

FIRST QUARTERLY REPORT

LOW TEMPERATURE BATTERY

by

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ABSTRACT

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The system, $\text{Mg/KSCN:NH}_3/\text{HgSO}_4\text{:S:C}$, has been studied in order to develop a primary cell with the capability of 72 hours operation at -90°C . Five methods of approach were developed from the original considerations. Method 1, the development of pasted-plate cathode construction, is the objective of the work covered by this report.

A maximum cell life of 117 hours was obtained at -90°C with a cathode comprising $\text{HgSO}_4\text{:S:C}$ in the ratio by weight of 5:1:3. Seven other HgSO_4/S cells ran for 71 or more hours.

Four S:C cells ran for periods ranging from 71 to 113 hours. The best one contained 87% sulfur and 15% carbon.

SUMMARY

In this program, experimental work was conducted in the pasted-plate or prismatic configuration to extend cell life at -90°C from the one day previously achieved to the goal of three days. Most of the cells contained only $1/5$ the required weight of oxidants; so the electrical loading was prorated to $1/5$ that of a full-sized cell. The peak anode current density was approximately 0.75 mA/cm^2 , except in special cases. An extensive investigation of the system, $\text{Mg/KSCN:NH}_3/\text{HgSO}_4\text{:S:C}$, was carried out in the following areas:

Separation

Three kinds of separation were examined:

- (a) SM-91 polypropylene non-woven fabric, 0.005" thick per layer;
- (b) M-1365 acetate and cotton non-woven fabric, 0.004" thick per layer;
- (c) Microporous rubber, 0.030" thick per layer.

It was concluded that adequate separation can be obtained for use at -90°C with five layers of the M-1365 fabric, as demonstrated by one cell that ran for 93 hours.

Electrolyte Volume and Level

Some excess electrolyte (34 weight percent KSCN) is desirable, but the level should not extend above the electrode connections. Most cells require about 100 cc, but the optimum amount is subject to some variation in the dimensions of the plastic envelope cell containers. Longer anode and cathode collector tabs for the electrical connections have been adopted to prevent the problem.

Cathode Collector Materials

The base material was expanded copper, designated by the Exmet Corporation as "20 Cu 30-2/0." It was used in three forms:

- (a) As received;
- (b) Silver plated, followed by cutting to size;
- (c) Silver plated after having been cut to size.

In general, the longest cell life was obtained by the use of form (c) in which the copper was completely masked by silver.

Cathode Composition

The relative proportions of HgSO_4 and sulfur were varied over a wide range from 100% HgSO_4 to 100% sulfur, while maintaining a constant weight of graphite and the same cathode thickness (approximately 1/8 inch). The data indicate the probability of achieving 72-hour performance at -90°C from any of the cathodes tested, with the possible exception of those containing no sulfur.

The results of a series of cell tests in which the weight ratio of sulfur to carbon was varied indicate that a ratio of S:C in excess of 1:1 would be best. At a ratio of 5.7:1, the cell life was 113 hours.

Cathode Plate Thickness

In order to simulate full cell capacity, the cathode weight and thickness and the electrical loading were increased five-fold. One cell ran 38 hours; the other, only 20 hours. Failure was due in part to insufficient electrolyte. However, it is believed that the resultant high anode current density contributed to failure through anode polarization.

Transition from Pasted-Plate to Bobbin Cell Structure

In order to preview the effects of single-sided discharge in a bobbin structure, a pasted-plate cell was built having three plates: one cathode with an anode on each side thereof. One anode was used for reference measurements only; the other, for discharge only. Therefore, the anode current density was twice that of a cell discharged with two anodes. The cut-off voltage of 1.3 was reached in only 15 hours, after which current-voltage polarization scans were made. An analysis of the scans and reference readings indicated that failure was due to anode film blocking.

Magnesium Anode Corrosion Losses

The percentage of the total anode weight losses due to corrosion increased sharply as the proportion of HgSO_4 was increased in HgSO_4 :S cathodes. It increased from 11% in the absence of HgSO_4 to 59% with a cathode containing a 1:1 mol ratio of HgSO_4 and sulfur.

Conclusions

Considerable success in meeting the goal of 72 hours was achieved during the first three months of this program. Of the fifty cells tested, eight HgSO_4 :S:C cells performed at -90°C under cyclic loading to the 1.3 volt cut-off for periods ranging from 71 to 117 hours, while four S:C cells ran under the same conditions for periods of from 71 to 113 hours.

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1. Introduction

The purpose of this program is the development of a low temperature cell with the capability of delivering 1.5 watts for six minutes and 0.3 watts for fifty-four minutes each hour for a minimum of 72 hours. The first task is to develop methods of extending performance at -90°C from the one day previously achieved in Contract NAS 3-6009 to at least three days. In that contract, it was found that the system $\text{Mg/KSCN:NH}_3/\text{HgSO}_4\text{:S:C}$ provided 27 hours to a cut-off of 1.3 volts in a conventional bobbin cell (No. T-119) and 13 hours under the full cyclic load in a pasted-plate cell (T-132) which featured large cathode area but only $1/5$ the cathode weight.

During the first three months of this contract, the work was limited to studies of prismatic cells. The cyclic loads were prorated in proportion to cathode capacity, and numerous parameters were varied in order to establish the best conditions for long life. The test results are summarized and discussed in the following sections.

Supporting data for all cells are provided in Appendix A. In Appendix B, methods of cell construction, a drawing of a pasted plate cell and sample calculations are presented.

2. Recommended Methods for Extending Ammonia Cell Operation
at -90°C from One Day to the Goal of 72 Hours

The first task of this program includes a study and recommendation of methods for extending cell operation at -90°C from the one day previously achieved* to the goal of 72 hours. This study was made and the following five methods were submitted for consideration by the Project Manager:

Method 1 - The development of pasted-plate cathode construction.

Method 2 - The collection of basic data on the physical and physico-chemical properties of cell components. Resistance measurements, polarization scans, chemical analyses, microscopy, vapor pressures and calorimetric determinations would be considered.

Method 3 - The exploration of other electrolyte solutes in ammonia, other oxidants, ion exchange membranes and separators.

Method 4 - The modification of bobbin-type cathode construction.

Method 5 - The evolution of better approaches to the study of the influence of geometry on cell operation.

Initially, the contractor was authorized by the Project Manager to begin the experimental activities of the "Minus 90°C Study and Test" task through the use of Methods 1 and 4.

The other methods were considered to be relevant but of lower priority than 1 and 4.

* Contract NAS 3-6009

3. Initial Cell Tests at -90°C

It seemed logical that the cell life could be extended greatly in a pasted-plate configuration by either a five-fold increase in cathode weight under the same electrical loading or a reduction to 1/5 the full load. This reasoning was confirmed by the first two cells (Nos. P-1 and P-2, Table I) which ran an average of 61 hours to 1.3 volts under 1/5 the full cyclic load. It should be possible, therefore, to obtain almost full capacity by employing five similar cells in parallel or by using a single plate with five times the area.

The KSCN/NH₃ solution used in these initial cells was slightly cloudy and, when the temperature reached -92°C, ammonia ice crystals formed at the gas-liquid interface and a sediment accumulated at the bottom of the container. X-ray diffraction studies showed that the sediment contained about 50% KSCN, some sulfides and potassium sulfate.

X-ray analyses of the analytical grade of KSCN from Baker and Adamson and from Fisher Scientific Company showed no significant difference between the two.

Since both salts were used in subsequent experiments with no indications of cloudiness, freezing or sedimentation, it is believed that the initial solution was contaminated.

In order to increase the operating life to at least 72 hours, a variety of experiments were designed to study the effects of separation, electrolyte volume, cathode collector materials, cathode composition and plate thickness.

4. Separation

A summary of some of the separator tests is given in Table I.

TABLE I

Cathode: $\text{HgSO}_4\text{:S:C} = 5\text{:1:3}$.

Cell No. P-	Separator Thickness (inches)			Electrolyte Vol. (cc)	Ave. Hours* to 1.3 V
	SM-91(a)	M-1365(b)	MPR(c)		
1 & 2	0.010	-----	-----	120	61
3 & 4	0.005	-----	-----	120	28
5 & 6	0.010	-----	-----	150	43
7 & 8	-----	0.020	-----	150	46
9 & 10	-----	0.020	-----	125	53
11 & 12	-----	0.008	0.030	125	50
53	-----	-----	0.060	150	117**
42	-----	-----	0.060	150	40**
52	-----	0.020	-----	100	93

* Under heavy load (a) 0.005" thick/layer

** Sealed MPR at edges. (b) 0.004" thick/layer

(c) 0.030" thick/layer

The trial of a single (rather than a double) layer of SM-91 polypropylene fabric (Cells P3 & 4) reduced the life to 28 hours because of leakage at the seal and possibly through the fabric.

Cells 5 & 6, with a double layer of SM-91, should have run as well as 1 & 2. One reason for the inferior performance may be that the volume of electrolyte was too high. Other experiments (see Table II) have indicated that an excess of electrolyte is necessary but that its level should not extend above the electrical connections to the electrodes.

The M-1365 non-woven acetate and cotton separator absorbs the electrolyte very rapidly and is desirable for this reason. The table indicates a modest improvement through its use as the volume of electrolyte was reduced from 150 cc to 125 cc and an increase to 93 hours with only 100 cc of electrolyte.

Microporous rubber, when used alone and sealed at the edges with rubber cement, provided a long life of 117 hours in one test, but only 40 hours in another. The reason for the difference was not obvious.

As a result of these tests and observations in many other cases, it is believed that adequate separation can be secured for use at -90°C with five or more layers of the M-1365 Webril paper.

5. Electrolyte Volume and Level

Table II shows some of the effects of variations in the quantity of electrolyte.

TABLE II

Cathode: $\text{HgSO}_4\text{:S:C} = 5\text{:1:3}$

Separator: M-1365 Webril - 5 Layers at 0.004" each.

<u>Cell No.</u> <u>P-</u>	<u>Electrolyte</u> <u>Vol. (cc)</u>	<u>Hours to*</u> <u>1.3 V</u>
13	50	13
13	100	83**
14	100	75
52	100	93
9 & 10	125	53
7 & 8	150	46

* Under heavy load

* Added 50 cc after 24 hours.

In cell 13, with only 50 cc of electrolyte, the voltage under heavy load decreased in 13 hours to 1.3 volts, but it recovered fully when an additional 50 cc were added and ran to a cumulative total of 83 hours.

Cells 14 and 52 were activated with an initial quantity of 100 cc. They operated well for 75 and 93 hours, respectively.

Volumes of 125 and 150 cc yielded relatively poor results.

It is believed that a certain minimum quantity of electrolyte is required but that its level should not extend above the electrical connections. A slightly larger cell container may be advantageous in providing a safe excess of electrolyte at a lower level. Improvement or elimination of the connections is also being studied.

6. Cathode Collector Materials

Three types of collectors have been used in pasted-plate construction:

Silver-plated copper Exmet from which the grids were cut after plating. The copper that was exposed at the edges by cutting was coated with Krylon. Designated in Table III as "Cut Ag-plate."

Pure copper Exmet. Designated in Table III as "Copper."

Copper Exmet, silver-plated after trimming to size. Designated as "Uncut Ag-plate."

It is assumed that the third type is best because the blue color derived from copper was largely eliminated.

The test results of comparable groups of cells are given in Table III, and a tendency for longer life is observed with complete masking of the copper grids by silver, especially in the absence of HgSO_4 .

TABLE III

Cell No. P-	HgSO_4 (g)	S (g)	C (g)	Separator		Electrolyte Vol. (cc)	Collector	Average Hours* to 1.3 V
				Thickness (in.) M-1365	MPR			
11 & 12	20	4	12	.008	.030	125	Cut Ag-plate	50
15 & 16	20	4	12	.008	.030	100	Copper	57
45	20	4	12	.020	.030	100	Uncut Ag-plate	28
48	20	4	12	.020	.030	100	Copper	21
52	20	4	12	.020	0	100	Uncut Ag-plate	93
17	0	8.5	12	.008	.030	100	Cut Ag-plate	66
22	0	8.5	12	.008	.030	100	Cut Ag-plate	71
35	0	8.5	12	.020	.030	100	Uncut Ag-plate	67
41	0	8.5	12	.020	.030	100	Copper	50
49	0	8.5	12	.020	.030	100	Copper	51

* Under heavy load.

The pure copper collectors used in Nos. 15 and 16 gave better life than 11 and 12, due probably to the reduction in electrolyte volume and level. In all other tests, the silver-plated grids were superior to the pure copper Exmet. Therefore, silver-plated material or silver will be adopted because there seems to be no reason to consider silver to be inferior.

7. Cathode Composition

The composition of the cathode has been studied over a wide range while maintaining the volume and weight of graphite and the thickness of the pasted plates constant. The oxidants tested varied from 100 percent sulfur through four ratios of S:HgSO₄ to 100 percent mercuric sulfate. The results are presented in Section 7.1.

Section 7.2 demonstrates the effects of varying the ratio of sulfur to graphite. As above, the plate thickness was essentially the same in all cells, namely 1/8 inch.

7.1 Mol Ratio of Sulfur to Mercuric Sulfate

A summary of the effects of varying this ratio is presented in Table IV. The type and thickness of separation is shown, even though the changes do not appear to demonstrate uniform significance. The amount of electrolyte, or its level in the cells, may be important, as indicated by the results of cell tests 9 through 14. (See, also, Section 5, page 5.)

The data indicate the probability of achieving the 72 hour requirement at -90°C with any of the cathodes tested, with the possible exception of the one comprising 100 percent HgSO₄, the performance of which was very erratic and unpredictable. The degree of reproducibility was best in the case of 100% sulfur. It would have been desirable and probably most informative to establish the most effective ratio of oxidant to graphite for each combination of oxidants. An example of such a determination may be found in the following section, 7.2.

TABLE IV

Cell No P-	Mol Ratio S:HgSO ₄	Separator Thickness (in.)		Electrolyte Vol. (cc)	(Note 1) Max. Temp. °C	Hours to*		
		M-1365	MPR		1.5 V	1.3 V		
17	100% S	∞	.008	.030	100	---	53	66
22		∞	.008	.030	100	---	64	71
29		∞	.020	.030	100	-70	52	62
35		∞	.020	.030	100	---	<u>60</u>	<u>67</u>
					Average		<u>57</u>	<u>66</u>
18	4:1	.008	.008	.030	100	---	51	62
23	4:1	.008	.008	.030	100	---	42	50
30	4:1	.020	.020	.030	100	-70	52	67
36	4:1	.020	.020	.030	100	---	<u>70</u>	<u>78</u>
					Average		<u>54</u>	<u>64</u>
19	2:1	.008	.008	.030	100	---	44	50
28	2:1	.020	.020	.030	100	---	<u>72</u>	<u>83</u>
					Average		<u>58</u>	<u>66</u>
9 & 10	1.86:1	.020	---	---	125	---	46	53
11 & 12	1.86:1	.008	.008	.030	125	---	43	50
13 & 14	1.86:1	.020	---	---	100	---	<u>73</u>	<u>79</u>
					Average		<u>54</u>	<u>61</u>
20	1:1	.008	.008	.030	100	---	34	38
	Part of mix fell off grid during fabrication of No. 20							
25	1:1	.008	.008	.030	100	---	54	63
31	1:1	.020	.020	.030	100	-70	54	59
37	1:1	.020	.020	.030	100	---	<u>69</u>	<u>73</u>
					Average		<u>59</u>	<u>65</u>
21	100% HgSO ₄	0	.008	.030	100	---	55	59
26		0	.008	.030	100	---	Very	8 noisy 9
27		0	.020	.030	100	---	---	22 24

* Under heavy load.

Note 1: Refrigeration problems have been experienced on several occasions during part of the discharge periods. In such instances, the maximum temperature is indicated. No entries are made in this column if the temperature was uniformly satisfactory.

7.2 Ratio by Weight of Sulfur to Graphite

Table V presents data to demonstrate the effects of variations in the proportion of graphite used in sulfur cathodes. It is obvious that some graphite is required, and that a ratio of S:C greater than 1:1 is best. Cells 33 and 38, containing 85 percent sulfur and 15 percent graphite (S:C ratio = 5.7:1), provided 113 hours under cyclic load to a cut-off voltage of 1.3.

There is some evidence in the performance of cells 38, 39, and 29 that higher temperatures may have an adverse effect on cell life.

TABLE V

Cell No. P-	Wt. Ratio S:C	Separator Thickness (in.)		(Note 1) Max. Temp. °C	Hours to*	
		M-1365	MPR		1.5 V	1.3 V
32	∞	.020	.030	---	0	8
33	5.7:1	.020	.030	---	109	113
38	5.7:1	.020	.030	-63	<u>74</u>	<u>113</u>
				Average	91	113
34	1.0:1	.020	.030	---	79	85
39	1.0:1	.020	.030	-63	<u>36</u>	<u>43</u>
				Average	57	64
17	0.7:1	.008	.030	---	53	66
22	0.7:1	.008	.030	---	64	71
29	0.7:1	.020	.030	-70	52	62
35	0.7:1	.020	.030	---	<u>60</u>	<u>67</u>
				Average	57	66

* Under heavy load.

Note 1: Refrigeration problems have been experienced on several occasions during part of the discharge periods. In such instances, the maximum temperature is indicated. No entries are made in this column if the temperature was uniformly satisfactory.

8. Cathode Plate Thickness

Most of the cells constructed thus far have contained only enough oxidant to furnish 1/5 of the capacity required and were operated under proportionately reduced rates of drain. Cells P43 and 44 contained five times the quantity, or 180 grams of cathode materials, pasted onto the same grid area and were discharged under the full electrical loading. The plate thickness was increased five times thereby to about 0.65 inches, and the net cell volume to approximately 26 cubic inches. The weight ratio of HgSO_4 :S:C was 5:3:1.

The voltages dropped very sharply during the first 17 hours of discharge because of insufficient electrolyte (200 cc initially), so the supply was replenished by the addition of 150 cc to No. 43 and 120 cc to No. 44, whereupon the voltages recovered. The voltage under heavy load of Cell 43 rose thereafter to 2.08 in the first hour; that of No. 44, to 1.62. From this point on, the heavy load voltage of No. 43 declined to the 1.3 volt cut-off at the 38th hour; No. 44, at the 20th hour.

The former cell may have benefited from the introduction of 1% paper pulp into the cathode mix.

Further studies of the effects of variations in pasted-plate thickness will be made.

9. Transition from Pasted-Plate Structure to Bobbin-Cell Structure

A tentative design center¹ pasted-plate cell (No. P50) was constructed in the normal fashion, but discharged from one anode only. The purpose of this type of discharge was to examine in the convenient flat-cell structure the effect of single-sided discharge which is normal in the bobbin-cell structure. The length of time that Cell P50 remained above the cut-off of 1.3 volts was only 15 hours. The other anode served as a convenient reference electrode. The voltage between the second anode and the cathode under load remained high during the entire discharge period. The implication here is that the anode under load was responsible for cut-off at 15 hours. However, since this reference anode was not located between the working anode and working cathode, this is by no means certain. After cut-off had occurred, current-voltage polarization scans were taken in ten-second increments ranging from open circuit to as low as two ohms. The results of these two scans are given in Table VI and Figure 1. In view of the substantial hysteresis to these curves and further to the considerably larger hysteresis displayed by the normal discharge data points appended to Figure 1, the hypothesis is raised that cut-off occurred due to anode polarization. This anode polarization occurred at twice the current density of the normally discharged flat-plate cells. The essentially linear nature of the voltage-current scans strongly suggests the development of a high internal resistance via anode film blocking. It is planned to construct additional exploratory cells to permit direct observation of this resistance and to further define the potential losses within similar cells by means of reference electrodes located between the working electrodes.

¹ This tentative prismatic "design center" cell may be described as comprising a single pasted-plate cathode with Mg anodes on both sides. (Refer to Figure 1 of Appendix B, p. B-2.) The paste consists of 20 grams of HgSO_4 , 4 grams of sulfur and 12 grams of graphite, and has the capability of providing 1/5 of the capacity required by a full-sized cell at -90°C . Examples of such cells are P-14 and P-52. The effects of modifications to the various physical features, composition, and treatments may be compared with this basic cell.

TABLE VI
 CURRENT-VOLTAGE SCANS AFTER 74 HOURS DISCHARGE

Cell No. P-50 HgSO₄:S:C = 5:1:3

End of Continuous Discharge:

$\frac{\text{Ohms}}{68} \frac{\text{Volts}}{1.44} \frac{\text{Amps.}}{0.0212}$
 13.5 0.59 0.0438

Anode (A) - Working			Anode (B) - Reference		
<u>Ohms</u>	<u>Volts</u>	<u>Amps.</u>	<u>Ohms</u>	<u>Volts</u>	<u>Amps.</u>
∞	2.21	0	∞	2.09	0
500	2.12	.0042	∞	2.15	0
250	2.09	.0083	500	2.12	.0042
100	1.99	.0199	250	2.10	.0084
50	1.86	.0372	100	2.07	.0207
25	1.70	.068	50	1.99	.0398
15	1.46	.097	25	1.85	.0740
10	1.30	.130	15	1.71	.114
8	1.20	.150	10	1.59	.159
5	0.97	.194	8	1.50	.1875
2	0.55	.275	5	1.31	.262
			2	0.91	.455
2	0.53	.265			
5	0.90	.180	2	0.90	.450
8	1.11	.138	5	1.24	.248
10	1.25	.125	8	1.48	.185
15	1.42	.094	10	1.51	.151
25	1.60	.064	15	1.66	.1106
50	1.86	.0372	25	1.78	.0712
100	2.00	.0200	50	1.89	.0378
250	2.10	.0084	100	1.96	.0196
500	2.14	.0042	250	2.03	.0081
∞	2.21	0	500	2.10	.0042
			∞	2.12	0

CURRENT-VOLTAGE SCANS AFTER DISCHARGE

Cell No. P-50 HgSO_4 :S:C = 5:1:3

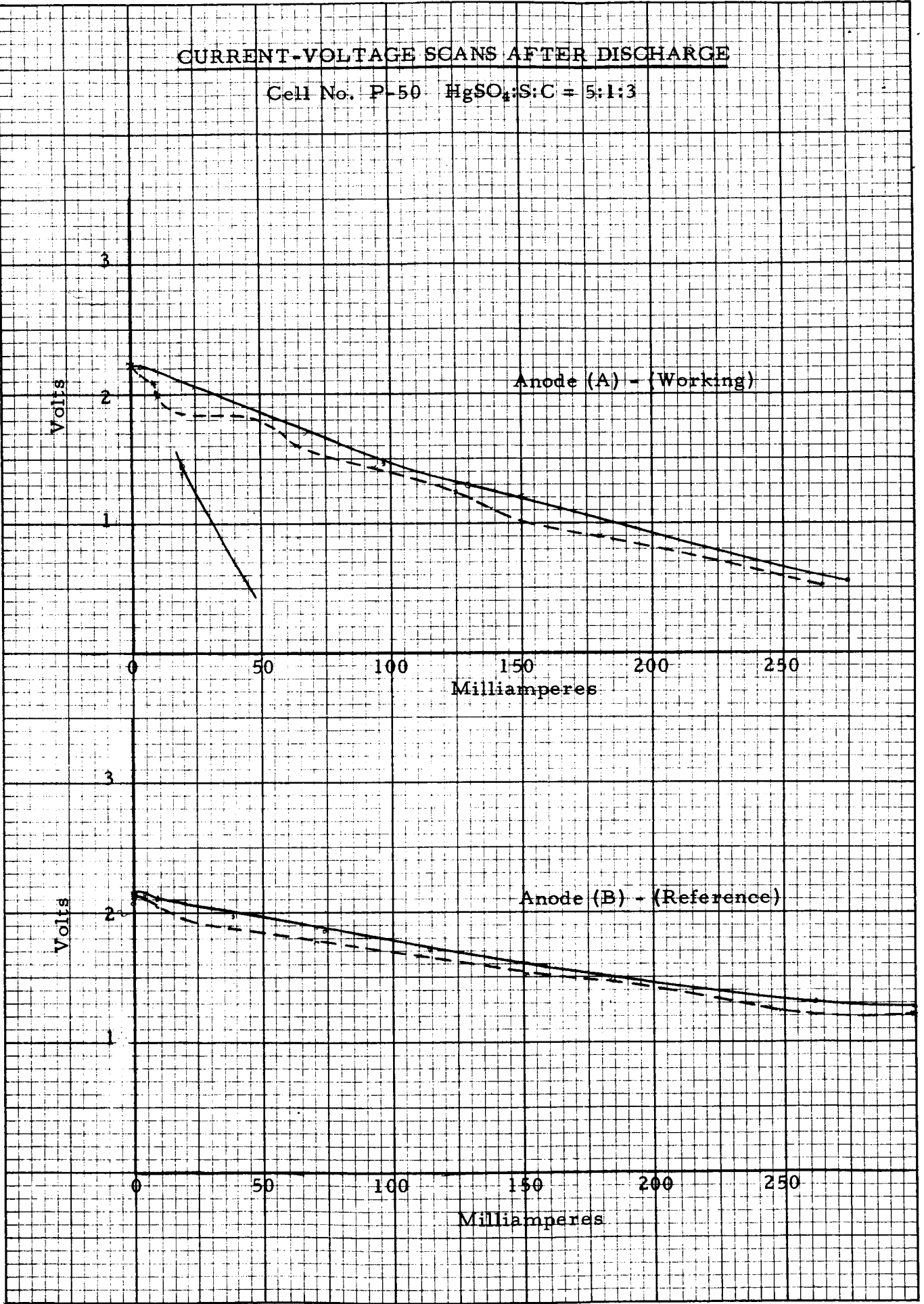


Figure 1

10. Mg Anode Corrosion Losses

After cells P-17 to 21 had been discharged, the anodes were removed, washed with light brushing to remove foreign deposits, dried and weighed to determine total loss of magnesium. The losses due to discharge were computed from the total coulombs generated. By deducting these losses from the total losses in each case, the corrosion losses were determined. A summary of the results follows in Table VII.

TABLE VII

Cell No. P-	17	18	19	20	21
Oxidant	<u>Mol Ratio of S:HgSO₄</u>				<u>100% HgSO₄</u>
	<u>100%</u>	<u>4:1</u>	<u>2:1</u>	<u>1:1</u>	
Hours to 1.3 V *	66	62	50	38	59
Hours on Discharge	109	109	110	87	87
<u>Mg Losses, % by Wt.:</u>					
Due to Discharge	88.9	65.7	54.1	41.3	48.4
Due to Corrosion	11.1	34.3	45.9	58.7	51.6

* Under heavy load.

It is noteworthy that HgSO₄ alone or in combination with sulfur is much more corrosive than sulfur.

11. Future Work

The substantial progress obtained during these first three months of -90°C study was obtained in the flat pasted-plate or prismatic structure. Since ammonia batteries involve pressures in the order of at least 100 psi at room temperature, it would be preferable if these accomplishments could be translated into a cylindrical form such as the bobbin cell developed under the previous contract. While further work must be conducted to define the -90°C pasted-plate cell performance, the major emphasis will shift from the achievement of greater than 72 hours of life at -90°C to the determination of what the cell parameters should be for cylindrical cell construction at -90°C .

In order to complete the assignment of this initial study program, a modest number of additional electrolyte salts will be selected and briefly studied at -90°C .

APPENDIX ANotes to Tables

- a) Loads shown as A/B represent cyclic loads of A ohms for 6 minutes and B ohms for 54 minutes.
- b) Cumulative hours based on heavy load.
Hours shown as A/B represent A hours to 1.5 volts and B hours to 1.3 volts.
- c) Based on lighter load.
- d) Based on heavier load.

Materials Identification

- j) HgSO_4 . A. R. Grade; Mallinckrodt Chemical Works, St. Louis, Mo.
- k) Sulfur. Sublimed; Merck & Co., Inc., Rahway, N. J.
- l) Carbon. Air spun graphite, type 200-44; Jos. Dixon Crucible Co., Jersey City, N. J.
- m) Binder. Polystyrene dissolved in toluene; (1.0 g/100 ml).
- n) KSCN. Reagent, B&A, Code 2144; Allied Chemical Co., New York, N. Y. L. E. C. Lot No. 8.
- o) KSCN. Reagent, Fisher P-317, Lot No. 743879; Fisher Scientific Co., Pittsburgh, Pa. L. E. C. Lot No. 7.
- p) Pure Mg sheet. Dow Chemical Co., Midland, Mich.
- q) AZ31B-Mg sheet. Dow Chemical Co., Midland, Mich.
- r) Silver-plated copper Exmet. Exmet Corp., Bridgeport, Conn.
- s) Pure copper Exmet. Exmet Corp., Bridgeport, Conn.
- t) SM-91 Polypropylene non-woven fabric; .005" thickness per layer; The Kendall Co., Walpole, Mass.
- u) M-1365 non-woven acetate & cotton; 0.004"/layer; The Kendall Co., Walpole, Mass.
- v) MPR - microporous rubber; .030"/layer; The American Hard Rubber Co., Butler, N. J.
- w) Copper Exmet; silver-plated after having been cut to size.

TABLE I

ELECTROCHEMICAL CELL TESTS

Pasted Plate Configuration.

Load = 13.5/68 Ohms^a.

Discharge Temperature = -90°C.

Polyethylene Bag Vehicles.

Cathode Binder^m = 0.2 g Polystyrene in 20 cc Toluene.

Cell Number P-

Major Variables

	1	2	3	4
	Load	Load	Separator Thickness	
				Separator Leaked
Electrolyte (34 Wt. % KSCN in L NH ₃)	n	n	n	n
Electrolyte Volume (cc)	120	120	120	120
Net Cell Volume (in. ³) (approx.)	9	9	9	9
Hours to End Voltage ^b (1.5/1.3 V)	42/52	55/71	26/30	17/26
Anode Thickness (inches)	0.015 ^P	0.015 ^P	0.015 ^P	0.015 ^P
Anode Area (cm ²)	232	232	232	232
Cathode: HgSO ₄ ^j (g)	19.4	19.4	20	20
Sulfur ^k (g)	3.9	3.9	4	4
Carbon ^l (g)	11.7	11.7	12	12
Cathode Collector Area (cm ²)	232 ^r	232 ^r	232 ^r	232 ^r
Separator Material	SM-91 ^t	SM-91 ^t	SM-91 ^t	SM-91 ^t
Separator Thickness (inches)	0.010	0.010	0.005	0.005
Initial Closed Circuit Voltage ^c	2.25	2.24	2.28	2.18
Peak Closed Circuit Voltage ^c	2.25	2.24	2.28	2.18
End Voltage (under maximum load)	1.30	1.30	1.30	1.30
End Voltage (under light load)	1.85	1.78	1.46	1.50
Peak Current Density ^d (mA/cm ²)	0.68	0.68	0.68	0.64
Observed Coulombs/gram HgSO ₄	361	490	203	171
Observed F/mol HgSO ₄	1.11	1.51	0.63	0.53
Watt Hours/Inch ³ of Net Cell	0.38	0.52	0.22	0.18

TABLE I
(continued)

5		6		7		8		9		10			
<u>Separator Thickness</u>		<u>Volume KSCN</u>		<u>Area</u>		<u>Separator Material</u>		<u>M-1365</u>		<u>Webril</u>		<u>Fisher KSCN</u>	
n	n	n	n	n	n	n	n	n	n	n	n	n	n
150	150	150	150	150	150	125	125	125	125	125	125	125	125
10	10	10	10	10	10	9	9	9	9	9	9	9	9
41/49	31/38	44/48	41/44	44/51	49/55	44/51	49/55	44/51	49/55	44/51	49/55	44/51	49/55
0.015 ^P	0.015 ^P	0.015 ^P	0.015 ^P	0.016 ^Q	0.016 ^Q	0.016 ^Q	0.016 ^Q	0.016 ^Q	0.016 ^Q	0.016 ^Q	0.016 ^Q	0.016 ^Q	0.016 ^Q
210	210	210	210	210	210	210	210	210	210	210	210	210	210
20	20	20	20	20	20	20	20	20	20	20	20	20	20
4	4	4	4	4	4	4	4	4	4	4	4	4	4
12	12	12	12	12	12	12	12	12	12	12	12	12	12
210 ^R	210 ^R	210 ^R	210 ^R	210 ^R	210 ^R	210 ^R	210 ^R	210 ^R	210 ^R	210 ^R	210 ^R	210 ^R	210 ^R
SM-91 ^T	SM-91 ^T	M-1365 ^U	M-1365 ^U	M-1365 ^U	M-1365 ^U	M-1365 ^U	M-1365 ^U	M-1365 ^U	M-1365 ^U	M-1365 ^U	M-1365 ^U	M-1365 ^U	M-1365 ^U
0.010	0.010	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
2.20	2.18	2.33	2.30	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20
2.20	2.18	2.35	2.30	2.22	2.22	2.22	2.22	2.22	2.22	2.22	2.22	2.22	2.22
1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30
1.70	1.50	1.55	1.45	1.58	1.53	1.58	1.53	1.58	1.53	1.58	1.53	1.58	1.53
0.75	0.74	0.81	0.80	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77
324	250	333	300	340	366	340	366	340	366	340	366	340	366
1.00	0.77	1.02	0.92	1.04	1.13	1.04	1.13	1.04	1.13	1.04	1.13	1.04	1.13
0.32	0.24	0.34	0.30	0.37	0.40	0.37	0.40	0.37	0.40	0.37	0.40	0.37	0.40

TABLE I

ELECTROCHEMICAL CELL TESTS

Pasted Plate Configuration.

Load = 13.5/68 Ohms^a.

Discharge Temperature = -90°C.

Polyethylene Bag Vehicles.

Cathode Binder^m = 0.2 g Polystyrene in 20 cc Toluene.

Cell Number P-	11	12	13		14
Major Variables	<u>Fisher KSCN MPR Separator</u>		<u>Volume of Electrolyte</u>		
Electrolyte (34 Wt. % KSCN in L NH ₃)	o	o	o		o
Electrolyte Volume (cc)	125	125	50	+50	100
Net Cell Volume (in. ³) (approx.)	9	9	7.5		7.5
Hours to End Voltage ^b (1.5/1.3 V)	45/52	41/48	10/13	78/83	68/75
Anode Thickness (inches)	0.016 ^q	0.016 ^q	0.016 ^q		0.016 ^q
Anode Area (cm ²)	210	210	210		210
Cathode: HgSO ₄ ^j (g)	20	20	20		20
Sulfur ^k (g)	4	4	4		4
Carbon ^l (g)	12	12	12		12
Cathode Collector Area (cm ²)	210 ^r	210 ^r	210 ^r		210 ^r
Separator Material	(M-1365 ^u + MPR ^v)		M-1365 ^u		M-1365 ^u
Separator Thickness (inches)	0.038	0.038	0.020		0.020
Initial Closed Circuit Voltage ^c	2.15	2.20	2.12	2.11	2.20
Peak Closed Circuit Voltage ^c	2.18	2.23	2.12	2.11	2.22
End Voltage (under maximum load)	1.30	1.30	1.30	1.30	1.30
End Voltage (under light load)	1.55	1.55	1.97	1.60	1.62
Peak Current Density ^d (mA/cm ²)	0.76	0.81	0.68	0.70	0.75
Observed Coulombs/gram HgSO ₄	342	321	84	537	499
Observed F/mol HgSO ₄	1.05	0.99	0.26	1.65	1.54
Watt Hours/Inch ³ of Net Cell	0.37	0.35	0.11	0.68	0.65

TABLE I
(continued)

15	16
<u>Pure Cu Collectors</u> <u>MPR Separator</u>	
n	n
100	100
7.5	7.5
43/54	47/61
0.015 ^P	0.015 ^P
210	210
20	20
4	4
12	12
210 ^S	210 ^S
(M-1365 ^u + MPR ^v)	
0.038	0.038
2.08	2.06
2.08	2.06
1.30	1.30
1.80	1.65
0.70	0.69
345	388
1.06	1.19
0.43	0.48

TABLE II

ELECTROCHEMICAL CELL TESTS

Discharge Temperature: -90°C . Load: 13.5/68 Ohms^a
 Pasted Plate Configuration. Polyethylene Bag Vehicles
 Net Cell Volume: Approx. 7.5 in.³
 Electrolyte: 100 cc of 34 Wt. % KSCNⁿ in liquid NH₃
 Anode^q Area (2 sides): 210 cm². Thickness: 0.016 in.
 Cathode Collector Area (2 sides): 210 cm². (Silver-plated Exmet)
 Cathode Binder^m: 0.2 g polystyrene in 20 cc toluene.

Cell No. P-	17	18	19	20
Major Variables	Sulfur to Mercuric Sulfate Molal Ratio (Constant Weight and Volume of Graphite)			
	100% S	4S:1 HgSO ₄	2S:1 HgSO ₄	1S:1 HgSO ₄
Hours to End Voltage ^b (1.5/1.3 V)	53/66	51/62	44/50	34/38
Cathode: HgSO ₄ (g) ^j	0	11.8	16.6	20.6
" S (g) ^k	8.5	5.1	3.6	2.2
" C (g) ^l	12	12	12	12
" Paper Pulp (g)				
" Collector	r	r	r	r
Separator Thickness (in.), M1365 ^u	0.008	0.008	0.008	0.008
Separator Thickness (in.), MPR ^v	0.030	0.030	0.030	0.030
Initial C.C. Voltage ^c	1.98	2.15	2.17	2.17
Peak C.C. Voltage ^c	1.98	2.17	2.22	2.22
End Voltage (Heavy Load)	1.30	1.30	1.30	1.30
End Voltage (Light Load)	1.60	1.57	1.60	1.54
Peak C.D. ^d (mA/cm ²)	0.64	0.75	0.76	0.77
Obs. Coulombs/g Total Oxidants	1040*	480	330	222
Obs. F/mol Total Oxidants	0.35*	0.42	0.41	0.38
Obs. F/mol Sulfur	0.35*	0.53	0.61	0.76
Obs. F/mol HgSO ₄	----	2.12	1.23	0.76
Watt Hours/in. ³ Net Cell	0.50	0.52	0.43	0.33
Terminal O. C. V. (at Hrs./V)	109/1.06	111/1.09	112/0.90	89/0.73

* Includes meter drain since 5 mA movement was used. Load was approximately 10% heavy.

TABLE II

(continued)

21	22	23	24	25	26	27
Sulfur to Mercuric Sulfate Molal Ratio -- (Constant Weight and Volume of Graphite)						
100% HgSO ₄	100% S	4S: 1 HgSO ₄	2S: 1 HgSO ₄	1S: 1 HgSO ₄	100% HgSO ₄	100% HgSO ₄
55/59	64/71	42/50	14/15	54/63	8/9	22/24
29.0	0	11.8	16.6	21.5	29.0	29.0
0	8.5	5.1	3.6	2.3	0	0
12	12	12	12	12	12	12
r	r	r	r	r	r	w
0.008	0.008	0.008	0.008	0.008	0.008	0.020
0.030	0.030	0.030	0.030	0.030	0.030	0.030
2.23	2.00	2.20	2.19	2.25	2.25	2.18
2.24	2.00	2.22	2.20	2.26	2.25	2.20
1.30	1.30	1.30	1.30	1.30	1.30	1.30
1.87	1.66	1.58	1.93	1.65	2.15	2.17
0.76	0.65	0.77	0.77	0.78	0.77	0.74
272	1042	394	98	384*	42	110
0.84	0.35	0.35	0.12	0.66*	0.13	0.34
----	0.35	0.43	0.18	1.31*	----	----
0.84	----	1.74	0.37	1.31*	0.13	0.34
0.52	0.54	0.43	0.13	0.60	0.08	0.21
89/0.84	140/1.02	69/1.47	19/2.12	69/1.77	16/1.2±	72/2.32

* Includes meter drain since 5 mA movement was used. Load was approximately 10% heavy.

TABLE II (continued)

ELECTROCHEMICAL CELL TESTS

Discharge Temperature: -90°C .Load: 13.5/68 Ohms^a

Pasted Plate Configuration.

Polyethylene Bag Vehicles

Net Cell Volume: Approx. 7.5 in.³Electrolyte: 100 cc of 34 Wt. % KSCNⁿ in liquid NH₃Anode^q Area (2 sides): 210 cm². Thickness: 0.016 in.Cathode Collector Area (2 sides): 210 cm². (Silver-plated Exmet)Cathode Binder^m: 0.2 g polystyrene in 20 cc toluene.

Cell No. P-	28	29	30	31
Major Variables	Sulfur to Mercuric Sulfate Molal Ratio (Constant Weight and Volume of Graphite)			
	2S: 1 HgSO ₄	100% S	4S: 1 HgSO ₄	1S: 1 HgSO ₄
Hours to End Voltage ^b (1.5/1.3 V)	72/83	52/62	52/67	54/59
Cathode: HgSO ₄ (g) ^j	16.6	0	11.8	21.5
" S (g) ^k	3.6	8.5	5.1	2.3
" C (g) ^l	12	12	12	12
" Paper Pulp (g)				
" Collector	w	w	w	w
Separator Thickness (in.), M1365 ^u	0.020	0.020	0.020	0.020
Separator Thickness (in.), MPR ^v	0.030	0.030	0.030	0.030
Initial C.C. Voltage ^c	2.20	2.03	2.21	2.24
Peak C.C. Voltage ^c	2.25	2.04	2.23	2.30
End Voltage (Heavy Load)	1.30	1.30	1.30	1.30
End Voltage (Light Load)	1.77	1.53	1.59	1.67
Peak C.D. ^d (mA/cm ²)	0.77	0.69	0.76	0.79
Obs. Coulombs/g Total Oxidants	551	923	530	363*
Obs. F/mol Total Oxidants	0.68	0.31	0.47	0.62*
Obs. F/mol Sulfur	1.02	0.31	0.58	1.24*
Obs. F/mol HgSO ₄	2.06	----	2.34	1.24*
Watt Hours/in. ³ Net Cell	0.73	0.48	0.59	0.58
Terminal O. C. V. (at Hrs./V)	1.94	71/1.70	73/1.75	67/1.82
Temp. control failed during part of run. Max. temp. attained °C:		-70	-70	-70

* Includes meter drain since 5 mA movement was used. Load was approximately 10% heavy.

TABLE II (continued)

32	33	34	35	36	37	38
Sulfur to Carbon Ratio by Weight				Mol Ratio:	Mol Ratio:	Weight Ratio:
∞	5.7	1.0	0.7	4S: 1 HgSO ₄	1S: 1 HgSO ₄	S:C = 5.7
0/8	109/113	79/85	60/67	70/78	69/73	74/113
0	0	0	0	11.8	21.5	0
25	21	11	8.5	5.1	2.3	21
0	3.7	11	12	12	12	3.7
w	w	w	w	w	w	w
0.020	0.020	0.020	0.020	0.020	0.020	0.020
0.030	0.030	0.030	0.030	0.030	0.030	0.030
1.43	1.95	2.03	2.00	2.24	2.24	1.90
1.65	1.98	2.05	2.00	2.26	2.27	2.03
1.30	1.30	1.30	1.30	1.30	1.30	1.30
1.65	1.90	1.73	1.51	1.63	1.67	1.80
0.47	0.64	0.66	0.66	0.77	0.78	0.64
36	667	983	985	621	413	680
0.01	0.22	0.33	0.33	0.55	0.70	0.23
0.01	0.22	0.33	0.33	0.68	1.41	0.23
----	----	----	----	2.74	1.41	----
0.05	0.85	0.67	0.51	0.69	0.65	0.88
94/1.79	115/2.05	94/1.74	71/1.70	94/1.81	94/1.75	
						-63

TABLE II (continued)

ELECTROCHEMICAL CELL TESTS

Discharge Temperature: -90°C .Load: 13.5/68 Ohms^a

Pasted Plate Configuration.

Polyethylene Bag Vehicles

Net Cell Volume: Approx. 7.5 in.³Electrolyte: 100 cc of 34 Wt. % KSCNⁿ in liquid NH₃Anode^q Area (2 sides): 210 cm². Thickness: 0.016 in.Cathode Collector Area (2 sides): 210 cm². (Silver-plated Exmet)Cathode Binder^m: 0.2 g polystyrene in 20 cc toluene.

Cell No. P-	39	40	41	42
Major Variables	Wt. Ratio: S:C 1.0	Pure Copper Collector	Wt. Ratio: S:C = 0.7	MPR sealed at edges. Vol. = 10 in. ³ 150 cc of electrolyte
Hours to End Voltage ^b (1.5/1.3 V)	36/43	42/44	48/50	36/40
Cathode: HgSO ₄ (g) ^j	0	20	0	20
" S (g) ^k	11	4	8.5	4
" C (g) ^l	11	12	12	12
" Paper Pulp (g)				
" Collector	w	s	s	w
Separator Thickness (in.), M1365 ^u	0.020	0.020	0.020	None
Separator Thickness (in.), MPR ^v	0.030	0.030	0.030	0.060
Initial C. C. Voltage ^c	1.99	2.00	1.85	2.27
Peak C. C. Voltage ^c	2.10	2.00	1.96	2.30
End Voltage (Heavy Load)	1.30	1.30	1.30	1.30
End Voltage (Light Load)	1.93	1.60	1.70	1.51
Peak C. D. ^d (mA/cm ²)	0.67	0.69	0.65	0.79
Obs. Coulombs/g Total Oxidants	502	228	725	227
Obs. F/mol Total Oxidants	0.17	0.30	0.24	0.29
Obs. F/mol Sulfur	0.17	0.46	0.24	0.45
Obs. F/mol HgSO ₄	----	0.85	----	0.84
Watt Hours/in. ³ Net Cell	0.35	0.34	0.37	0.27
Terminal O. C. V. (at Hrs./V)	----	118/1.05	104/1.13	----
Temp. control failed during part of run. Max. temp. attained °C:	-63	-57	-57	-63

A-11
TABLE II
(continued)

43	44	45	48	49	50	52	53
Thick Cathodes 0.70" 0.62" 2.7/13.5 ohms Details in text.		Separation	Pure Cu Collector		Discharged with only one anode	Omitted MPR	MPR sealed at edges. <u>Vol. = 10 in.³</u> 150 cc of electrolyte
36/38	19/20	27/28	17/21	41/51	14/15	81/93	98/117
100	100	20	20	0	20	20	20
20	20	4	4	8.5	4	4	4
60	60	12	12	12	12	12	12
1.8							
w	w	w	s	s	w	w	w
0.020	0.020	0.020	0.020	0.020	0.020	0.020	None
0.030	0.030	0.030	0.030	0.030	0.030	None	0.060
2.12	2.18	2.25	2.12	1.95	2.23	2.21	2.22
2.26	2.18	2.27	2.12	1.97	2.26	2.23	2.27
1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30
2.05	1.92	1.88	1.88	1.77	2.10	1.76	1.65
3.7	2.9	0.77	0.71	0.66	1.47	0.72	0.76
214	110	158	113	744	84	519	660
0.28	0.14	0.20	0.15	0.25	0.11	0.67	0.85
0.43	0.22	0.31	0.23	0.25	0.17	1.03	1.31
0.79	0.41	0.58	0.42	----	0.31	1.92	2.42
0.47	0.25	0.25	0.17	0.38	0.13	0.82	0.73
48/2.29	48/2.32	137/2.10	114/2.00	114/1.38	242/1.92	137/1.68	157/1.62
-63	-63						

TABLE III

PERIODIC CELL VOLTAGES

Test No.	High Load Voltage after: (hours)				Low Load Voltage after: (hours)				Hours to: ^d					
	12	24	36	48	60	72	12	24	36	48	60	72	1.5 V	1.3 V
P- 1	1.70	1.73	1.64	1.38	1.18	1.10	2.10	2.13	2.10	1.92	1.76	1.70	42	52
P- 2	1.83	1.73	1.60	1.55	1.41	1.28	2.10	2.10	2.02	1.98	1.85	1.77	55	71
P- 3	1.87	1.58	0.95	-----	-----	-----	2.05	1.75	1.07	-----	-----	-----	26	30
P- 4	1.65	1.38	0.97	-----	-----	-----	1.83	1.58	1.05	-----	-----	-----	17	26
P- 5	1.97	1.84	1.68	1.32	1.12	-----	2.15	2.10	1.95	1.70	1.45	-----	41	49
P- 6	1.93	1.61	1.38	-----	-----	-----	2.09	1.81	1.58	-----	-----	-----	31	38
P- 7	2.27	2.18	1.73	1.30	-----	-----	2.30	2.28	1.91	1.53	-----	-----	44	48
P- 8	2.25	2.08	1.66	1.13	-----	-----	2.28	2.22	1.80	1.27	-----	-----	41	44
P- 9	1.93	2.11	1.59	1.37	1.11	-----	2.12	2.20	1.75	1.63	1.33	-----	44	51
P-10	2.08	2.09	1.63	1.51	1.12	-----	2.17	2.18	1.80	1.70	1.30	-----	49	55
P-11	1.94	1.98	1.60	1.41	1.10	-----	2.10	2.12	1.77	1.63	1.30	-----	45	52
P-12	2.16	1.94	1.55	1.30	0.99	-----	2.21	2.10	1.73	1.55	1.18	-----	41	48
P-13a	1.42	-----	-----	-----	-----	-----	2.00	-----	-----	-----	-----	-----	10	13
P-13b	-----	1.92	1.96	1.92	1.60	1.54	-----	2.09	2.13	2.12	1.84	1.77	73	83
P-14	1.95	2.02	1.90	1.75	1.55	1.38	2.14	2.15	2.13	1.97	1.80	1.67	68	75
P-15	1.90	1.77	1.62	1.36	1.25	-----	1.98	1.95	1.95	1.86	1.75	-----	43	54
P-16	1.88	1.73	1.63	1.48	1.32	-----	1.95	1.92	1.92	1.84	1.66	-----	47	61
P-17	1.73	1.69	1.63	1.53	1.40	1.03	1.97	1.95	1.90	1.85	1.80	1.30	53	66
P-18	2.09	1.93	1.65	1.54	1.32	1.13	2.15	2.05	1.83	1.73	1.57	1.35	51	62
P-19	2.13	2.05	1.60	1.37	1.06	0.98	2.19	2.17	1.80	1.64	1.27	1.13	44	50
P-20	2.15	2.05	1.40	0.95	-----	-----	2.21	2.17	1.62	1.09	-----	-----	34	38
P-21	x	2.12	1.95	1.74	1.24	-----	x	2.22	2.17	2.11	1.83	-----	55	59

TABLE III

PERIODIC CELL VOLTAGES

Test No.	High Load Voltage after: (hours)				Low Load Voltage after: (hours)				Hours to: ^d					
	12	24	36	48	60	72	12	24	36	48	60	72	1.5V	1.3V
P-22	1.80	1.77	1.72	1.65	1.55	1.27	2.00	1.98	1.96	1.90	1.85	1.63	64	71
P-23	2.15	1.72	1.60	1.33	1.10	-----	2.21	1.90	1.79	1.62	1.33	-----	42	50
P-24	1.89	-----	-----	-----	-----	-----	2.08	-----	-----	-----	-----	-----	14	15
P-25	2.19	2.14	1.97	1.55	1.42	-----	2.24	2.24	2.20	1.92	1.72	-----	54	63
P-27	2.02	1.27	-----	-----	-----	-----	2.19	2.17	1.77	1.92	1.99	-----	22	24
P-28	2.08	1.77	2.17	1.91	1.69	1.50	2.23	2.16	2.26	2.18	1.97	1.88	72	83
P-29	1.80	1.80	1.92	1.60	1.33	-----	2.03	2.02	2.07	1.92	1.62	-----	52	62
P-30	2.15	1.93	2.02	1.60	1.39	-----	2.22	2.16	2.13	1.90	1.67	-----	52	67
P-31	2.08	2.18	2.26	1.62	1.27	-----	2.25	2.26	2.31	1.97	1.64	-----	54	59
P-33	1.72	1.73	1.67	1.70	1.63	1.64	1.98	1.99	1.98	1.98	1.96	1.95	109	113
P-34	1.83	1.81	1.74	1.81	1.73	1.66	2.02	2.01	1.99	2.02	1.99	1.95	79	85
P-35	1.80	1.77	1.79	1.78	1.53	-----	2.00	2.00	1.99	1.96	1.87	-----	60	67
P-36	2.17	2.17	1.77	1.74	1.58	1.45	2.25	2.25	2.00	1.98	1.88	1.75	70	78
P-37	2.20	2.18	2.15	1.59	1.62	1.35	2.26	2.27	2.25	1.95	2.00	1.72	69	73
P-38	1.79	1.66	1.62	1.59	1.53	1.52	2.03	1.90	1.88	1.87	1.85	1.86	74	113
P-39	1.88	1.69	1.32	1.34	1.23	-----	2.09	1.98	1.96	1.51	1.90	-----	36	43
P-40	1.93	1.92	1.75	1.25	-----	-----	1.97	1.97	1.95	1.50	-----	-----	42	44
P-41	1.78	1.80	1.55	1.48	-----	-----	1.92	1.94	1.87	1.75	-----	-----	48	50
P-42	2.23	1.70	1.46	1.05	-----	-----	2.30	1.85	1.66	1.24	-----	-----	36	40
P-45	2.03	1.81	0.81	-----	-----	-----	2.24	2.04	1.71	-----	-----	-----	27	28
P-48	1.61	1.13	-----	-----	-----	-----	1.95	1.67	-----	-----	-----	-----	17	21
P-49	1.67	1.56	1.57	1.37	1.17	-----	1.95	1.90	1.85	1.80	1.64	-----	41	51
P-52	2.01	2.03	1.98	1.81	1.66	1.54	2.23	2.23	2.21	2.03	1.90	1.85	81	93
P-53	2.16	2.11	1.94	1.84	1.73	(1.65)	2.26	2.25	2.22	2.18	2.12	(2.00)	98	117

APPENDIX B1. Pasted-Plate Cell Construction

Figure 1 illustrates a cell comprising a pasted-plate cathode enclosed and sealed within a separator, two magnesium anodes and a plastic envelope case. A silver-plated copper Exmet (expanded metal) grid serves as the carrier for the paste and as a cathode collector. The lead wire is soldered to the Exmet, and the joint is coated with Krylon or rubber cement.

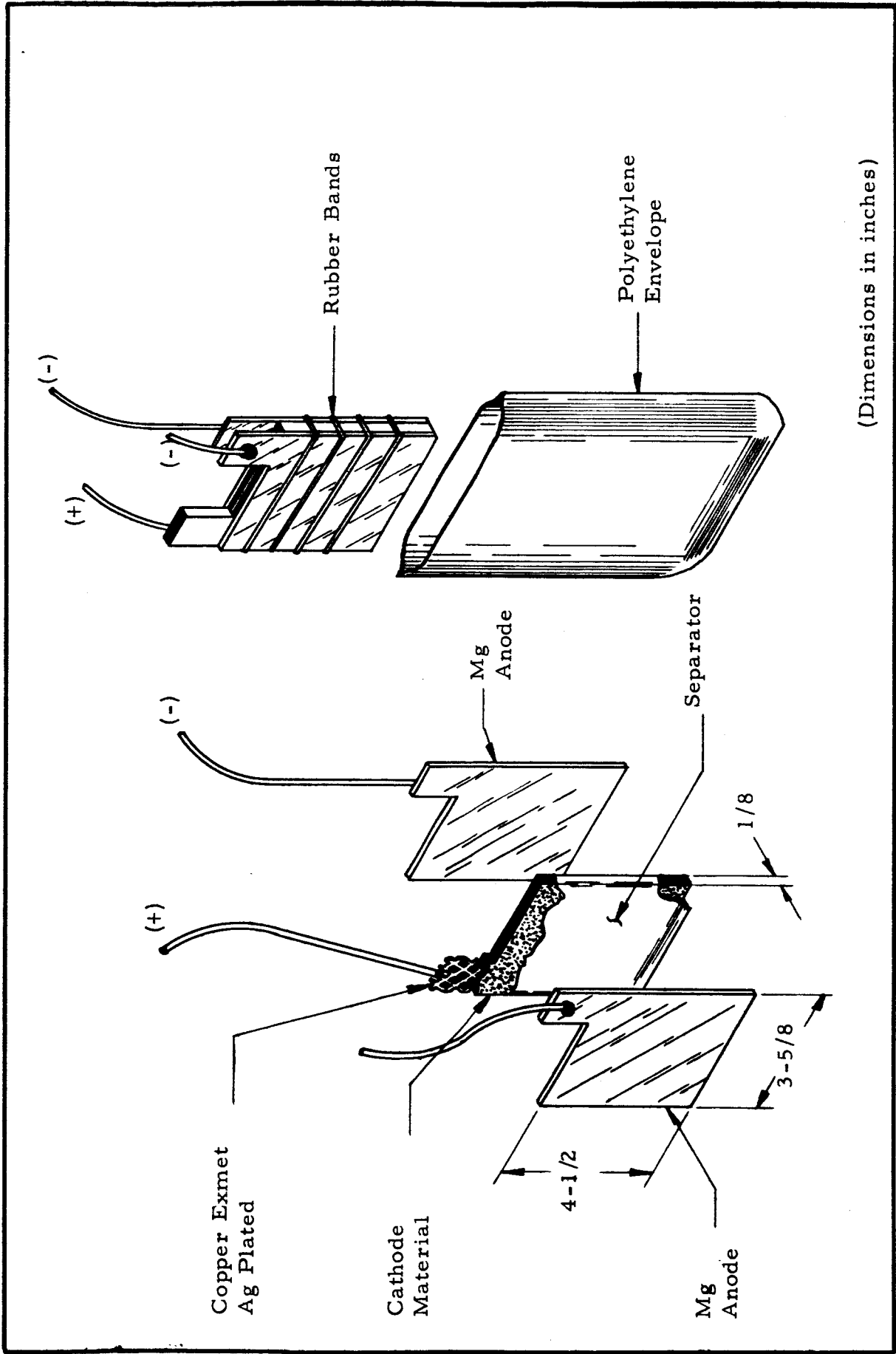
The oxidant(s) and graphite in the desired proportions are dry-blended and are then mixed with a binder (1% solution of polystyrene in toluene) into a workable paste. The paste is spread evenly on both sides of the grid with a spatula. During this procedure, the surface may be moistened with toluene as necessary to counteract evaporation. The finished plate is air-dried overnight, or until the odor of toluene has disappeared. Forced drying is not applied in order to avoid shrinking and cracking of the paste.

A suitable separator is then wrapped around the dried plate and sealed at the seams.

A magnesium sheet anode is applied to each face of the cathode on the outside of the separator, and the two anodes are held tightly in place with rubber bands which permit swelling of the cathode during activation and discharge. The anode lead wires are attached with aluminum rivets, and the connections are protected with Krylon or rubber cement.

The entire cell assembly is encased in a polyethylene envelope which may be used as a vehicle for discharge at any temperature below the boiling point of liquid ammonia.

The general design may be varied at will to meet the requirements of special tests.



(Dimensions in inches)

TYPICAL PASTED-PLATE CELL

Figure 1

APPENDIX B2. Sample Calculations

Power required for full capacity cell at nominal potential of 2 volts = 1.5 watts for 6 minutes (0.1 hour) and 0.3 watts for 54 minutes (0.9 hour).
 Total power each hour = $(1.5 \times 0.1) + (0.3 \times 0.9) = 0.42$ watts.

Resistance = $E^2/W = 4/1.5 = 2.67$ ohms for 0.1 hour.
 = $4/0.3 = 13.33$ ohms for 0.9 hour.

Average Resistance = Ave. E^2 /Ave. $W = 4/0.42 = 9.53$ ohms.

Current Drain = $W/E = 1.50/2 = 0.750$ amperes for 0.1 hour.
 = $0.30/2 = 0.150$ amperes for 0.9 hour.

For the smaller cells which contained 1/5 as much oxidant, the power output and current were reduced to 1/5 by increasing the load resistance five-fold. The values would be:

Power = 0.30 watts for 0.1 hour and 0.06 watts for 0.9 hour.
 Total power each hour = $(0.30 \times 0.1) + (0.06 \times 0.9) = 0.084$ watts.

Resistance = $2.67 \times 5 = 13.33$ ohms for 0.1 hour.
 = $13.33 \times 5 = 66.65$ ohms for 0.9 hour.

Average Resistance = $9.53 \times 5 = 47.65$ ohms.

Current Drain = $0.750/5 = 0.150$ amperes for 0.1 hour.
 = $0.150/5 = 0.030$ amperes for 0.9 hour.

Example: Cell No. P-36

Peak Current Density under heavy load:

C. D. = $(\text{Peak Voltage})(1000)/(\text{R})(\text{Plate Area}) = (2.19)(1000)/(13.5)(210) = 0.77$ mA/cm².

Average Voltage = (P. C. C. V. under light load) + (end voltage under heavy load), divided by 2. $(2.26 + 1.30) / 2 = (1.78)$

Coulombic Output = $(\text{Ave. E})(\text{Hours})(3600) / (\text{Ave. R})$
 = $(1.78)(78)(3600) / (47.6) = 10480$ coulombs

Coulombs/gram of Oxidant = $10480 / (11.8 \text{ g HgSO}_4 + 5.1 \text{ g S}) = 621$

$$\text{Faradays} = 10480/96500 = 0.1087$$

$$\text{Mols HgSO}_4 = \text{grams/Mol. Wt.} = 11.8/297 = 0.0397$$

$$\text{Mols Sulfur} = \text{grams/Mol. Wt.} = 5.1/32 = 0.1593$$

$$\text{Faradays/mol of total oxidants} = 0.1087/(0.0397 + 0.1593) = 0.55$$

$$\text{Faradays/mol of sulfur} = 0.1087/0.1593 = 0.68$$

$$\text{Faradays/mol of HgSO}_4 = 0.1087/0.0397 = 2.74$$

$$\begin{aligned} \text{Watt hours/in.}^3 \text{ Net Cell} &= (\text{Ave. E})^2(\text{Hours})/(\text{Ave. R})(\text{Net Cell Vol.}) \\ &= (1.78)^2(78)/(47.6)(7.5 \text{ in.}^3) = 0.69 \end{aligned}$$

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