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TECHNICAL NOTE 100-2

Predicting Hydrostatic Performance of Syntactic Foam

INTRODUCTION

All syntactic foams lose a portion of their buoyancy when subjected to hydrostatic pressure. Most of the initial loss is due to elastic compression. Most of the long-term loss is due to water absorption. This paper provides rules of thumb which are helpful in estimating these losses and predicting the performance of syntactic foam. Although materials may differ among various grades and manufacturers, these concepts apply equally well to all syntactic foam buoyancy products.

ELASTIC LOSS

Elastic buoyancy loss is caused by the syntactic foam compressing under hydrostatic pressure. The amount of compression is inversely proportional to the bulk modulus of the material, expressed as follows:

(1) V = 100(P/K)
where:
V = Percent change in volume, %.
P = Hydrostatic pressure, psi.
K = Bulk modulus, psi.

In most syntactic foams, the bulk modulus K is about the same as the elastic modulus E, and of such a value that volume compression at rated service pressure does not exceed 1.0% - 2.0%. This usually corresponds to a maximum service pressure equal to 65% - 75% of the crush pressure. Elastic compression in this range occurs immediately upon pressurization, remains constant throughout time under pressure, and recovers fully when pressure is removed. Volume strain approaching 3.0%, however, will cause the onset of cell collapse and permanent crushing.

WATER ABSORPTION

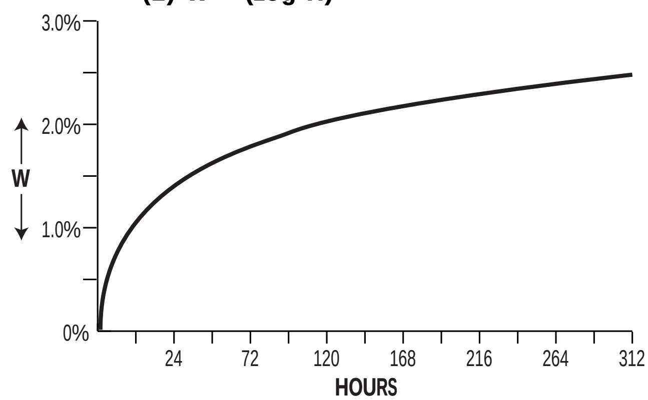
The surface of any syntactic foam float is covered with a multitude of tiny cracks and voids which gradually absorb water when exposed to hydrostatic pressure. The rate of water absorption diminishes with time in a way that can be described logarithmically, as follows:

(2) W = X(Log NH) + Y
where:
W = Percent weight gain, %.
N = Number of cycles to pressure.
H = Total no. of hours at rated service pressure.
X,Y = Dimensionless empirical constants.
Log = Logarithm to base 10.

For most materials, X = 1 and Y = 0. Setting N = 1, a typical plot of weight gain versus time at constant pressure can be plotted, as shown in Figure 1.

The weight gain and corresponding buoyancy loss resulting from water absorption is permanent and irreversible. Even if the syntactic foam is allowed to dry out and return to its original weight, the damage to the outer surface remains and will immediately fill with water upon pressurization.

Figure 1 WEIGHT GAIN vs. TIME
(2) W = (Log H)



PERFORMANCE AT DIFFERENT PRESSURES

Equation (2) is most often defined as behavior at *rated service pressure*, but it can be adapted to describe performance at other pressures by comparing the test pressure P to the crush pressure C (hydrostatic strength) of the syntactic foam as follows:

(3) R = 0.25/{1- (P/C)}
where:
R = Relative rate of water absorption.
P = Hydrostatic pressure, psi.
C = Crush pressure, psi.

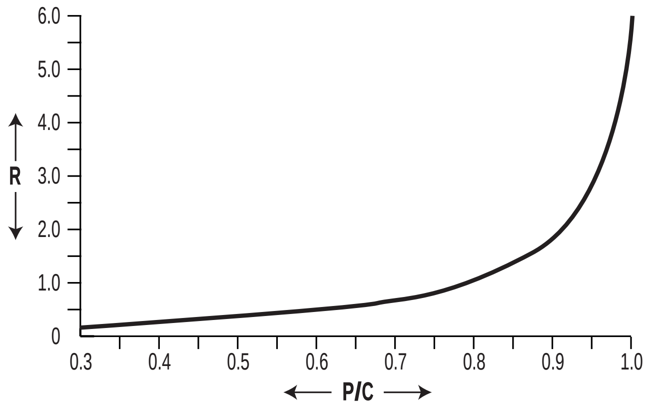
It will be seen that R= 1.0 when (P/C)= 0.75. We can now combine equations (2) and (3) to predict weight gain at different pressures. The following chart compares weight gain at rated service pressure versus lower and higher pressures:

Chart 1 WEIGHT GAIN AT CONSTANT PRESSURE

	Lower Pressure P/C = 0.65 R = 0.71	Rated Pressure P/C = 0.75 R = 1.0	Higher Pressure P/C = 0.85 R = 1.67
1 Day (24 hours)	0.98%	1.38%	2.30%
1 Week (168 hours)	1.59%	2.22%	3.71%
1 Month (720 hours)	2.04%	2.86%	4.76%
1 Year (8,760 hours)	2.82%	3.94%	6.57%
5 Years (43,800 hours)	3.32%	4.64%	7.74%

Equation (3) can also be used to compare actual test data taken at one pressure to predicted behavior at a different pressure, or to design an accelerated test program as shown in Paragraph 5. It should be noted, however, that at very high pressures ($P/C > 0.90$), syntactic foam behavior may become unstable and unpredictable. Figure 2 is a plot of the relative rate R of water absorption versus increasing pressure.

Figure 2 **WT. GAIN vs. PRESSURE**
(3) R = 0.25/{1-P/C)}



ACCELERATED TESTING

If adequate test data cannot be obtained, it may be desirable to perform accelerated testing. The long-term performance of syntactic foam can be simulated by a combination of higher pressure and/or cycling. Equation (4) relates equations (2) and (3) to permit the design of an accelerated test program:

(4) $P_1/C = 1 - \{(1 - P_2/C)\ (\text{Log } N_1H_1/\text{Log } N_2H_2)\}$

where:

- P_1 = Short-term pressure, psi.
- P_2 = Long-term pressure, psi.
- C = Crush pressure of syntactic foam, psi.
- N_1 = Short-term number of pressure cycles.
- N_2 = Long-term number of pressure cycles.
- H_1 = Total number of hours in short test.
- H_2 = Total number of hours in long test.

For example, equation (4) predicts that a one-cycle 100-hour test at 1,400 psi will simulate ten years of continuous service at 533 psi for a syntactic foam with a crush pressure of 2,000 psi.

EFFECTS OF HEAT

Like all plastics, syntactic foam suffers some degradation in physical properties at higher temperature. This is no problem in most marine applications, where the float is surrounded by cold sea water. But some designs may place the buoyancy material in contact with piping carrying hot fluids. Typical syntactics will lose 25% or more of their strength at 100 F, and at least 50% at 200 F, with corresponding increases in their water absorption rates.

AREA-TO-VOLUME RATIO

Weight gain per equation (2) is primarily a surface phenomenon. Therefore, the water absorption rate is influenced by the area-to-volume ratio of the float; large buoys will tend to perform better than small buoys because of their favorable A/V ratios. The effect can be estimated as follows:

(5) $W_2/W_1 = (A_2/V_2)\ /\ (A_1/V_1) = (V_1/V_2)$

Where:

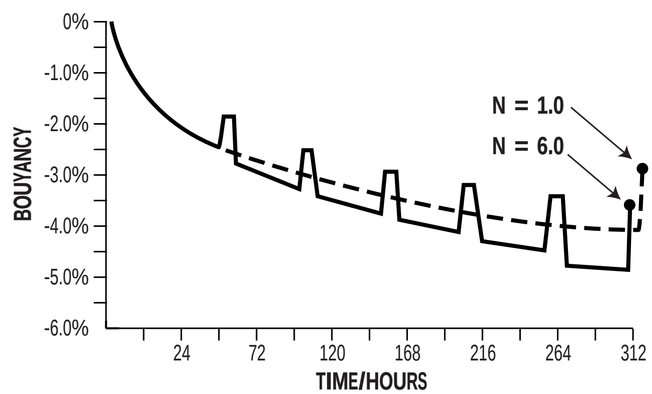
- A_1 = Surface area of smaller object
- V_1 = Volume of smaller object
- W_1 = Percent weight gain of smaller object
- A_2 = Surface-area of larger object
- V_2 = Volume of larger object
- W_2 = Percent weight gain of larger object

For example, if a large float were evaluated on the basis of testing of a small sample one-tenth its volume, then the percent absorptive loss of the large float may be expected to be one-half that shown by the small sample, assuming both to be of similar geometries.

EFFECTS OF PRESSURE CYCLING

Equation (2) has a term N for the number of cycles from atmospheric pressure to test pressure. This is because repeated pressure cycling has a fatigue effect on syntactic foam which increases the water uptake rate. The effect is illustrated in Figure 3:

Figure 3 **EFFECT OF PRESSURE CYCLES**
(2) W = (Log NH)



FURTHER APPLICATIONS

All of these predictions should be verified by manufacturer's data or by actual testing. Translating compression and weight gain into total buoyancy loss requires knowledge of the density of the syntactic foam. For further discussion, see Technical Note 100-3, "Syntactic Foam Material Selection and Depth Rating".

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