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Batteries from three manufacturers were divided into control and test groups. The test groups were modified to allow pressure compensation with white mineral oil. The performance of the test batteries was not degraded by exposure to the mineral oil or high pressure (10,000 psig). An average loss of capacity of 10% was experienced when the batteries were cycled cold (32°F) and at pressure (10,000 psig). However, this capacity loss is significantly less than the 35-70% loss experienced in previous tests with standard batteries in similar conditions. Thus, lead-acid batteries with gelled electrolyte were found to be suitable for use in deep ocean conditions in a pressure compensated mode.

Table of Contents

INTRODUCTION

Lead-acid batteries have traditionally been the major source of electrical power for deep ocean applications. They are readily available, reasonably priced and reliable in most situations. However, tests and experience with standard cells containing liquid electrolyte (H_2SO_4) have shown a marked degradation in performance when the ambient environment is both cold (near $0^{o}C$) and hyperbaric. It has been hypothesized that the electrolyte stratifies at low temperature because the high pressure eliminates the hydrogen gas bubbles which normally rise from the plates thereby forcing circulation of the electrolyte. Previous unpublished test results showed capacity losses of about 35% at 6000 psi and temperatures from $32\text{-}35^{o}F$. This capacity loss increased to as much as 70% when the batteries were allowed to stand in these deep ocean conditions for five days prior to discharge.

Recent commercial developments have allowed the production of lead-acid cells with the electrolyte in a gelled or paste form. Because of the gelled form of the electrolyte, it was believed that the electrolyte would not stratify, thus improving deep ocean lead-acid battery performance. The purpose of these tests was to establish the suitability and performance of gelled electrolyte batteries in a pressure compensated mode exposed to deep ocean conditions. If these batteries will perform in the test environment without experiencing major capacity losses, a reliabile power source that would not have to be contained within a pressure housing would be commercially available.

TEST PROCEDURE

To test the theory that gelled electrolyte lead-acid batteries could produce improved results for many deep ocean applications, six 6-volt batteries were procured from 3 commercial suppliers as representative examples of this class of battery. It is important to note that none of the selected batteries were designed for use under the conditions of these tests. Also their selection for these experiments does not imply a recommendation for their use for any application. The performance of these batteries is being determined to evaluate gelled electrolyte batteries only in a generic sense as compared to conventional liquid electrolyte batteries. It is not intended to evaluate performance of particular suppliers or to compare performance between suppliers.

The batteries from Globe-Union Inc. (2.6 AH), General Electric Co. (2.5 AH) and Gates Energy Products Inc. (2.5 AH) are shown in Figures 1, 2 and 3 respectively. As can be seen, the Globe battery is one integral unit while the others are a package containing three separable 2V cells.

One battery from each vendor was dissected to identify appropriate methods to provide pressure compensation. Small holes were drilled in the battery tops as shown in Figures 1-3 to allow complete flooding of the cells with compensating oil.

Five 6V batteries from each vendor were connected in series during the tests. These fifteen batteries were charge/discharge cycled at 1 atmosphere and approximately 70°F. The first discharge was for 2½ hours at 450 mA. This constituted about a 50% of rated capacity discharge. The second discharge was to a low battery cutoff voltage of 5.0V. As each battery reached cutoff voltage it was removed from the circuit. This pattern was repeated through six discharges (cycle 1-6) until the batteries had received three 50% discharges and three 100% discharges.

Each charge was started at the 250 mA rate and continued until a battery reached 7.5V. That battery was then removed from charge until all the batteries reached 7.5V at 250 mA. Then the batteries were placed back in the circuit at 100 mA and the current was continually tapered to keep the voltage of all cells at or below 7.5V until the current had been reduced to 30 mA. As each battery reached 7.5V at 30 mA it was removed and the taper charge continued until all batteries reached 7.5V at 30 mA. This charging procedure remained the same throughout the entire test series.

The capacities of the five batteries from each manufacturer were then checked. The highest capacity and the lowest capacity batteries from each manufacturer were arbitrarily selected as control batteries. The three middle capacity batteries from each manufacturer became the test batteries. The control batteries and test batteries were cycled again as a series connected assembly of 15 batteries. However, the six control batteries were operated at 1 atmosphere and approximately 70°F, while the test batteries were subjected to a variety of deep ocean conditions described below.

The most widely used fluid for compensating deep ocean batteries is white mineral oil (e.g. Marcol 70). This fluid was judged to be compatible with the construction of the gel cells and the gelled electrolyte. It was, therefore, chosen as the compensating medium for the remainder of these tests.

To determine effects of introducing mineral oil within the cells, six more cycles (7-12) were conducted in the same manner as the first six cycles except all of the test batteries were submerged in mineral oil at 1 atmosphere and 70°F. The control batteries were cycled in air.

To determine effects of pressure upon battery performance the test batteries were next cycled four times (13-16) while submerged in mineral oil at 10,000 psig and about 70°F. The pressure remained at 10,000 psig during charges and discharges.

Partial discharges, by definition, do not provide a measurement of battery capacity. Therefore, in order to increase the number of data points generated, all discharges while operating in the pressure vessel (beginning with cycle 13) were to low battery cutoff voltage for each battery. The control batteries were cycled simultaneously in air.

During the final four cycles (cycles 17-20) the test batteries were charged and discharged in oil at 10,000 psig and 32-35^{o}F. The control batteries were still at 1 atmosphere and 70^{o}F in air. Prior to the second discharge at low temperature (cycle 18) the test batteries were allowed to stand about 62 hours fully charged at 10,000 psig and 32^{o}F. During the other five cycles the stands between the end of charge and start of discharge were less than 16 hours.

TEST RESULTS

The average capacities discharged from the control batteries and test batteries for each cycle are shown in Figures 4-6. (Data from individual batteries are shown in Appendix A.) As previously noted, cycles 1, 3, 5, 7, 9, and 11 were partial discharges. Since full battery capacity was not measured these cycles were not used as data points for the following analysis. At the end of the sixth cycle the highest and lowest capacity batteries from each vendor were chosen to be control batteries. The other three were designated as test batteries.

The mean capacity for the test batteries from each supplier was the average of the full discharge capacities for all three test batteries during all three full discharges conducted from cycles 1-6 (nine data points). Similarly, the mean of the two control batteries was calculated for each supplier's batteries from the three complete discharges conducted from cycles 1-6 (six data points). A statistical check (using Student t distribution) showed there was no significant difference between the mean capacities (at 1 atmosphere and 70^{o}F) of the control (M_C) and test batteries (M_T) from General Electric and Gates at a significance level of 0.1. That is, the null hypothesis that $M_T - M_C = 0$ was found to be true at that significance level. However, the batteries chosen from Globe for control batteries had a mean capacity significantly higher than the test batteries, and thus the null hypothesis was rejected. A more complete description of the statistical analysis is given in Appendix B. The mean capacities are shown for each vendor in Table 1 below and also in cycles 1-6 of Figures 4, 5 and 6.

Table 1.

Mean Battery Capacities (AH) for Cycles 1-6
(1 atmosphere, 70^{o}F, in air)

	Globe	General Electric	Gates
Control Batteries (M_C)	1.58	1.78	2.08
Test Batteries (M_T)	1.47	1.79	2.11
$M_T - M_C$	-0.11	+.01	+.03
Null Hypothesis: $M_T - M_C = 0$	reject	accept	accept

In order to evaluate effects on battery capacity caused by the compensating oil, the mean capacities of the test batteries and the control batteries for cycles 7-12 were compared for changes from the previous six cycles. Any bias existing between the control batteries and test batteries during cycles 1-6 (e.g. the Globe batteries as previously discussed) was subtracted so that only significant changes in the relative mean capacities were evaluated. It was hypothesized that introducing the oil would have no significant effect, that is, after adjusting for bias, $M_T - M_C = 0$ at a significance level of 0.1. A summary of this analysis is shown in Table 2.

Table 2.

Mean Battery Capacities for Cycles 7-12
(1 atmosphere, 70^0F, test batteries in mineral oil)

	Globe	General Electric	Gates
M_C	1.48	1.22	1.77
M_T	1.42	1.49	2.00
$\Delta(M_T - M_C)$	0.05	0.27	0.20
Null Hypothesis: $\Delta(M_T - M_C) = 0$	accept	reject	reject

There was no significant change in the Globe batteries after the introduction of mineral oil, although there was a slight decrease in the magnitude of the difference between the test battery capacities and the control battery capacities ($M_T - M_C$). While this indicates a slight relative improvement with the addition of oil, it was not statistically significant. However, the test batteries from GE and Gates showed significant relative battery capacity improvements when operating in oil. Thus, the hypothesis that the oil had no effect was rejected for batteries from these two suppliers. (The compensating oil actually had a positive effect upon battery capacity.)

The test batteries were operated during cycles 13-16 at 10,000 psig submerged in mineral oil. Each battery was discharged to low voltage cutoff on every cycle (no partial discharges). Once again after subtracting the bias introduced by prior testing (cycles 7-12), relative changes in the mean capacities of the control batteries and test batteries were analyzed to determine pressure effects. (As before the hypothesis was no change in capacity would be caused by operating at pressure.) Table 3 shows the results of this analysis.

Table 3.

Mean Battery Capacities for Cycles 13-16
(10,000 psig, 70°F, test batteries in mineral oil)

	Globe	General Electric	Gates
M_C	1.56	1.13	1.60
M_T	1.49	1.37	1.93
$\Delta(M_T - M_C)$	-0.01	-0.03	0.10
Null Hypothesis: $\Delta(M_T - M_C) = 0$	accept	accept	accept

Thus, there was no statistically significant effect, at the 0.1 significance level, upon mean battery capacity caused by operating at 10,000 psig.

The final test performed involved cooling the pressure vessel and test batteries down to 32°F and cycling them cold at 10,000 psig. The same statistical tests were performed to determine the validity of the hypothesis that no significant relative change in the mean battery capacities would occur due to the cold ambient conditions. Table 4 shows the results of these tests.

Table 4.

Mean Battery Capacities (AH) for Cycles 17-20
(10,000 psig, 32°F, in mineral oil)

	Globe	General Electric	Gates
M_C	1.49	0.88	1.36
M_T	1.23	1.06	1.46
$\Delta(M_T - M_C)$	-0.19	-0.06	-0.23
Null Hypothesis: $\Delta(M_T - M_C) = 0$	reject	accept	reject

By the same type of statistical analysis previously used, the hypothesis that low temperature did not affect battery capacity significantly was tested. For the General Electric batteries the hypothesis was accepted. Although there was some relative drop in the test batteries' capacities, it was not significant at the 0.1 level. However, the hypothesis was rejected for the Globe batteries and the Gates batteries as they showed significant capacity losses when operated cold. Even so, the capacity losses were still less than those previously measured with standard batteries. (Reference (1))

Prior to discharge #18 the test batteries stood cold at 10,000 psig for 62 hours. The average drop in capacity between the first discharge cold (#17) and the second discharge cold (#18), which was preceded by the long stand, was only 0.1 AH. Thus, the long stand while cold did not have a significant effect.

One other comment on the test data concerns the variation of battery performance between manufacturers. When Figures 4-6 are compared, it can be seen that the batteries aged in somewhat different manners. The Globe batteries started with the lowest initial capacity, but degraded very little throughout the test. The Globe batteries were among the highest in capacity at the end of the test. The General Electric batteries had good initial capacities which declined rapidly in early cycling and continued to drop throughout the tests. The Gates batteries had the highest initial capacities and maintained the highest capacities throughout most of the tests. However, the Gates batteries exhibited a greater than average loss of capacity (16%) during low temperature operations. Under these test conditions none of the batteries delivered their rated capacity of 2.5-2.6 AH. However, they were being discharged at approximately the 5-hour rate as opposed to the 20-hour rate upon which the nominal battery capacity ratings are based.

Previous data (reference (1)) concerning similar testing done with liquid electrolyte batteries indicated large capacity losses when the batteries were cycled at low temperature and high pressure. In those tests an average capacity degradation of 35% was noted. Comparing the gelled electrolyte test and control batteries (Table 4) shows that two of the three sets of test batteries were actually outperforming the control batteries even though the test batteries were operating at pressure and cold. This may be due to the small sample size (i.e., the test cells may have just been better cells and the small sample did not allow the cell quality variation to average out). However, if the mean capacity of test batteries, shown in Table 4, is compared with these capacities while warm, shown in Table 3, it can be seen that the test batteries experienced a noticeable drop in capacity when the temperature was reduced. When this drop in capacity is adjusted for normal capacity decline due to aging (estimated from control batteries) it represents about a 10% capacity degradation. Similar testing of standard lead-acid cells (reference (1)) indicated a capacity loss of about 35% occurred with the battery operated at 6000 psig and 33°F. This capacity degradation increased to a dramatic 70% loss when the batteries were allowed to stand charged for five days prior to discharge. Thus although, the gelled electrolyte lead-acid batteries are adversely affected when operating at reduced temperatures, the capacity loss is considerably less than for standard cells operating in the same environment.

CONCLUSIONS

Although the test data resulted from a statistically small sample, the general consistency of results for cells from different vendors and the reaffirmation of lead-acid battery historical effects (e.g. neither mineral oil nor pressure affect their capacity) supports the conclusions drawn here. Thus, concerning the suitability of lead-acid gel cells for deep ocean applications it is concluded that:

1. Commercially available lead-acid gelled electrolyte batteries can be modified to compensate them internally for operation at high pressure.

2. White mineral oil provides a suitable compensating fluid with no adverse effects upon battery performance. In fact, some batteries may exhibit slightly improved performance when submerged in mineral oil.

3. Operating at high ambient pressures (10,000 psig) has no significant effect upon battery performance.

4. Operating at reduced ambient temperatures ($32^{o}F$) and high pressure simultaneously can cause a reduction in available battery capacity.

5. The capacity drop for the gelled electrolyte batteries when operated cold and at pressure is considerably less than the loss experienced with standard cells. (10% capacity loss as compared to 35% loss for these tests.)

6. Long stands (62 hours as compared to 16 hours) at reduced temperatures do not cause a further reduction in battery capacity for gelled electrolyte batteries.

7. Under the special test conditions described in this report, the performance characteristics of gelled electrolyte lead-acid batteries varied appreciably between manufacturers.

ACKNOWLEDGEMENTS

The assistance of Mr. L.W. Tucker and Mr. F.J. Potter was invaluable in conducting these tests and in analyzing the data.

REFERENCE

1. Unpublished data from CEL tests, 1972.

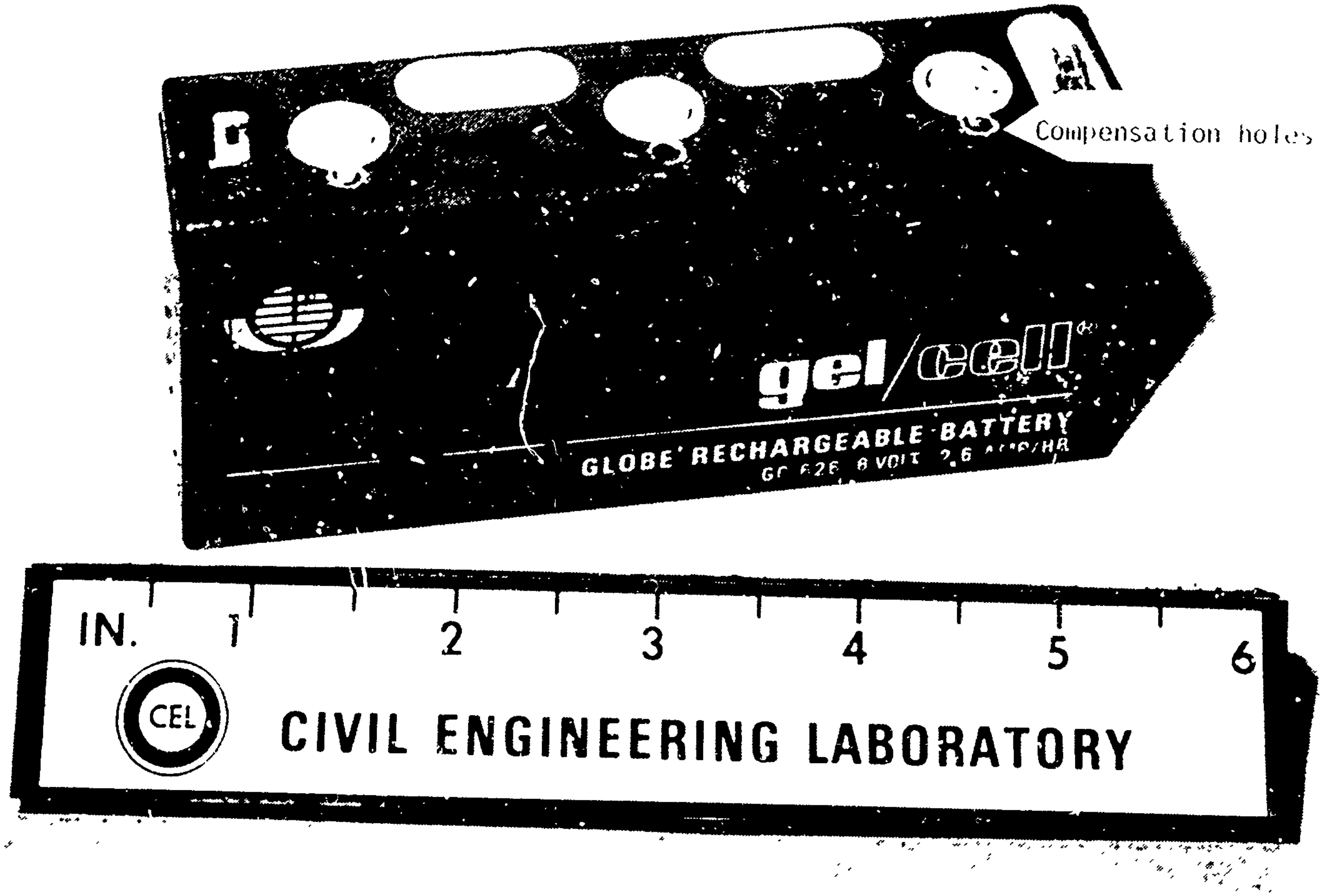

Figure 1. Globe Battery.

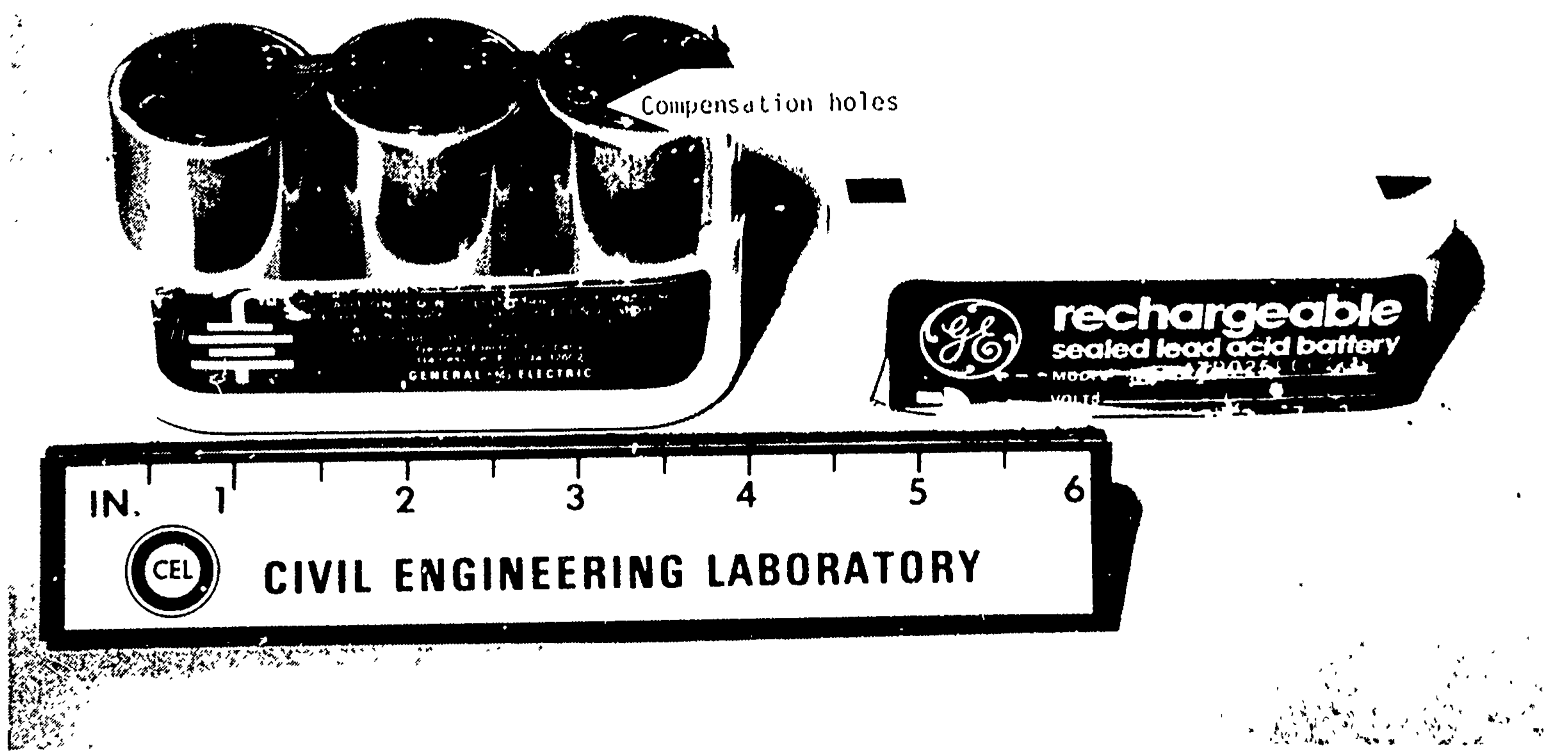

Figure 2. General Electric Battery.

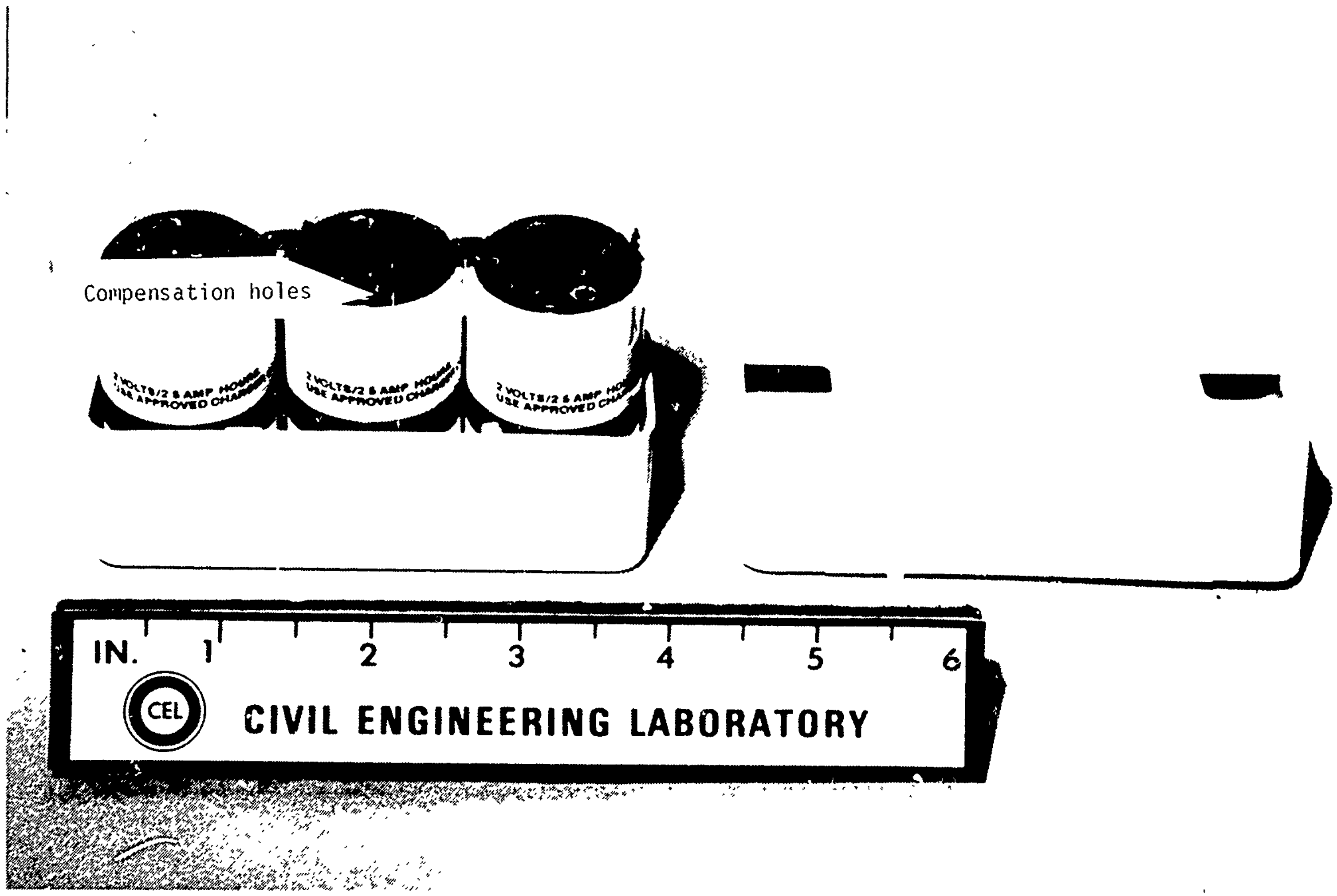

Figure 3. Gates Battery.

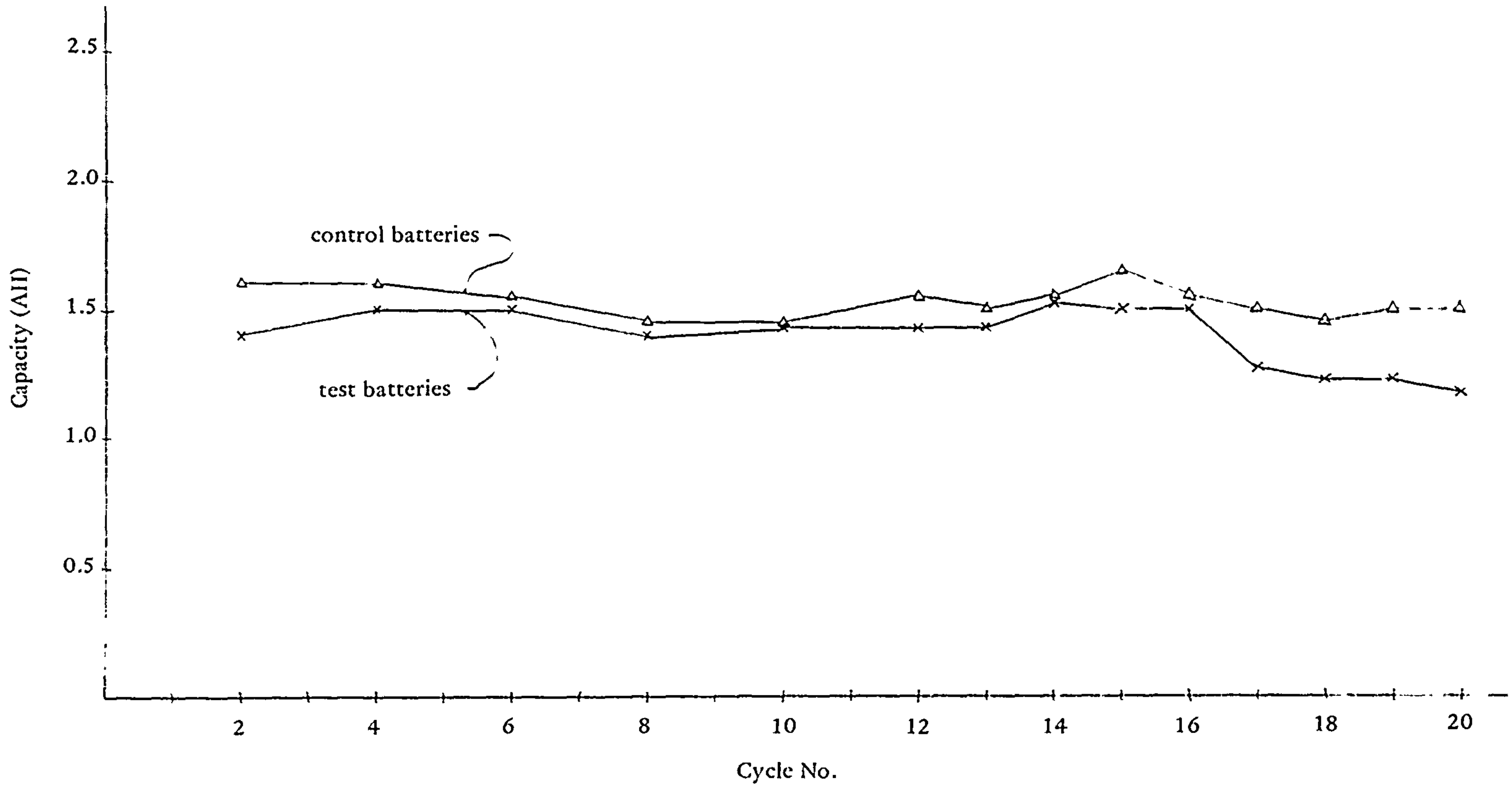

Figure 4. Average Capacities of Globe Batteries.

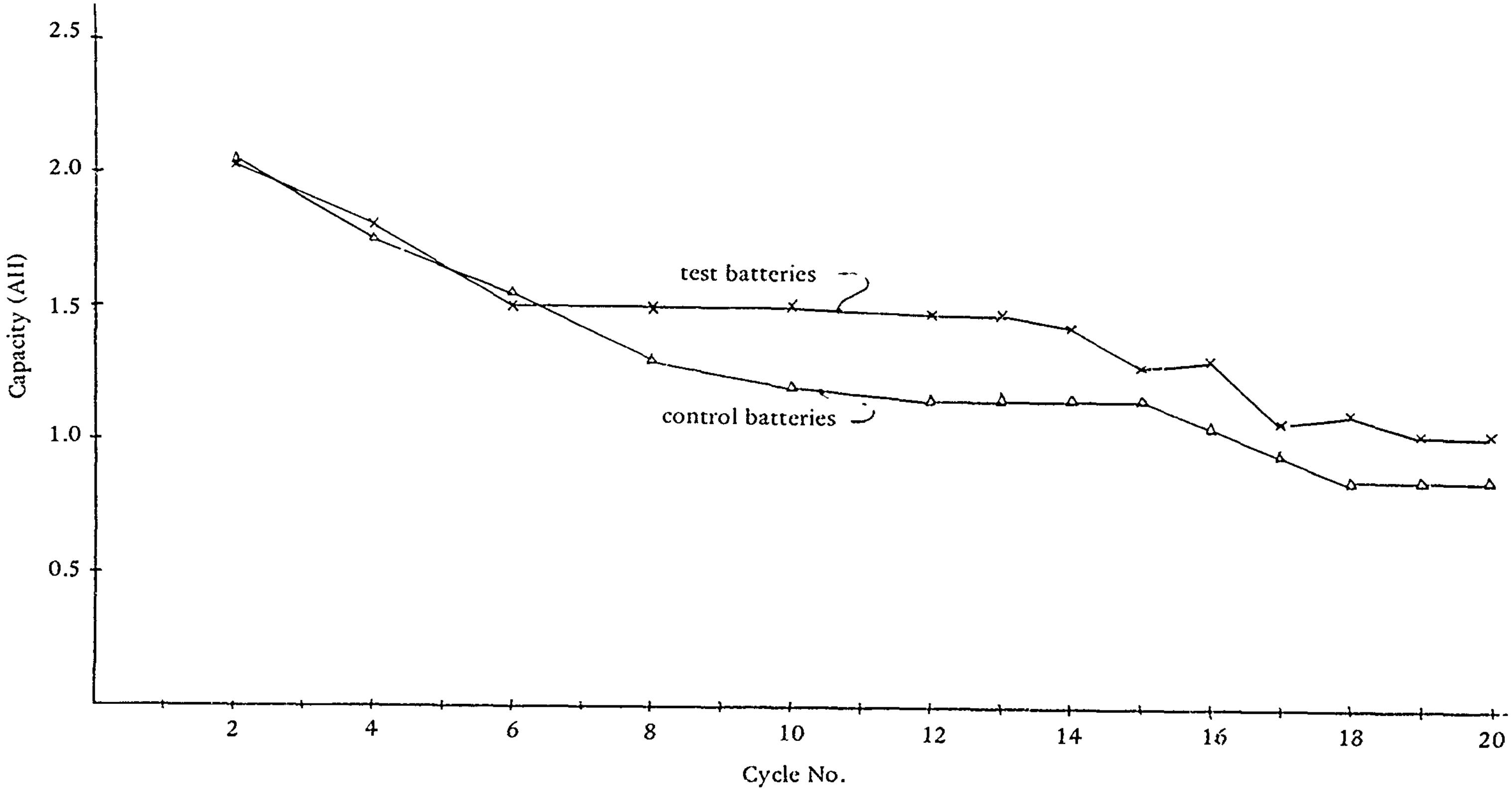

Figure 5. Average Capaci--s of General Electric Batteries.

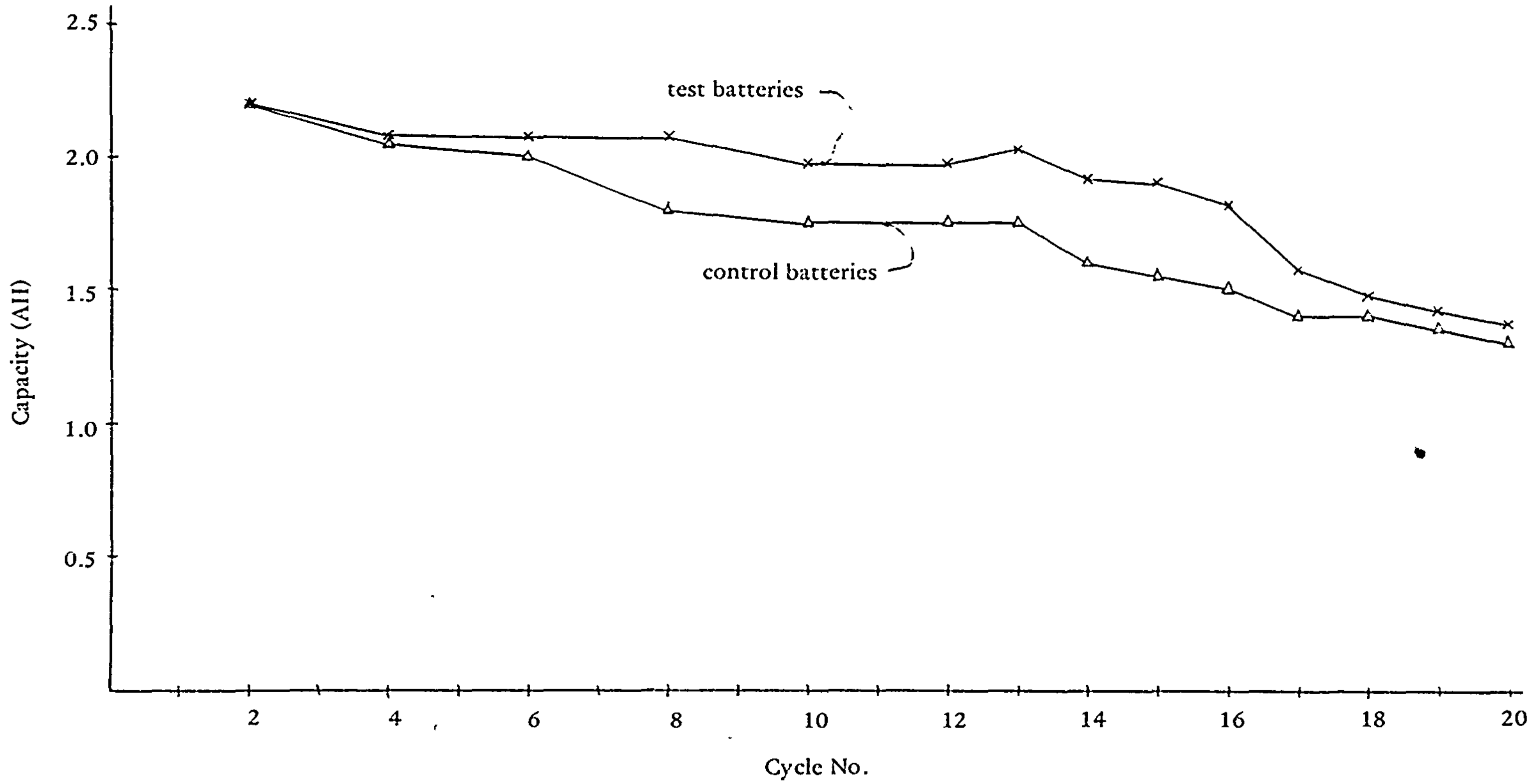

Figure 6. Average Capacities of Gates Batteries.

Appendix A. Individual Battery Capacities.

Test Environment		Air, 1 atm, 70°F						Mineral Oil, 1 atm, 70°F						Mineral Oil, 10,000 psig, 70°F				Mineral Oil, 10,000 psig, 32°F					
Cell Type and No.	Cycle No.	1*	2	3*	4	5*	6	7*	8	9*	10	11*	12	13	14	15	16	17	18	19	20	Total	
Globe	0	1.2	1.4	1.0	1.5	1.0	1.5	1.1	1.4	1.0	1.4	1.0	1.4	1.4	1.5	1.5	1.5	1.2	1.2	1.2	1.2	24.4	Test Battery
	1	1.2	1.4	1.0	1.5	1.0	1.5	1.1	1.4	1.0	1.5	1.0	1.5	1.5	1.6	1.5	1.5	1.3	1.3	1.3	1.2	26.3	Test
	2	0.9	1.4	1.0	1.5	1.0	1.5	1.1	1.4	1.0	1.4	1.0	1.4	1.4	1.5	1.5	1.5	1.3	1.2	1.2	1.1	25.3	Test
	3	1.2	1.7	1.0	1.5	1.0	1.4	1.1	1.3	1.0	1.3	1.0	1.4	1.3	1.4	1.5	1.4	1.3	1.3	1.4	1.4	25.9	Control
	4	1.2	1.5	1.0	1.7	1.0	1.7	1.1	1.6	1.0	1.6	1.0	1.7	1.7	1.7	1.8	1.7	1.7	1.6	1.6	1.6	29.5	Control
General Electric	5	1.2	2.2	1.0	1.9	1.0	1.7	1.1	1.4	1.0	1.3	1.0	1.2	1.2	1.2	1.2	1.1	1.0	0.9	0.9	0.9	24.4	Control
	6	1.2	2.1	1.0	1.8	1.0	1.6	1.1	1.5	1.0	1.5	1.0	1.5	1.5	1.5	1.3	1.5	1.1	1.3	1.2	1.2	26.9	Test
	7	1.2	2.0	1.0	1.8	1.0	1.4	1.1	1.5	1.0	1.5	1.0	1.4	1.4	1.4	1.2	1.2	1.0	1.0	0.9	0.9	24.9	Test
	8	1.2	2.0	1.0	1.8	1.0	1.5	1.1	1.5	1.0	1.5	1.0	1.5	1.5	1.4	1.3	1.2	1.1	1.0	1.0	1.0	25.6	Test
	9	1.2	1.9	1.0	1.6	1.0	1.4	1.1	1.2	1.0	1.1	1.0	1.1	1.1	1.1	1.1	1.0	0.9	0.8	0.8	0.8	22.2	Control
Gates	10	1.2	2.1	1.0	1.9	1.0	1.8	1.1	1.6	1.0	1.6	1.0	1.6	1.6	1.5	1.5	1.4	1.3	1.3	1.3	1.3	28.1	Control
	11	1.2	2.3	1.0	2.2	1.0	2.2	1.1	2.0	1.0	1.9	1.0	1.9	1.9	1.7	1.6	1.6	1.5	1.5	1.4	1.3	31.3	Control
	12	1.2	2.1	1.0	2.0	1.0	2.0	1.1	2.0	1.0	1.9	1.0	1.9	2.0	1.9	1.8	1.8	1.5	1.4	1.4	1.3	31.3	Test
	13	1.2	2.2	1.0	2.1	1.0	2.1	1.1	2.1	1.0	2.0	1.0	2.0	2.1	2.0	1.9	1.9	1.6	1.5	1.5	1.4	32.7	Test
	14	1.2	2.3	1.0	2.1	1.0	2.1	1.1	2.1	1.0	2.0	1.0	2.0	2.0	1.9	2.0	1.8	1.6	1.5	1.4	1.4	32.5	Test

* Indicates partial discharge

APPENDIX B

To analyze the data generated during tests of lead-acid batteries with gelled electrolyte, a methodology of statistical analysis was utilized. This methodology was intended to determine the effects of introduction of compensating fluid, operation at pressure and operation cold upon battery capacity through the use of standard statistical techniques.

The batteries (five from each of three different suppliers) first underwent a break-in period in air. As described in the report the batteries from each supplier were separated into three test batteries (exposed to the test environment) and two control batteries (operated in air). Furthermore, the batteries from each supplier were analyzed separately. The mean capacity for each group in air was estimated from the average capacities of the batteries during the first six cycles (three full discharges). Thus, the means were estimated as follows:

M_T = estimate of the mean of the test battery capacities

$$M_T = \frac{\sum_{j=1}^{3} \sum_{i=1}^{K} Xj,i}{3K}$$

and M_C = estimate of the mean of the control battery capacities

$$M_C = \frac{\sum_{j=1}^{2} \sum_{i=1}^{K} Yj,i}{2K}$$

where K = number of complete discharges during the test

Xj,i = the capacity measured for the jth test battery during the ith complete discharge

Yj,i = the capacity measured for the jth control battery during the ith complete discharge

The standard deviation of each group of data was also estimated as follows:

S_T = estimate of the standard deviation of the test battery capacities

$$S_T = \sqrt{\frac{\sum_{j=1}^{3} \sum_{i=1}^{K} (Xj,i - M_T)^2}{N_T - 1}}$$

and S_C = estimate of the standard deviation of the control battery capacities

$$S_C = \sqrt{\frac{\sum_{j=1}^{2} \sum_{i=1}^{K} (Y_{j,i} - M_C)^2}{N_C - 1}}$$

where N_T = number of data points from the test batteries = 3K

N_C = number of data points from the control batteries = 2K

The data was then analyzed to determine if a significant difference existed between the test group and the control group, and to determine any bias introduced by the arbitrary division of the batteries into two groups. It was hypothesized that there was no existing bias between the groups and their means would be essentially the same (i.e. $M_T - M_C = 0$).

Since the sample was small and the true standard deviation was not known, the Student t distribution was chosen as the most appropriate statistic with which to analyze the data. The standard error of the difference between two sample means can be estimated as follows according to reference (1):

S_D = estimate of the standard error of $M_T - M_C$

$$S_D = \sqrt{\frac{N_T S_T^2 + N_C S_C^2}{N_T + N_C - 2}} \quad \sqrt{\frac{N_T + N_C}{N_T \; N_C}}$$

Thus using the data and the t statistic with $N_T + N_C - 2$ degrees of freedom the difference between M_T and M_C can be checked for significance. The level of significance α was arbitrarily chosen to be 0.1 for this analysis. This means that the probability of accepting the "null hypothesis", $M_T - M_C = 0$, if it is in fact true, is $1-\alpha = 0.90$. This may be restated as the probability of rejecting the hypothesis when it is in fact true is $\alpha = 0.1$. From tables in reference (1) the value of the t statistic can be found ($t_{.1,13} = 1.771$). If the value of the t ratio $= \frac{M_T - M_C}{S_D}$ lies within the interval from -1.771 to +1.771 then the null hypothesis can be accepted. If the t ratio lies outside this range, then the null hypothesis can be rejected at a significance level of 0.1.

This analysis was conducted for the first test with both groups of batteries operating in air at about 70°F. The values of the various statistics and results of testing for each supplier's batteries is presented in Table B-I.

Table B-I.

(All batteries in air at 1 atmosphere and 70^{o}F) (Units in AH)

	Globe	General Electric	Gates
M_T	1.47	1.788	2.11
S_T	0.05	0.24	0.09
M_C	1.58	1.783	2.08
S_C	0.13	0.28	0.19
S_D	0.05	0.145	0.08
$M_T - M_C$	-0.11	.005	0.03
$t_{ratio} = \frac{M_T - M_C}{S_D}$	-2.20	0.03	0.37
$t_{.1,13}$	1.771	1.771	1.771
Null Hypothesis: $M_T - M_C = 0$	reject	accept	accept

The second test performed on the batteries was intended to determine any effects caused by allowing the test batteries to flood with mineral oil for the purpose of pressure compensation. Appropriate holes were drilled in the cell tops and the test batteries were submerged in mineral oil during cycles 7-12. The cycling was otherwise identical to cycles 1-6.

When analyzing the data from cycles 7-12 to determine the effects of introducing mineral oil into the cells, it is desirable to "subtract" any bias identified between the means of the test and control group during cycles 1-6. Therefore, prior to applying the test statistic to the difference between the estimated means, $M_T - M_C$, the difference between the means from the first test, $(M_T - M_C)^*$, was subtracted. Thus, the change in the relative difference between the means was analyzed to determine possible effects of introducing mineral oil. The null hypothesis for this test was $\Delta(M_T - M_C) = (M_T - M_C) - (M_T - M_C)^* = 0$. The results of this analysis are shown in Table B-II.

Table B-II.

(Test batteries submerged in oil at 1 atmosphere, $70^{O}F$) (Units are AH)

	Globe	General Electric	Gates
M_T	1.42	1.49	2.0
S_T	0.044	0.033	0.071
M_C	1.48	1.22	1.77
S_C	.172	0.117	0.186
S_D	.065	0.044	0.079
$M_T - M_C$	-.06	0.27	0.23
$\Delta(M_T - M_C) = (M_T - M_C) - (M_T - M_C)^*$	.05	0.265	0.20
$t_{ratio} = \frac{\Delta(M_T - M_C)}{S_D}$	0.769	5.98	2.70
$t_{.1,13}$	1.771	1.771	1.771
Null Hypothesis: $\Delta(M_T - M_C) = 20$	accept	reject	reject

During the third test conducted the test batteries were operated at an ambient pressure of 10,000 psig. Once again, it is desirable to analyze the changes in capacity caused by operating at pressure. Therefore the difference in the mean capacities during the previous test was subtracted from the difference estimated from the data of cycles 13-16. With bias introduced by operation to this point eliminated, the statistical analysis was conducted and the results are shown in Table B-III.

Table B-III

(Test batteries submerged in oil at 10,000 psig, 70^{O}F) (Units are AH)

	Globe	General Electric	Gates
M_T	1.49	1.37	1.92
S_T	0.051	0.123	0.097
M_C	1.56	1.12	1.60
S_C	0.185	0.071	0.151
S_D	0.019	0.060	0.058
$M_T - M_C$	-.07	0.25	0.33
$\Delta(M_T - M_C)$	-.01	-0.035	.095
$t_{ratio} = \frac{\Delta(M_T - M_C)}{S_D}$	-0.53	-0.42	1.63
$t_{.1,18}$	1.734	1.734	1.734
Null Hypothesis: $\Delta(M_T - M_C) = 0$	accept	accept	accept

The final test (cycles 17-20) was designed to determine the effect of low ambient temperature (32^{O}F) in combination with high ambient pressure (10,000 psig) upon battery capacity. In order to look just at the effects of this test the differences between the mean capacities of the test batteries and the control batteries from the previous test (cycles 13-16) were once aga`~ subtracted. The statistical analysis of the change in the difference ,f the sample means was repeated. The results are shown in Table B-IV.

Table IV.

(Test batteries submerged in oil at 10,000 psig, $32^{o}F$) (Units are AH)

	Globe	General Electric	Gates
M_T	1.22	1.06	1.46
S_T	0.062	0.124	0.090
M_C	1.49	0.88	1.36
S_C	0.155	0.071	0.092
S_D	0.053	0.051	0.044
$M_T - M_C$	-0.26	0.18	0.09
$\Delta(M_T - M_C)$	-0.19	-0.06	-0.23
$t_{ratio} = \dfrac{\Delta(M_T - M_C)}{S_D}$	-3.673	-1.217	-5.279
$t_{.1,18}$	1.734	1.734	1.734
Null Hypothesis: $\Delta(M_T - M_C) = 0$	reject	accept	reject

Reference (1): Statistics: Methods and Analysis by Lincoln L. Chao, McGraw-Hill, 1969.

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