65-95 percent.

The addition of sand to a fracturing foam can have a significant effect on the actual flow rate of the base liquid at the surface. This effect on the surface will change the foam flow rate and foam quality desired down hole. The hydrostatic pressure exerted by the fracturing foam will also be effected as sand concentration changes. Using the true volume of sand as a basis, several equations are presented in this paper which will compensate for the effects of sand concentration in foam. A well designed foam frac job is necessary for proper implementation of the stimulation treatment.

INTRODUCTION

Advantages of using foam as a fracturing fluid include reduced hydrostatic pressure, faster well clean up, good fluid loss control, reduced formation damage, high effective viscosity, and reduced friction pressure. Fracturing foams also have high sand suspending and carrying capabilities and concentrations up to 3½ pounds per gallon have been used.

As sand is added to a fracturing foam, the quality of the foam and hydrostatic pressure exerted by the foam can increase considerably. The true volume of sand, .0459 gallons per pound, is the basis for making the correct adjustments on surface to maintain the desired down hole conditions as the sand concentration changes.

APPLICATION AND JOB CONTROL

Foams used as fracturing fluids are generated by mixing a base liquid and compressed nitrogen gas. These two components are pumped separately and are combined at a pre-designed ratio. The volumetric composition of compressed nitrogen gas in the fracturing foam, referred to as foam quality, is normally in the range of 65-95 percent under calculated downhole treating conditions. As the foam quality increases, the viscosity of the foam increases. Foams with less than 65 percent nitrogen are known as wet foam and are too thin to be suitable for fracturing fluids. Dry foams, foam with more than 95 percent nitrogen, degenerate into a mist and are too unstable to be used as fracturing fluids. 1*

The base liquid content of the foam is divided into two portions. The main portion, a low-residue cellulose-type polymer, passes through a blender where proppant is added at a regular rate. The second smaller portion is a gel breaker which destroys the viscosity of the sand-gel slurry. After the sand-gel slurry passes through the blender and pump trucks, the two portions are combined and the gel begins breaking on the fly. A small amount of surfactant foaming agent is also included in the breaker which helps produce and stabilize the foam when the compressed nitrogen gas is added to the base liquid.

The gas is added to the fluid at a "T" in the line downstream from the pumps. The turbulence of the fluid combined with the turbulence of the addition of the gas phase acts as a foam generator. The foam is then injected into the well. 2* A typical equipment set up for a foam frac operation is shown in Figure 1.

To maintain the calculated foam quality and scheduled fracturing rate, the ratio of the nitrogen to liquid pumping rates must be held constant. The nitrogen pumping rate is calculated based on fracturing treating pressure and temperature. The rate of the gas is metered before it is injected into the main line. To determine the liquid rate, a flow meter is placed in the line before the "T" where the gas phase is introduced. The quality of the foam can then be easily calculated and pump rates of both constituents can be adjusted during the pad volume to obtain the desired foam quality. Because the liquid flow meter shows the rate of the sand-liquid slurry, sand concentration will have an effect on foam quality. The sand concentration in the sand-liquid slurry changes the volume of liquid being pumped. As sand is added to the liquid, less liquid is actually being pumped due to the volume of space occupied by the sand. When this happens, the nitrogen to liquid pump rate will increase and therefore increase the foam quality. Table I shows the effect sand can have on a 70 quality foam pumped at 10 BPM as sand concentration changes from 1 pound per gallon to 3 pounds per gallon.

If a foam-fracturing treatment is designed properly, the effect of sand concentration can be corrected before the job begins. Because the sand concentration to be used is known, and the true volume of sand is .0459 gallons per pound, the rates of the base-liquid and nitrogen can be adjusted to maintain foam quality and foam rate. Adjusting the nitrogen flow-rate alone is not a satisfactory correction for the problem; the foam quality can be maintained, but the total foam rate will decrease. (See Table II) Foam quality can also be maintained by increasing the liquid flow rate and holding the nitrogen rate constant, however this adjustment will increase the total foam rate. (Table III) Therefore the rates of both constituents must be adjusted to correct the problem. (Table IV)

Figures 2-5 show the effect of sand concentration on foam quality at the surface for several different foam qualities.

Sand concentration also effects the hydrostatic pressure of foam. Foam is a compressible fluid, therefore the density will vary with changes in pressure and temperature. Using equation 1 to calculate foam density, figures 6-9 show hydrostatic pressures for a 75 quality foam at various sand concentrations.

$$\frac{CsF + 8.34\ (1-F.Q.)}{1 + CsF\ (.0459)} + \frac{(.349)\ F.Q.\ Pa}{Ta\ \ Za} \qquad (1)$$

FOAM FRAC DESIGN

Because of the many well variables, it is important that each foam fracturing job be individually designed. To get the maximum benefits of foam, the proper ratio of gas to liquid must be determined.

To allow for the effect of sand concentration, flow rate calculations for both the base liquid and nitrogen should be made for each different concentration of sand to be used. Equation 2 can be used to determine the actual flow rate of the liquid.

$$Qw = (1-FQ)\left[Qt - Qt\ (.0459)\ CsF\right] \qquad (2)$$

The nitrogen flow rate in scf/min should be calculated using the results from equation 2. Equation 3 gives the flow rate of the sand-liquid slurry. Once the slurry flow rate is known, the concentration of sand in the liquid phase at the blender can be calculated using equation 4.

$$Qs = Qw + \left[Qt\ (CsF)\ (.0459)\right] \qquad (3)$$

$$CsW = \frac{(Qt)(CsF)}{Qs} \qquad (4)$$

When determining surface treating pressures for a foam frac treatment, equation 1 can be used to calculate hydrostatic pressure exerted by the foam as sand concentrations are increased.

NOMENCLATURE

FQ - Foam Quality
Qt - Total Flow Rate - BPM
Qw - Water Injection Rate - BPM
Qs - Slurry Flow Rate - BPM
CsF - Sand Concentration Foam - lb/gal
CsW - Sand Concentration Water - lb/gal
Pa - Average Pressure - psi
Estimated surface pressure plus bottom hole pressure divided by 2.
Za - Average Compressibility Factor
Ta - Average Temperature - ^{o}R

CONCLUSIONS

1. The addition of sand to a fracturing foam can have a significant effect on the foam quality and hydrostatic pressure.

2. A properly designed foam fracturing job will show what adjustments should be made on the surface to maintain the desired downhole conditions as the sand concentration changes.

REFERENCES

1. BJ-Hughes, Inc. Foam Frac. Houston, Texas (1980)
2. Smith, Michael A., and Holcomb, David L. "Foamed Hydrocarbons: An Effective and Economical Alternative to Conventional Stimulation Methods", Proceedings of the Twenty-sixth Annual Meeting, Texas Tech University, Lubbock, Texas (April 1979), p. 67

ADDITIONAL REFERENCES

1. Blauer, R.E., and Holcomb, D.L. "Foam-Fracturing-Application and History" Proceedings of the Twenty-second Annual Meeting, Texas Tech University, Lubbock, Texas (April 1975).
2. Blauer, R.E., and Kohlhaas, C.A. "Formation Fracturing with Foam" paper SPE 5003 presented at SPE 49th Annual Fall Meeting, Houston, Texas (October 6-9, 1974).

TABLE I

LIQUID FLOW RATE BPM	SAND CONCENTRATION IN FOAM LBS/GAL	SAND RATE LBS/MIN	SAND CONCENTRATION AT BLENDER LBS/GAL	SLURRY FLOW RATE-BPM	NITROGEN FLOW RATE BPM	FOAM FLOW RATE BPM	FOAM QUALITY %
3	0	0	0	3	7	10	70
2.541	1	420	3.33	3	7	10	73
2.082	2	840	6.67	3	7	10	77
1.623	3	1260	10.00	3	7	10	81

TABLE II

LIQUID FLOW RATE BPM	SAND CONCENTRATION IN FOAM LBS/GAL	SAND RATE LBS/MIN	SAND CONCENTRATION AT BLENDER LBS/GAL	SLURRY FLOW RATE-BPM	NITROGEN FLOW RATE BPM	FOAM FLOW RATE BPM	FOAM QUALITY %
3	0	0	0	3	7	10	70
2.541	1	420	3.33	3	5.929	8.929	70
2.082	2	840	6.67	3	4.858	7.858	70
1.623	3	1260	10.00	3	3.787	6.787	70

TABLE III

LIQUID FLOW RATE BPM	SAND CONCENTRATION IN FOAM LBS/GAL	SAND RATE LBS/MIN	SAND CONCENTRATION AT BLENDER LBS/GAL	SLURRY FLOW RATE-BPM	NITROGEN FLOW RATE BPM	FOAM FLOW RATE BPM	FOAM QUALITY %
3	0	0	0	3	7	10	70
3	1	420	2.89	3.459	7	10.459	70
3	2	840	5.10	3.918	7	10.918	70
3	3	1260	6.85	4.377	7	11.377	70

TABLE IV

LIQUID FLOW RATE BPM	SAND CONCENTRATION IN FOAM LBS/GAL	SAND RATE LBS/MIN	SAND CONCENTRATION AT BLENDER LBS/GAL	SLURRY FLOW RATE-BPM	NITROGEN FLOW RATE BPM	FOAM FLOW RATE BPM	FOAM QUALITY %
3	0	0	0	3	7	10	70
2.862	1	420	3.01	3.321	6.678	10	70
2.724	2	840	5.49	3.642	6.357	10	70
2.587	3	1260	7.56	3.964	6.036	10	70

FIGURE 1

TYPICAL EQUIPMENT SET UP FOR FOAM FRAC OPERATION

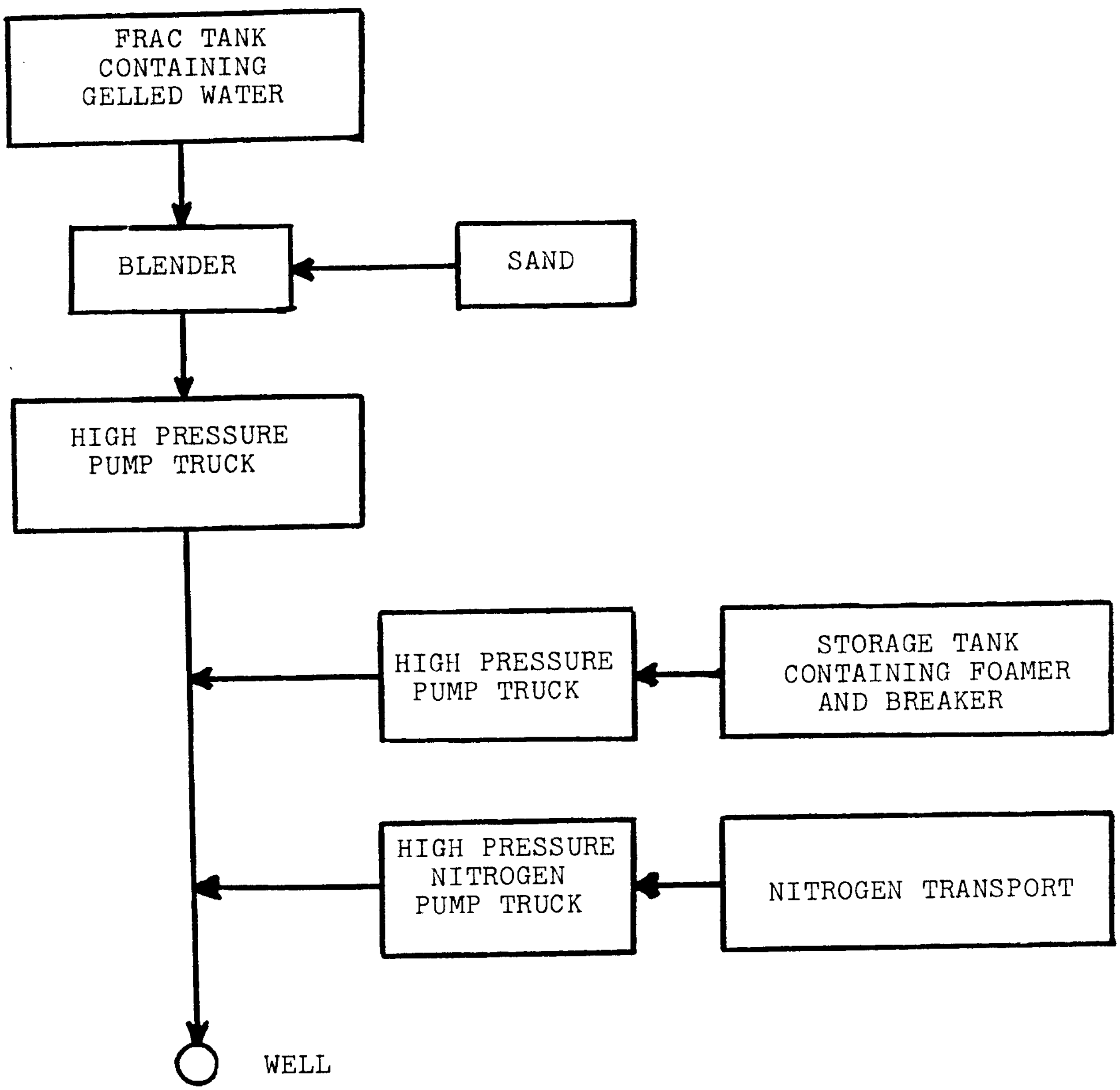

FIGURE 2

EFFECT OF SAND CONCENTRATION ON 65 QUALITY FOAM

FOAM QUALITY vs. SAND CONCENTRATION

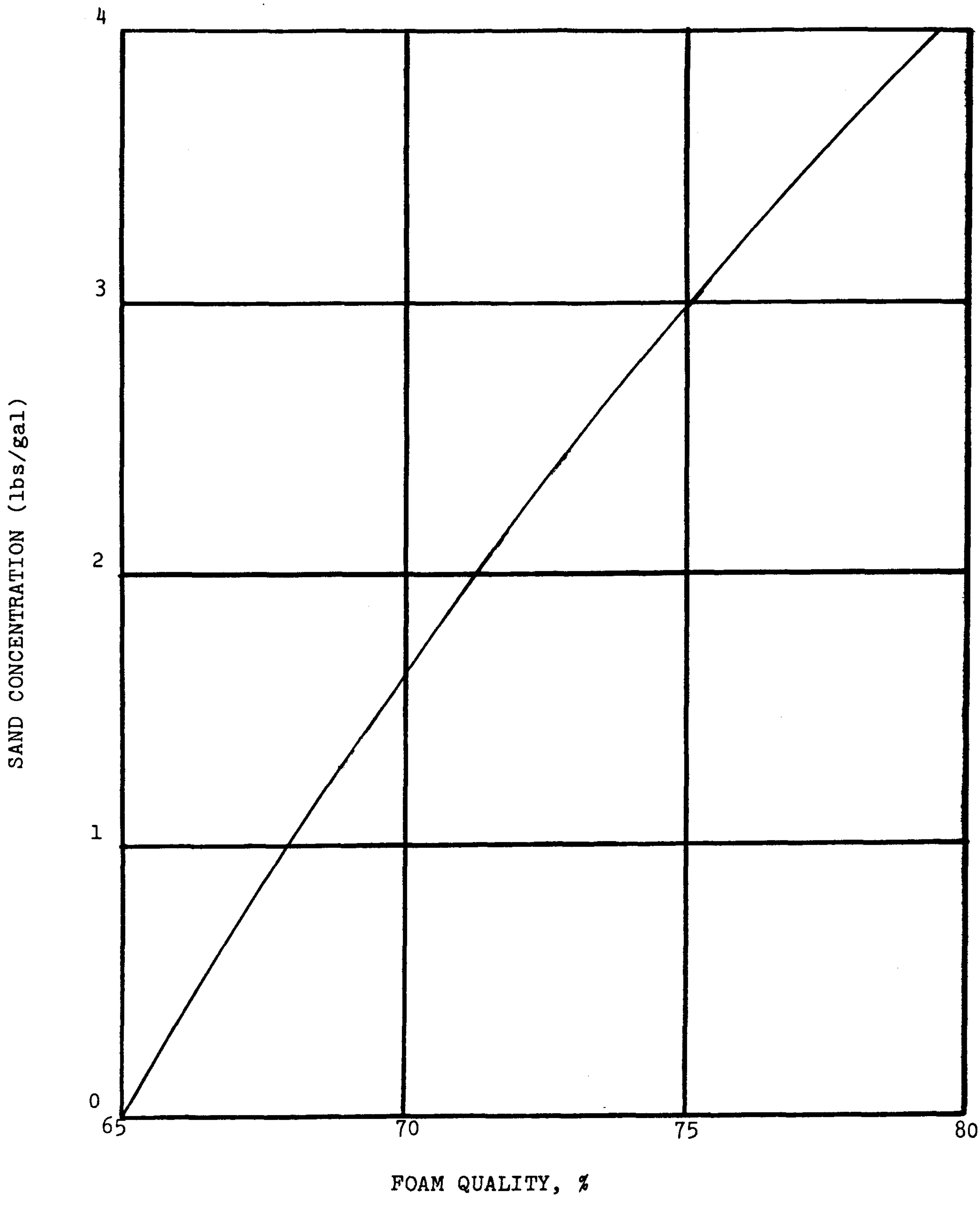

FIGURE 3

EFFECT OF SAND CONCENTRATION ON 70 QUALITY FOAM

FOAM QUALITY vs. SAND CONCENTRATION

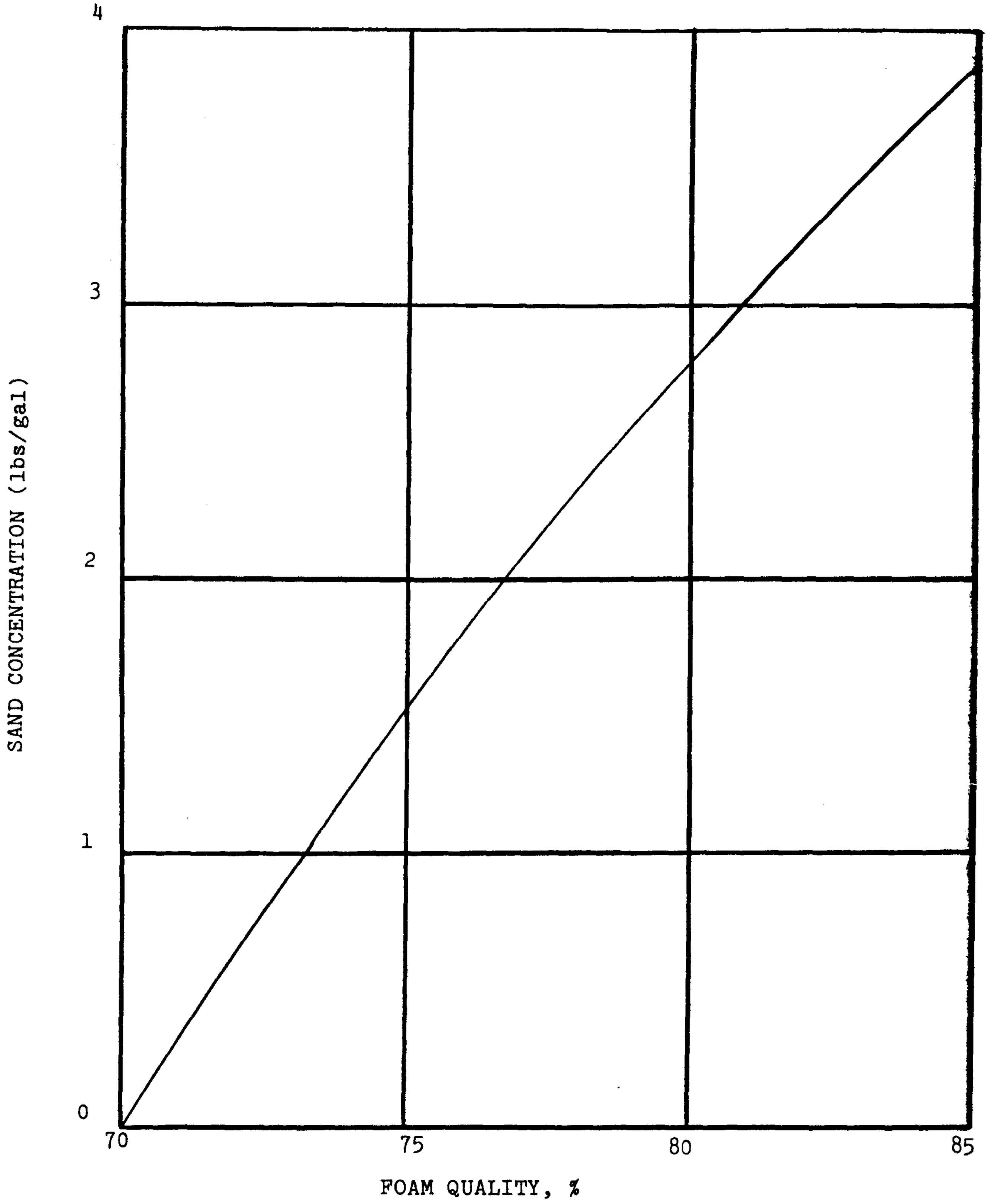

FIGURE 4

EFFECT OF SAND CONCENTRATION ON 75 QUALITY FOAM

FOAM QUALITY vs. SAND CONCENTRATION

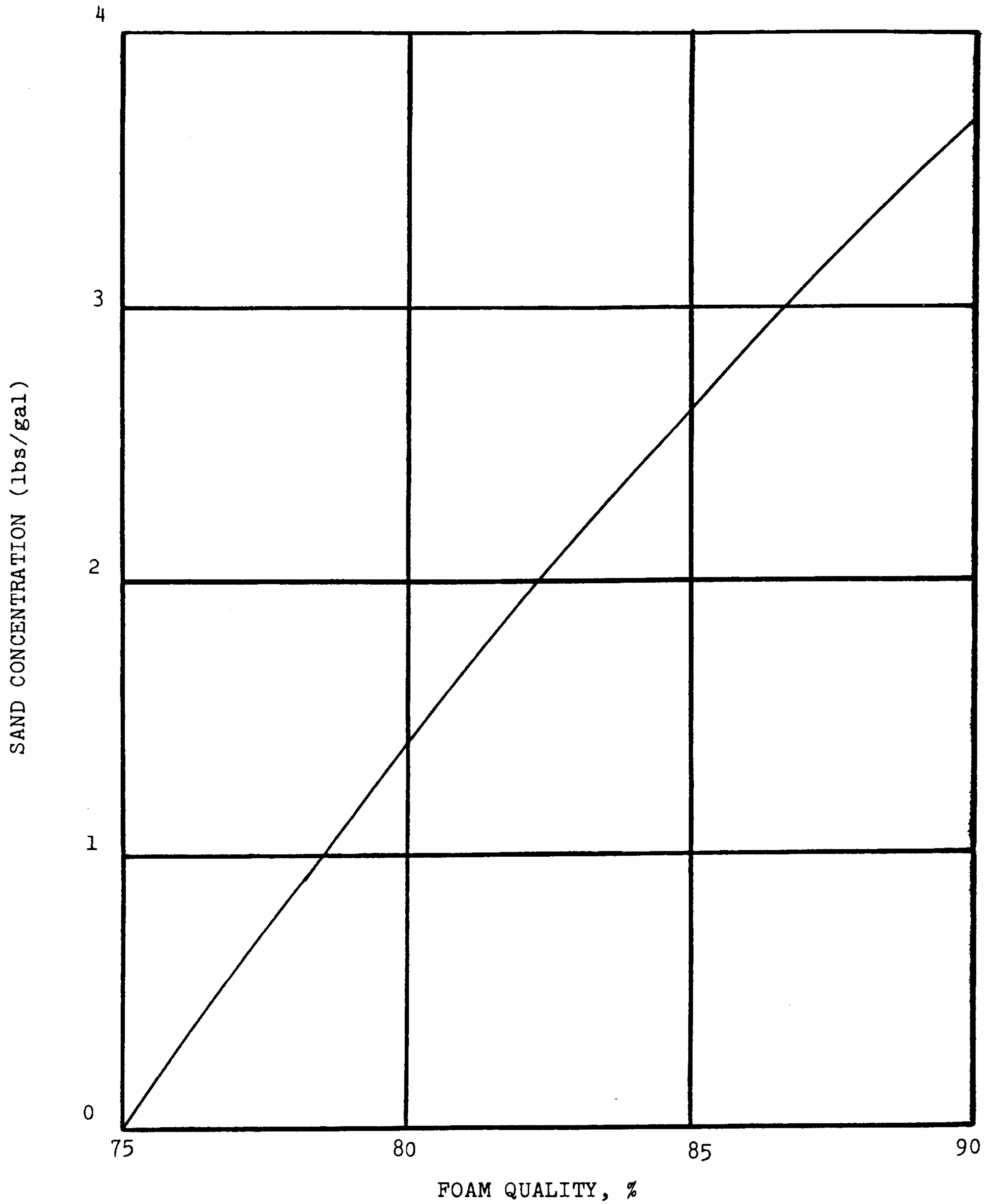

FIGURE 5

EFFECT OF SAND CONCENTRATION ON 80 QUALITY FOAM

FOAM QUALITY vs. SAND CONCENTRATION

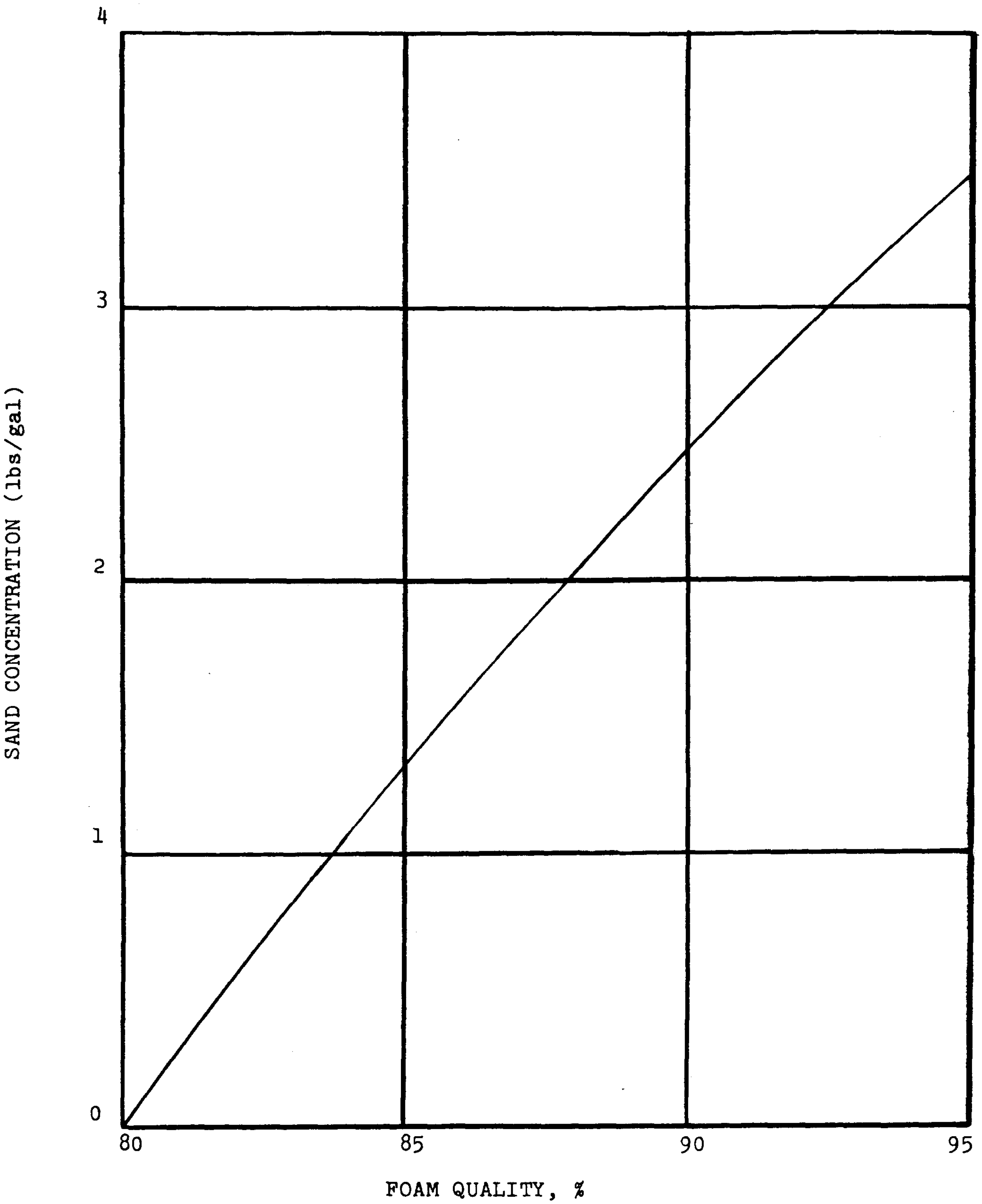

FIGURE 6 HYDROSTATIC PRESSURE vs. DEPTH

FOR A 75 QUALITY FOAM

(AS A FUNCTION OF AVERAGE PRESSURE-PA)

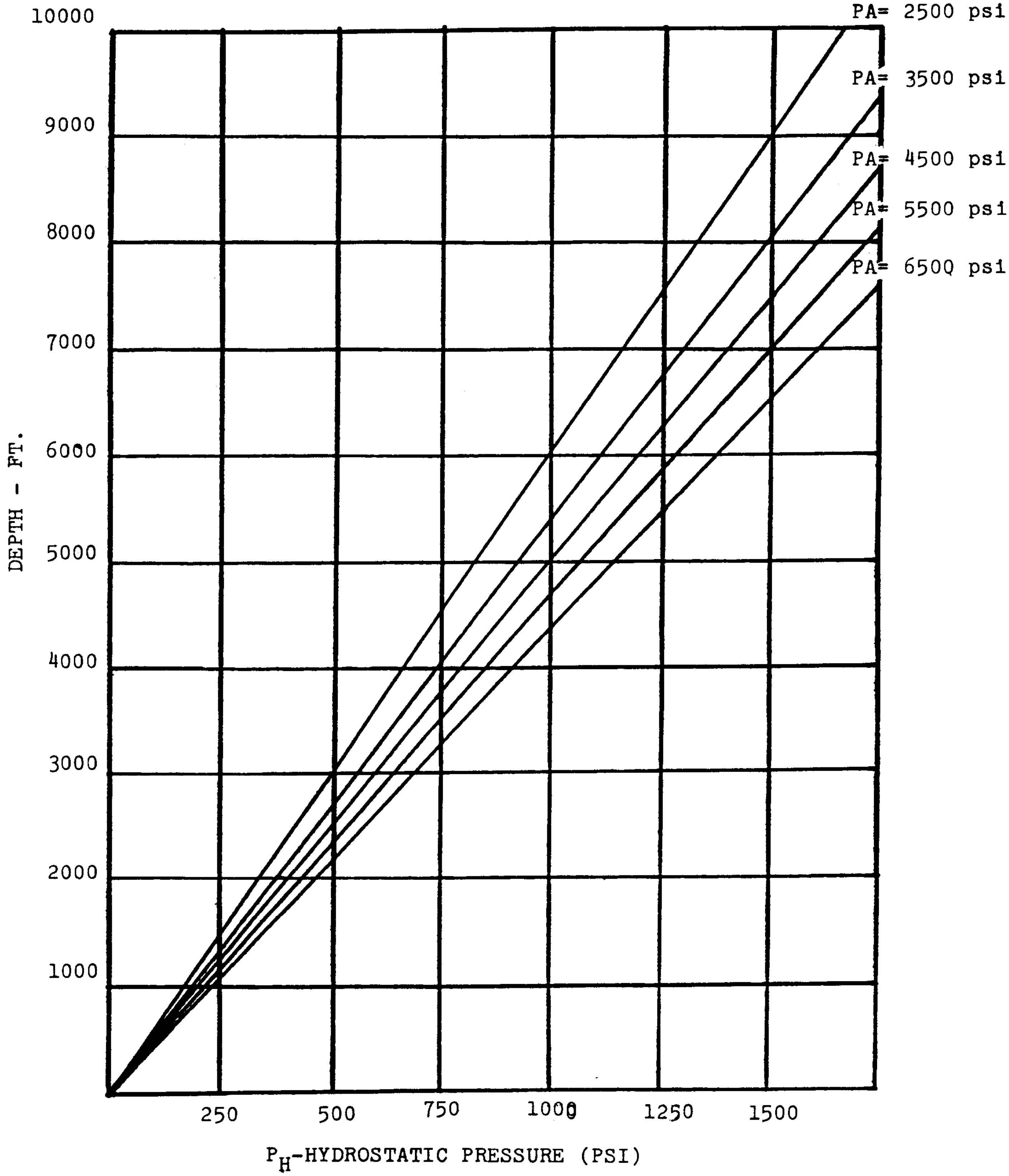

FIGURE 7 HYDROSTATIC PRESSURE vs. DEPTH

FOR A 75 QUALITY FOAM CONTAINING 1 lb/gal SAND

(AS A FUNCTION OF AVERAGE PRESSURE-PA)

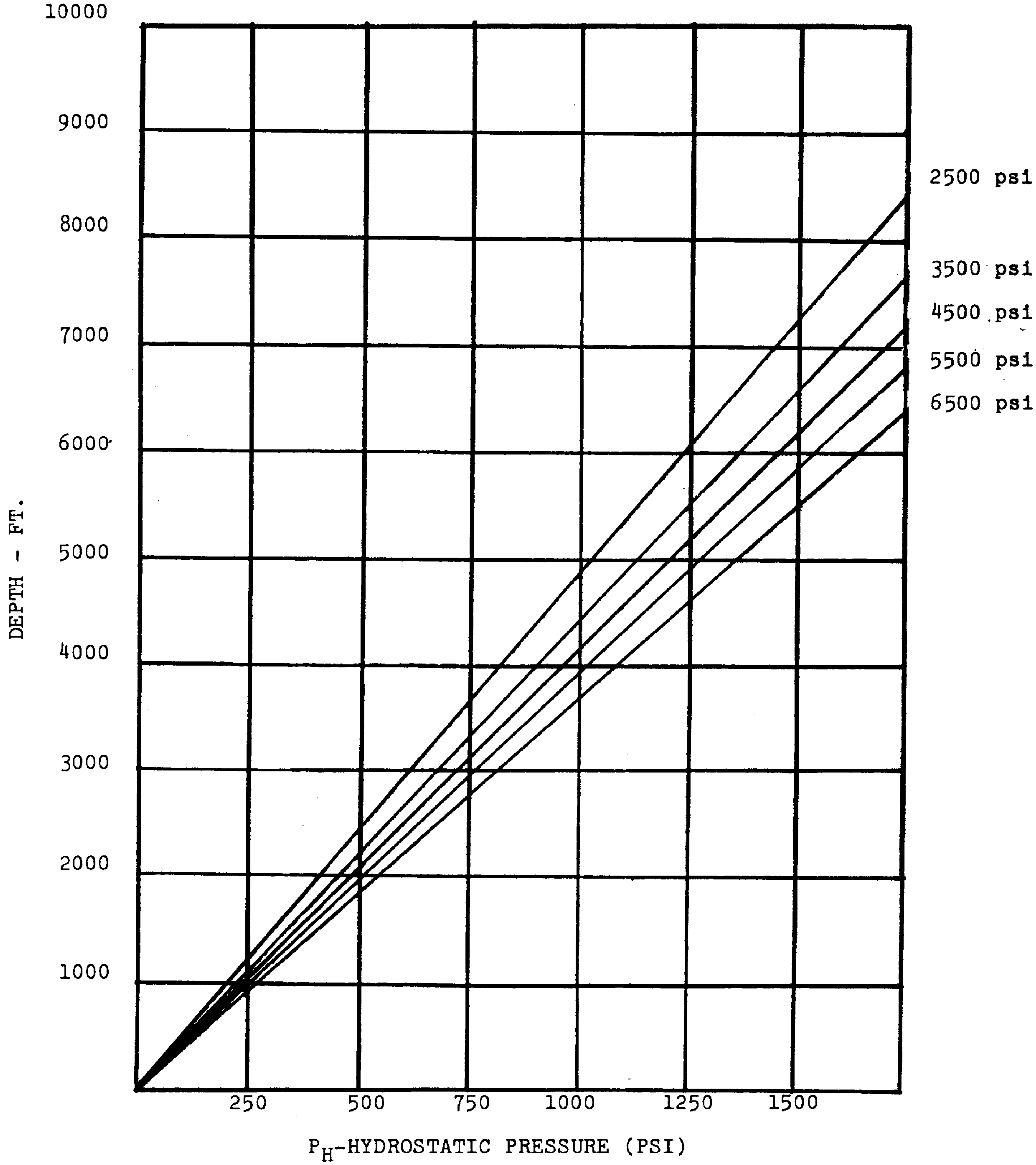

FIGURE 8 HYDROSTATIC PRESSURE vs. DEPTH

FOR A 75 QUALITY FOAM CONTAINING 2 lb/gal SAND

(AS A FUNCTION OF AVERAGE PRESSURE - PA)

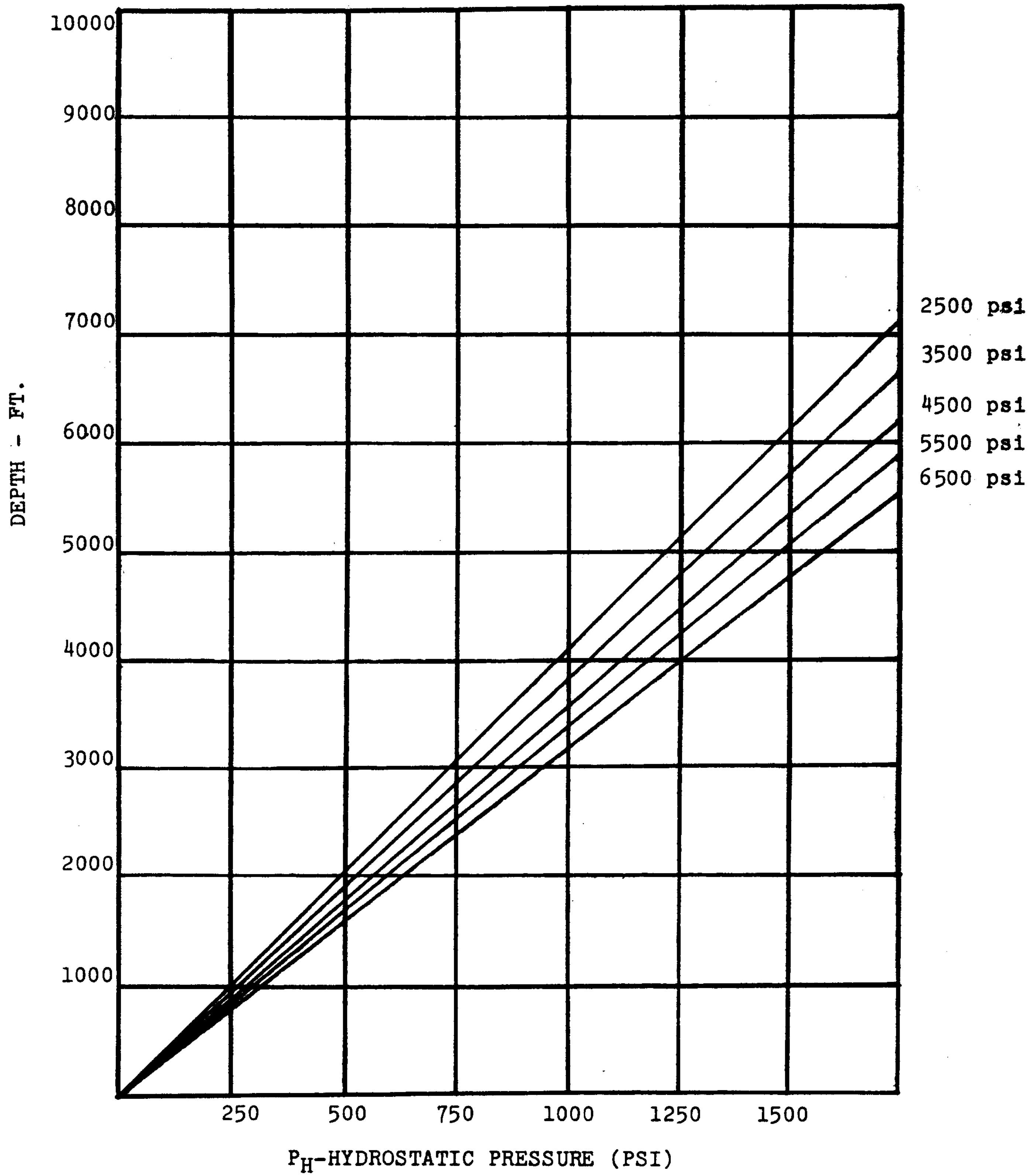

FIGURE 9 HYDROSTATIC PRESSURE vs. DEPTH

FOR A 75 QUALITY FOAM CONTAINING 3 lb/gal SAND

(AS A FUNCTION OF AVERAGE PRESSURE - PA)