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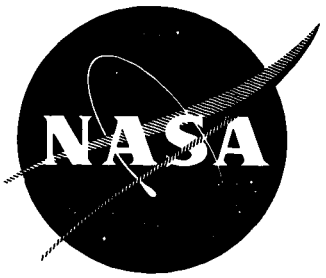

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Quarterly Report No. 5

DEVELOPMENT OF THE DRY TAPE BATTERY CONCEPT

9 June 1966 to 9 September 1966

By

John S. Driscoll

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For

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I. SUMMARY

The reproducibility of tests in both aqueous and non-aqueous systems has been greatly improved. Results can be duplicated to ± 5 per cent.

Energy densities were increased to 115-120 watt-hr/lb in 4-hour static tests of the $Mg/MgBr_2$/ACL-85® system operating at a constant 2.0 volts. In constant potential (3.2 volts) tests of the $Li/LiClO_4$-methyl formate/ACL-70® system, energy densities as high as 169 watt-hr/lb were obtained in 12-hour tests. Energy density calculations include the weights of anode, cathode, separator, and electrolyte.

The partial replacement of Shawinigan acetylene black (SAB) by graphite in ACL-85 tapes increased the resistance of the cathode, and decreased the thickness and energy density.

The cathode void volumes, electronic and electrolytic resistances for our best aqueous and non-aqueous systems were computed and compared to the observed overpotentials. At optimized electrolyte volumes, only 80-90% of the cathode void volume is filled with electrolyte.

A photomicrographic study of the effect of blending techniques on cathode mix particle size was carried out. Waring blended SAB had drastically changed degree of agglomeration.

Surfactants marginally increased the performance of aqueous cells.

Binders such as polyvinyl formal and polyvinylpyrrolidone increase the mechanical properties of machine-made ACL-85 cathodes but reduce electrochemical performance.

A dynamic test of an unoptimized zinc-oxygen tape cell gave an energy density of 127 watt-hr/lb.

A mathematical analysis of aqueous and non-aqueous constant voltage discharge curves shows that the current varies as $(time)^{-1/2}$ The results indicate a mass transport limitation.

II. TASK I. HIGH ENERGY COUPLE RESEARCH

A. AQUEOUS SYSTEMS

1. ACL-85® Cathode Research

a. General

A considerable effort was made early in this quarter to standardize the variables in the preparation of the ACL-85 tape cathodes used in static tests. Attention was also devoted to standardizing all test variables. As a result of this program, tape performance has become much more reproducible. All aqueous data are listed in Table A-1.

The amount of electrolyte used was changed this quarter from a specific volume per tape to a volume per gram of cathode. This volume is distributed equally over the tape at 15 points. This procedure requires activation times of approximately 3 minutes, and because of the increased wet-stand, we discharged most cells by presetting the voltage and connecting the cell to allow discharge to start during the activation process. All runs this quarter were at constant voltage.

b. Cathode Carbon Composition

(1) Reduction of Carbon Content

An attempt was made to decrease the carbon content of the cathode in order to decrease the electrolyte volume necessary for activation. Tapes 90065-1,3 had ratios of SAB to ACL-85 of 0.49, 0.23, and 0.15. The efficiency of the tapes with a ratio of 0.49 was greater than that of the tapes with a ratio of 0.23, while the energy density was lower. With an SAB/ACL-85 ratio of 0.15, both the efficiencies and energy densities were reduced.

The initial results shown in Table 1 indicate that changes in operating voltage and electrolyte volume do not change significantly the energy densities obtained when 20% SAB was used. The benefit from the greater weight of active material in the 20% SAB cathode appears to be offset by the somewhat lower cathode efficiencies. However, 20 per cent SAB was used throughout most of this quarter, and improvements were made in efficiency at low electrolyte volumes.

Table 1

DISCHARGE OF $Mg/MgBr_2/ACL-85$ CELLS
WITH A SAB TO ACL-85 RATIO OF 15 TO 65

Electrolyte Volume per Gram of Cathode (ml/g)	2.0 volts			2.2 volts		
	Energy Density (w-hr/lb)	Efficiency (%)	Theoretical Capacity (amp-min)	Energy Density (w-hr/lb)	Efficiency (%)	Theoretical Capacity (amp-min)
1.5	75 (83)	59 (65)	33	71	48	33
	70 (87)	50 (62)	52	50 (84)	32 (54)	51
	87	69	26			
1.7	76 (83)	61 (67)	35	66 (85)	46 (61)	34
	79	69	26			

Cut-off values at 50 min. or 60 ma (if <50 min) are given without parenthesis

Cut-off at 60 ma (>50 min) are in parenthesis

(2) Effect of Addition of Graphite

With the present cathode formulation the void volume is about 71% (see next section on cathode resistance). This entire volume cannot be filled with electrolyte if we are to obtain high energy densities. We are, therefore, attempting to decrease this void volume. One method would be to use a high density, high conductivity, micronized graphite in the cathode mix in place of part of the SAB.

Tapes were prepared replacing 25, 50, and 100% of the SAB with Micro-6 Graphite (Asbury Graphite Mills, Inc.). The data are shown in Table 2.

The thickness of these tapes decreased only moderately with increased graphite (14% for a 100% replacement). However, the cathode resistance increased by a factor of 10. A partial replacement of SAB with graphite is possible, however, and if the electrolyte is decreased in proportion to the void volume, the energy density is not greatly affected (neither increased nor decreased). For the conditions used, there appears to be no advantage to adding graphite to the mix.

Future plans for decreasing void volumes include studies of cathode formation pressure and the use of other graphitic carbons.

c. Resistance of Cathodes

(1) Electronic Resistance

As the carbon black percentage is decreased, the electronic conductivity in the cathode decreases. This electronic conductivity is important in transferring electrons from the site of the reaction to the collector plate.

In a macroscopic sense, one can measure the electronic conductivity of the cathode and compare the IR loss due to this conduction through the cathode(separator to collector) to the observed total overpotential. This is done below. This method assumes that the conductivity is homogeneous throughout the cathode. Actually, the electronic conductivity could limit the discharge in discrete pockets of a nonuniform cathode. The change in cathode conductivity with a change in cathode composition is valuble information for correlating cell performance.

Table 2

EFFECT OF GRAPHITE ON Mg/ACL-85 DISCHARGE (3 in.^{2} Tape Area)

Percent Graphite in the SAB	Thickness[1] (mils/g)	Resistance[2] (ohms/g)	Amount of 2M $MgBr_2$ Used at two Electrolyte Ratios: 1.2 ml/g Eff.	1.2 ml/g W-h/lb	1.2xThickness Ratio[3] Eff.	1.2xThickness Ratio[3] W-h/lb
0	33.6	44	57	90	57	90
25	28.6	60	48	80	46	81
50	27.5	77	42	73	34	86
100	24.2	460	10	21		

(1) mils per gram of cathode mix

(2) ohms per gram of cathode mix

(3) $\text{ml/gm} = \frac{(1.2)\ [\text{Thickness of cathode (mils)}]}{\text{Ave. Thickness of 100\% SAB cathodes (40 mil)}}$

The conductivity measured in this report was obtained from the circuit and apparatus shown in Figure 1. The four probes are wires imbedded in polypropylene. The circuit plate was pressed on the unwetted cathode, and the current and voltage were determined. The thickness and conductivity data are given in Table A-1 (Tapes 90075-90088).

Using the values 50 ohms and 40 mil (Tape 90077), a conductivity value of 0.20 ohm^{-1} cm^{-1} is obtained for the electronic matrix. The resistance from the separator side to collector side is 0.027 ohm. At 2.0 amperes this corresponds to a 54 mv IR loss, which is approximately 5% of the total overpotential. Two amperes is a relatively high current in our system and at lower currents the voltage is even less influenced by the bulk electronic resistivity.

In scanning the conductivities obtained with other tapes (Table A-1) it is apparent that CDB-85 tapes have lower electronics conductivities. This is presumably due to the small particle size of the CDB-85, whch results in a lower packing density of the cathode. The tapes prepared with Micro-6 graphite also had definitely lower conductivity than those made with SAB.

(2) Electrolytic Resistance

In order to discharge the ACL-85 at the collector plate, the current path must be entirely through the electrolyte phase. This electrolytic resistance can be calculated and compared to the electronic resistance. The IR loss due to electrolyte resistance can be calculated and compared to the total overpotential. As with electronic conductivity, however, the limiting effect may be high resistance pockets in the cathode rather than a high average resistance.

Again taking the data from Tape 90077, the void volume can be calculated as shown in Table 3. The per cent void volume in the cathode is 71% and in the separator it is approximately the same. The conductivity of 2M $MgBr_2$ is 0.156 ohm^{-1} cm^{-1}. Using an equation for conductivity and assuming the voids are filled, one obtains 0.093 ohm^{-1} cm^{-1} for the electrolytic resistance of the cathode (Table 4). The total volume of the cathode and separator is 2.22 cm^3. Since 1.35 cm^3 of electrolyte was used, this gives a 61% filled volume. Hence, all the voids (71%) are not filled. Using the same formula, with 61% void filled, one obtains 0.074 ohm^{-1} cm^{-1}. This gives a resistance of 0.080 ohm, for the electrolytic resistance from anode to collector plate.

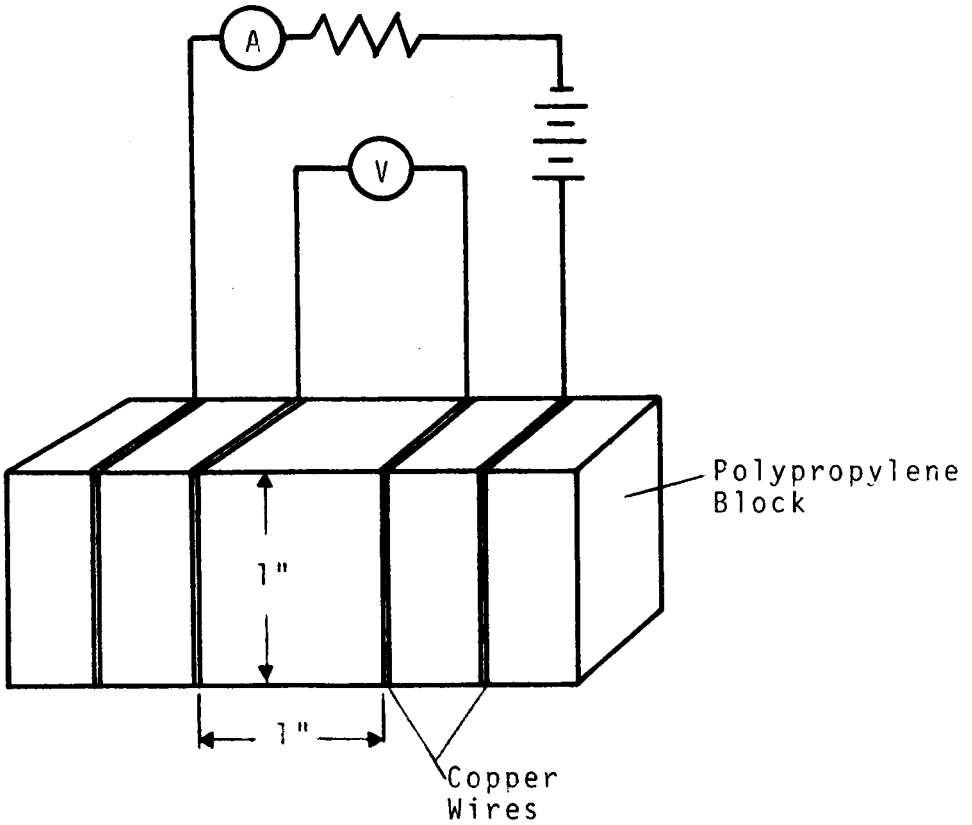


Figure 1. Apparatus for Measuring the Electronic Resistance of Cathode Mixes

Table 3

CATHODE VOID VOLUME CALCULATION (Tape 90077)

Material	Weight, g	Density, g/cm^3	Volume, cm^3	Meas. Volume, cm^3
ACL-85	0.92	2.02	0.45	
SAB	0.18	1.98	0.09	
Paper Pulp	0.04	1.4	0.03	
Total Cathode	1.14		0.57	1.97
Separator	0.08	1.1	0.073	0.27

Percent Cathode Void Volume $\frac{(100\%)(1.97-0.57)}{1.97}$ = 71%

Table 4

CATHODE ELECTROLYTIC RESISTANCE
(Tape 90077)

$$\kappa = \kappa' (1-f)^{1.5}$$

$$\kappa = 0.156 \times (0.71)^{1.5}$$

$$\kappa = 0.093 \text{ ohm}^{-1} \text{ cm}^{-1}$$

κ = Cathode electrolytic resistance

κ' = conductivity of electrolyte

f = volume fraction of dispersed phase

At a current of 2.0 amperes, this resistance corresponds to a 0.16-volt IR loss, which is about 16% of the overpotential.

Thus, the calculated electronic (5%) and electrolytic (16%) resistances of the cathode mix do not account for the observed overpotential.

d. Cathode Blending Methods

Cathode mix blending methods were found to have a larger influence on cathode performance than expected. Metal-to-ACL-85 contact was found to have a detrimental effect. When the dry ingredients (ACL-85+SAB) were blended in a Waring Blendor for 2 minutes, the active chlorine analysis after blending showed a 3% loss. This is a small loss. However, more significant was the fact that some cathode material, which had stuck to the blender blades, and a 48% loss of active chlorine. While the final tapes had only a 6% loss in active chlorine, the discharge was poor (Table 5, 90033). It is possible that the poor performance was due to the metal-catalyzed production of chlorine from ACL-85. Chlorine is known to inhibit cathode performance (Quarterly Report No. 3). The next tapes were blended only 45 seconds in the Waring Blendor, and the discharges were significantly better (Tape 90037). The next batch (Tape 90039) was blended for 90 seconds in the Waring Blendor and the results were intermediate.

The results of no dry blending before trichloroethylene mixing are shown in Table 5 (90044-90051). This procedure appears to give improved performance. Hence, slurry mixing was used as the standard for most of the tapes this quarter.

In other experiments (Tapes 90061 and 90064), the slurry mixing time was decreased by half, to 1.5 minutes. This had very little effect on the performance of the tape. For these reasons, we currently give the dry ingredients a preliminary blending with a Teflon spatula in a glass beaker before stirring the slurry mechanically (glass apparatus) for 1.5 minutes.

e. A Photomicrographic Study of Cathode Mixes

The importance of mixing variables was shown by the effect of mixing procedures on performance, and again by the i vs $t^{-1/2}$ relationship. A mass transport limitation is suggested by these data. A series of photomicrographs was obtained on the starting materials, mixes, and on new and used tapes. It was hoped that

Table 5

EFFECT OF BLENDING ON TAPE DISCHARGE

Mg/2M $MgBr_2$/ ACL-85
2.0 volts, 50 min. cut-off, 1.7 ml Electrolyte/g Tape

Cell No.	Blending Method	Cathode Efficiency	Cathode Capacity (amp-min)	Notes
90033-10	WB[a] 120 sec.	25	29	
90037-4	WB[a] 45 sec.	48	32	
90039-10	WB[a] 90 sec.	40	29	
90042-10	WB[a] 45 sec.	46	29	
90044-1	Glass[b] 180 sec.	54	22	2.0v set before activation
90047-1	Glass[b] 180 sec.	59	35	2.0v set before activation
90049-6	Glass[b] 180 sec.	66	33	2.0v set before activation
90051-4	Glass 120 sec. (dry) 180 sec. (wet)	61	35	2.0v set before activation

[a] Waring Blendor dry mixing for indicated time, 3 min. stirring of trichloroethylene slurry.

[b] No dry mixing, 3 min. stirring in trichloroethylene.

a correlation between the mixing variables and performance would be found, and the mix improved. Some of the photomicrographs are shown in Figures 2-6. A transmission microscopy technique using polarized light was also used. It differentiates crystalline and noncrystalline phases. A Bausch and Lomb 286176 Petrographic microscope with crossed Nicol attachment was used in this study. The crystalline phases (ACL-85 and ACL-70, paper pulp, and electrolyte salt crystals) are bright areas in the crossed Nicol pictures. The magnification in all pictures is approximately 90 X.

Figure 2 shows the effect of Waring blending on Shawinigan acetylene black (SAB). Waring blending destroys the primary agglomorates. However, considerable structure remains, and the bulk density, actually decreases after blending for five minutes.

Figure 3 shows the particle size of ACL-70 and ACL-85 samples. The distribution in ACL-70 runs from < 5 to 70 microns. Mechanical grinding does not appear to influence the larger particles. ACL-85 particles on the average are larger: 10 to 100 microns.

Figure 4 shows the fibrous filler materials used in our cells. The paper pulp is prepared by Waring blending Whatman filter paper. In polarized light (Fig. 4c), the paper pulp is seen to be crystalline.

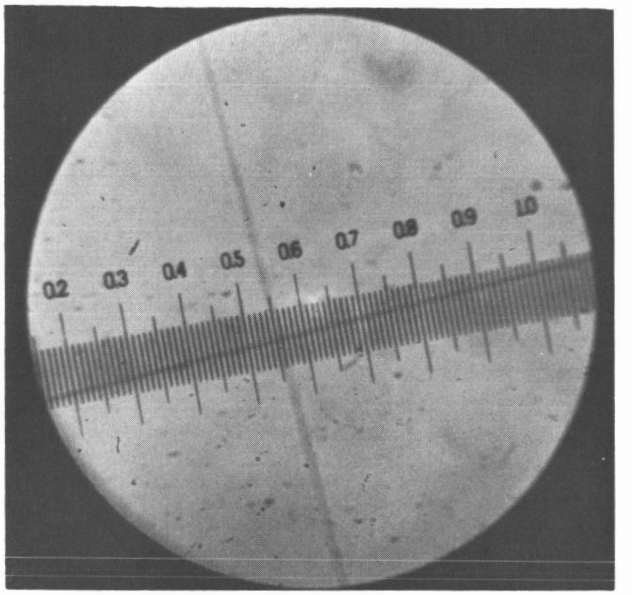
The photomicrographs in Figure 5 show ACL-70 cathode mixes as a function of various blending techniques. The mortar and pestle mix ran very poorly (Cell 90867) in a non-aqueous test.

Figure 6 shows an ACL-85 cathode mix from the Paterson-Kelly blender. The agglomerates are much larger than those produced by other blending methods.

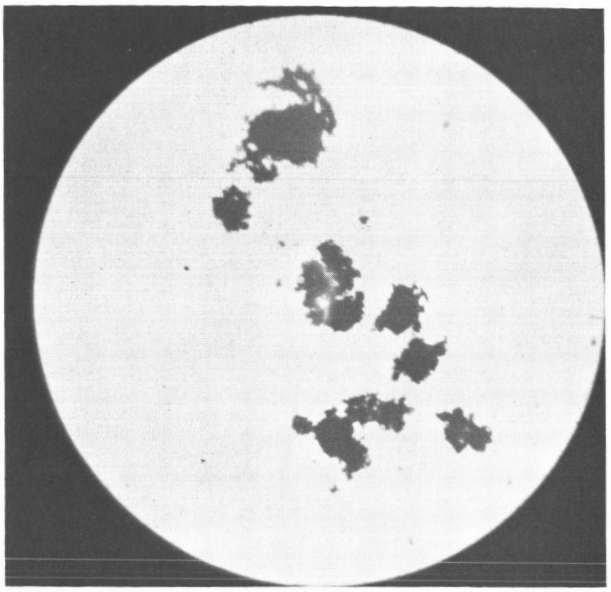
Many additional photographs of tape cathodes before and after discharge were taken. Too little definition exists in the spent cathodes to allow comparisons to be made.

f. The Effect of Surfactants on Cell Performance

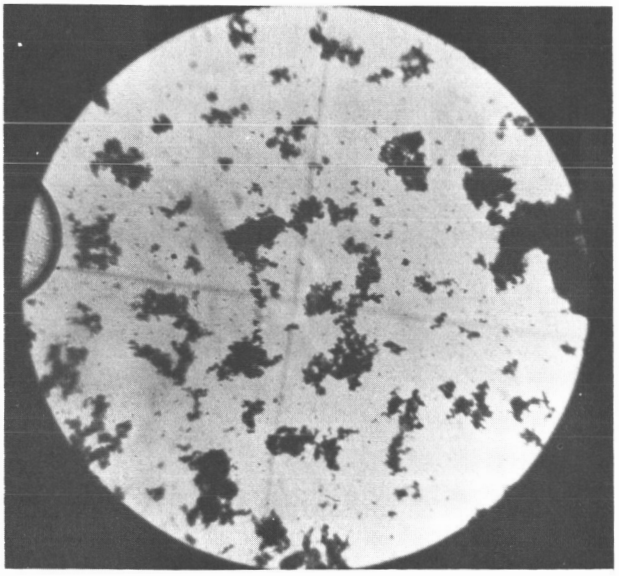
It was shown in the previous discussion of cathode void volume that all the voids are not filled with electrolyte at optimum operating conditions. It was reasonable, therefore, to carry out a study of the effects of surfactants in improving the electrolyte distribution in the cathode mixes. If improvement could be accomplished, less electrolyte might be needed and energy densities would be improved.



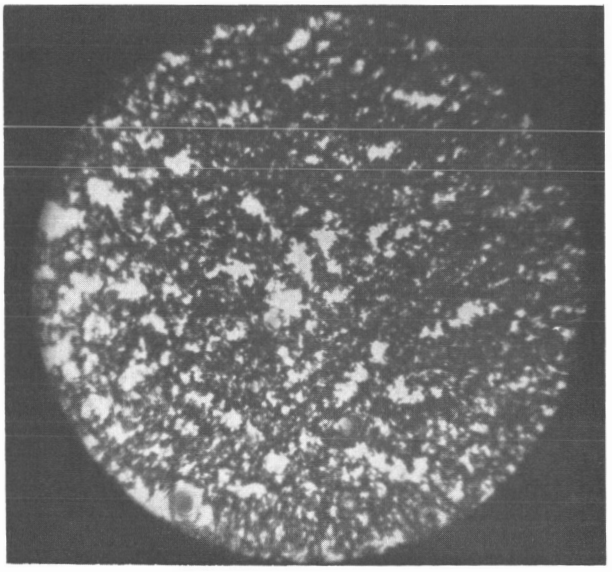
2a
Magnification Calibration
(Line spacing 0.01 mm)



2b
SAB as received

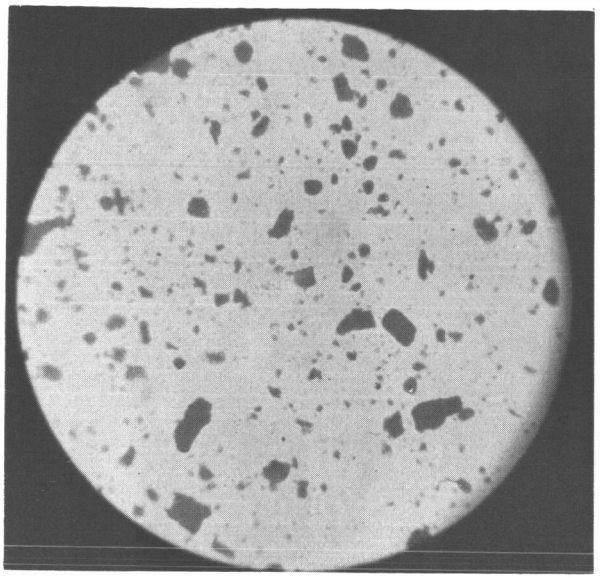


2c
1 min. blending

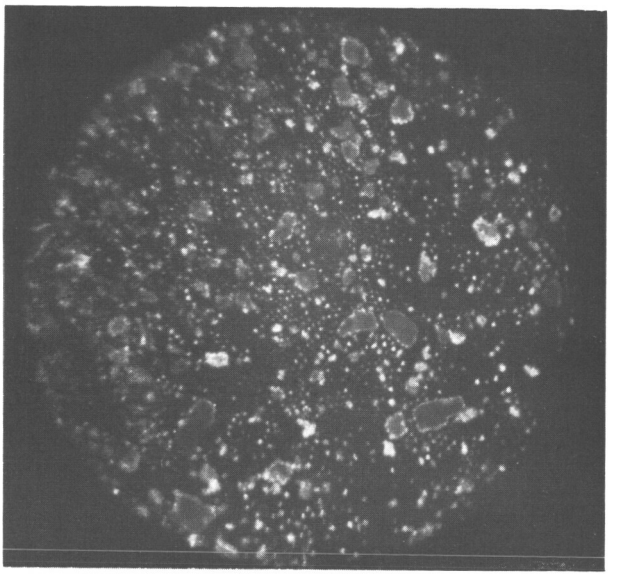


2d
5 min. blending

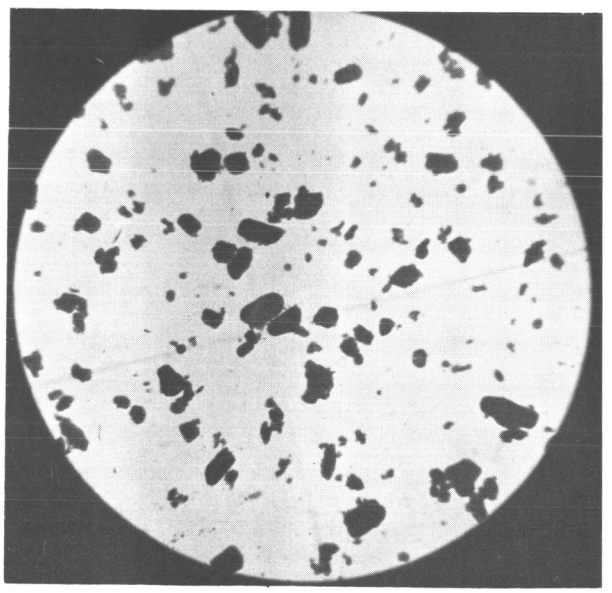
Figure 2. The Effect of Waring Blending on Shawinigan Acetylene Black (SAB)



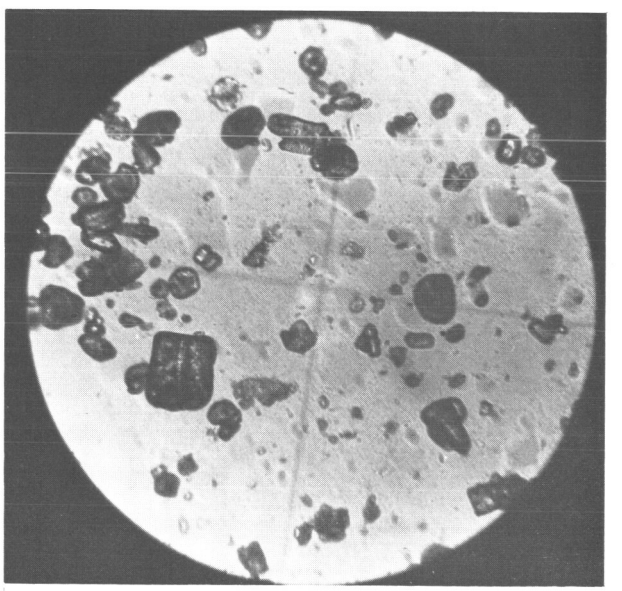
3a
ACL-70 as received



3b
3a with polarized light

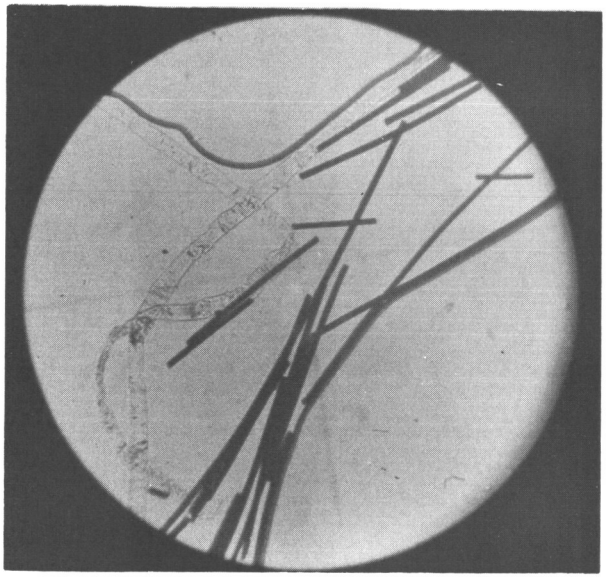


3c
ACL-70 after mortar and pestle

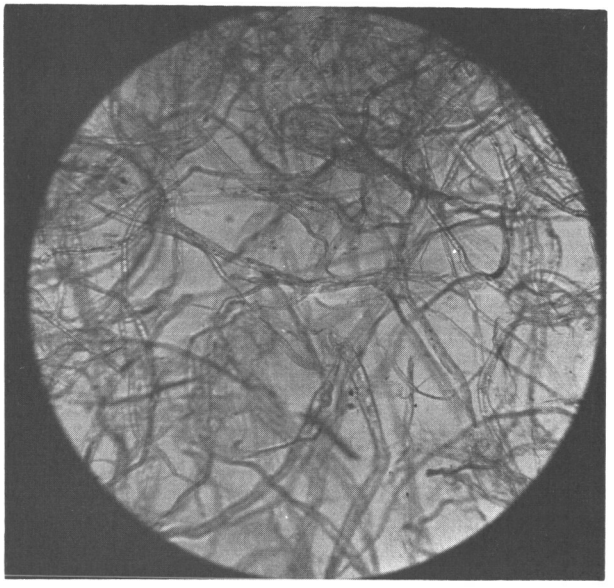


3d
ACL-85 as received

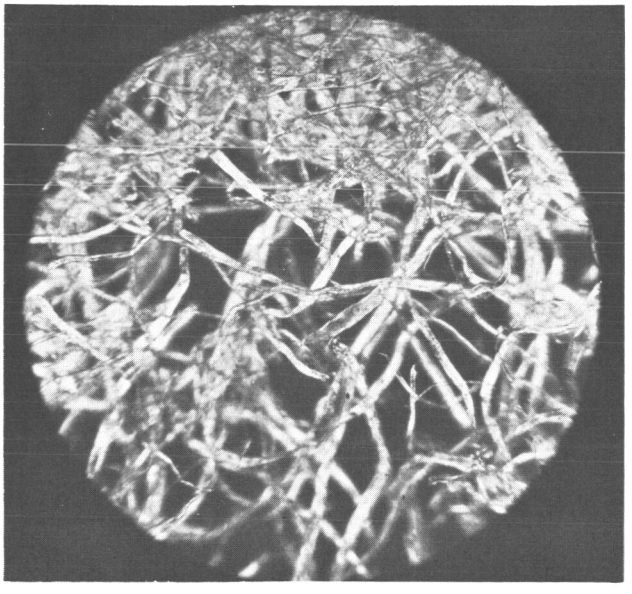
Figure 3. Particle Size of ACL-70 and ACL-85



4a
Carbon Fibers-Thompson Fiber Co.

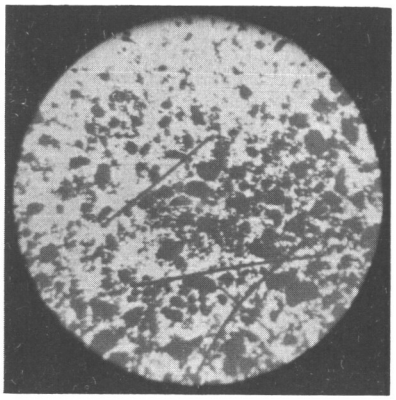


4b
Paper Pulp

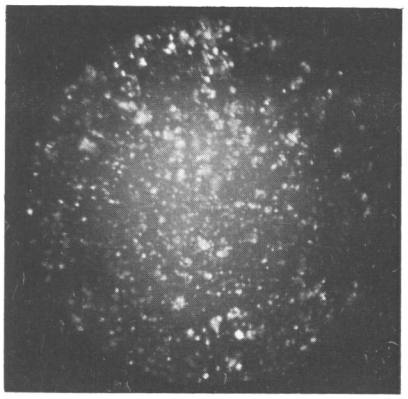


4c
4b with polarized light

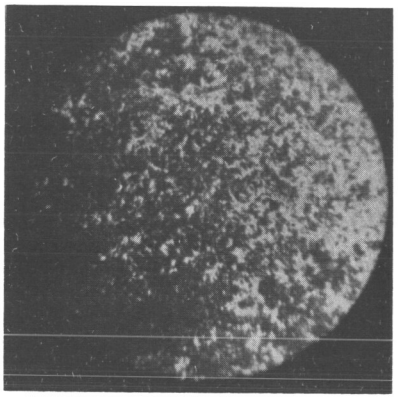
Figure 4. Fiberous Filler Materials



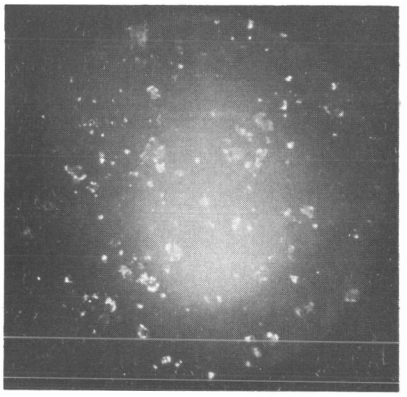
5a
Cathode mix ground with mortar and pestle



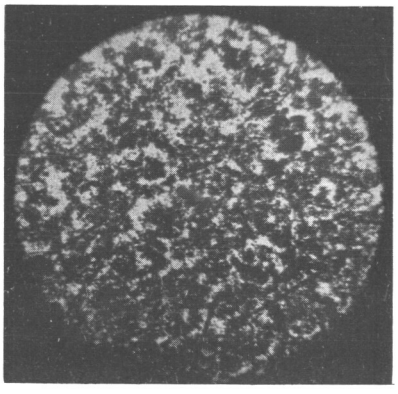
5b
5a with polarized light



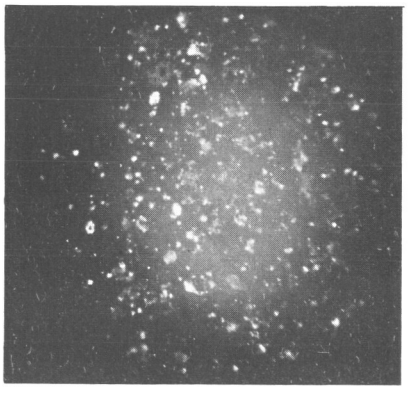
5c
Cathode mix Waring blended



5d
5c with polarized light

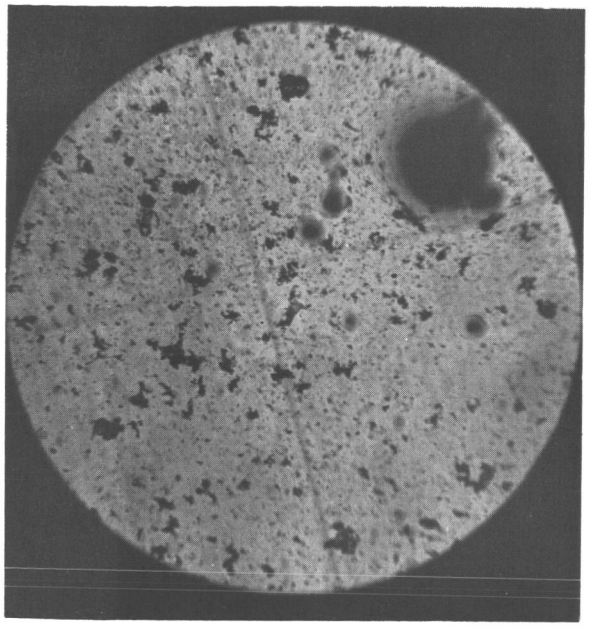


5e
SAB and carbon fibers Waring blended 1 min; ACL-70 mechanically stirred into carbon

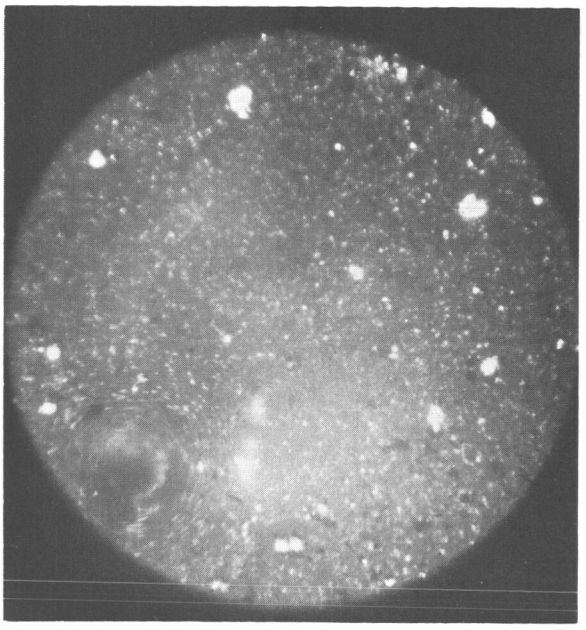


5f
5e with polarized light

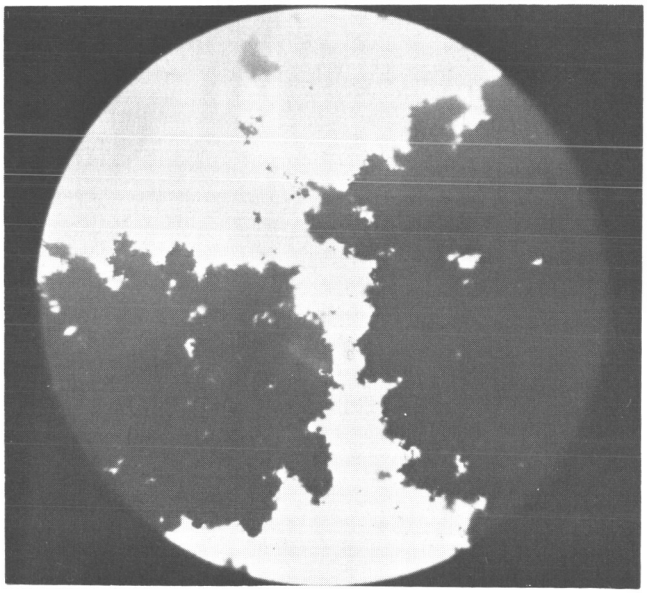
Figure 5. Cathode Mixes (ACL-70, Shawingan Acetylene Blabk and Carbon Fibers) Prepared by Various Blending Techniques



(g)
Trichloroethylene slurry after mechanical stirring



(h)
g with polarized light



(i)
Cathode mix from Patterson-Kelly blender

Figure 6. ACL-85 Cathode Mixes Prepared by Different Blending Techniques.

Wetting of acetylene black was attempted by adding a polar organic liquid with the water. The addition of acetone was tested to improve carbon wet-out. An analysis of tapes 90073, 90075, 90077-2 and 90088 shows no improvement due to acetone (Table 6).

Any surfactant that decreases the surface tension of water is a candidate for increased utilization of electrolyte. Three commercial surfactants were tested. These were DDBSA-94 (dodecylbenzenesulfonic acid-Monsanto Co.) Triton X-100 (Alkyl-phenoxypolyethoxyethanol-Rohm & Haas) and Zonyl A (nonionic type - duPont). An improvement in the use of nonionic surfactants is evident (Table 6). Furthermore, lower electrolyte volumes may be used.

2. Mg/ACL-85 Energy Densities

Initial currents at a constant 2.0 volts in this system approach 1.5 amperes (0.5 amp/in^2). The current decays with time as shown in Figure 7.

Four hours discharge time are needed to obtain the maximum energy density (126 watt-hr/lb) from the cell. However, 60% of the total (80 watt-hr/lb) was obtained after 30 minutes, and 80% (100 watt-hr/lb) after a 1-hr discharge period.

Energy density data as a function of time are given for almost all the cells listed in Table A-1. Data on several of our best aqueous cells are given in Table 7.

3. Analysis of Constant Voltage Discharge Curves

In quarterly Report No. 4, the reasons for the change to a constant voltage discharge were presented, as was a mathematical development which predicted a logarithmic current decay with time. However, when discharge curves were plotted as log i vs time, the plots were not linear as the mathematical model predicted. The logarithmic relationship would be expected to hold if the activity of the electrode varied with the amount of ACL-85 compound remaining; this would include material not dissolved. If, however, the activity is a function of dissolved ACL-85, the relationship might be similar to the equation 1*

$$i = \frac{nFAD^{1/2}C^{0}t^{-1/2}}{\sqrt{\pi}} \qquad (1)$$

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* Delahay, P. "New Instrumental Methods in Electrochemistry", p. 51, Interscience N.Y. (1954).

Table 6

EFFECT OF SURFACTANTS ON $Mg/MgBr_2$/ACL-85 DISCHARGE

Surfactant	No. of Tests	Average Coulombic Efficiency (%)	Average Energy Density after 50 min. (Watt-hr/lb)
		1.20 ml/g	
None	3	51.0	80.3
Acetone	7	50.9	81.9
DDBSA-94	1	49.0	79.0
Zonyl-A	1	59.0	94.0
		1.10 ml/g	
Triton x-100	3	53.7	91.3

Table 7

$Mg/MgBr_2$/ACL-85 ENERGY DENSITIES
(4 hr runs at 20 volts)

Cell	Cathode Efficiency (%)	Energy Density (watt-hr/lb)
90073-5	82	115
90075-6	71	117
90077-2-12	77	118
90077-2-8	76	126
90088-1	69	116

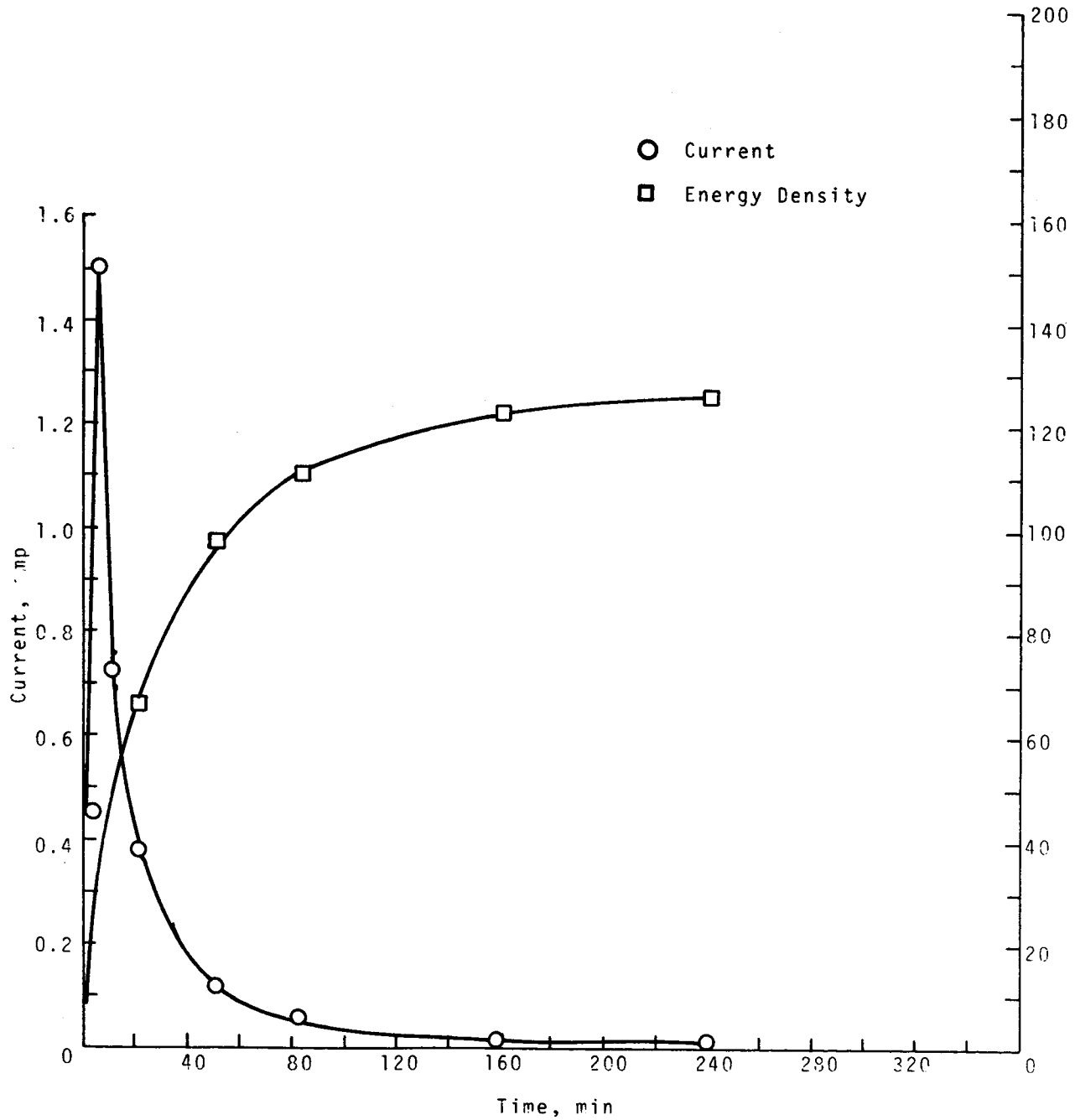

Figure 7. $Mg/MgBr_2/ACL-85$ Cell Current and Energy Density as a Function of Discharge Time (Cell 90077-8)

where n = no. of electrons, F = Faraday constant, A = tape area, D = diffusion coefficient for ACL-85, C° = concentrations of dissolved ACL-85, and t = time. The fact that this current-time dependence is followed is shown in Figure 8. This type of plot is only possible when the tape is discharged after activation so that t = 0 is a well defined point. The above equation assumes that the limitation is diffusion of soluble ACL-85 to the active carbon surface. The derivation assumes an infinite solution layer and an invariant ACL-85 concentration in the bulk of the solution. This concentration would be the solubility of ACL-85 in our case. Equations have been derived for finite solution thicknesses and for partial activation control (voltage control).* However, these equations involve too many parameters for the analysis of our present system. The present analysis shows a sufficient i vs $t^{-1/2}$ dependence to suggest solution concentration control, and to suggest that increasing the solubility (C°) or the effective diffusion coefficient would be beneficial. This indicates that cell improvement can be expected from improvement of process (mixing) variables which decrease the diffusion limit. The intercept of the i vs $t^{-1/2}$ should indicate the entire amount of material available (as $\int idt = nFQ$). In equation 1 the intercept is zero, indicating a relatively infinite supply of material.

It is also possible that the i vs $t^{-1/2}$ dependence is due to some other limiting mass transport phenomenon, such as electrolyte resistance. If the slope can be correlated with an electrolyte property such as conductivity, or ACL-70 solubilization, then this problem can be resolved. At present, this data is not available. However, a mass transport limitation is definitely indicated by the i vs $t^{-1/2}$ relation, and mixing and packing variables are therefore expected to be important.

B. NON-AQUEOUS SYSTEMS

1. General

This quarter, the non-aqueous experiments were converted from constant current to the constant voltage discharge method. The results of these tests are shown in Table A-2. This procedural change makes the aqueous and non-aqueous discharge methods the same, and more closely simulates the dynamic dry tape discharge system.

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* Bowers, R. C., Wilson, A. M. J. Am. Chem. Soc. 81, 1840 (1959)

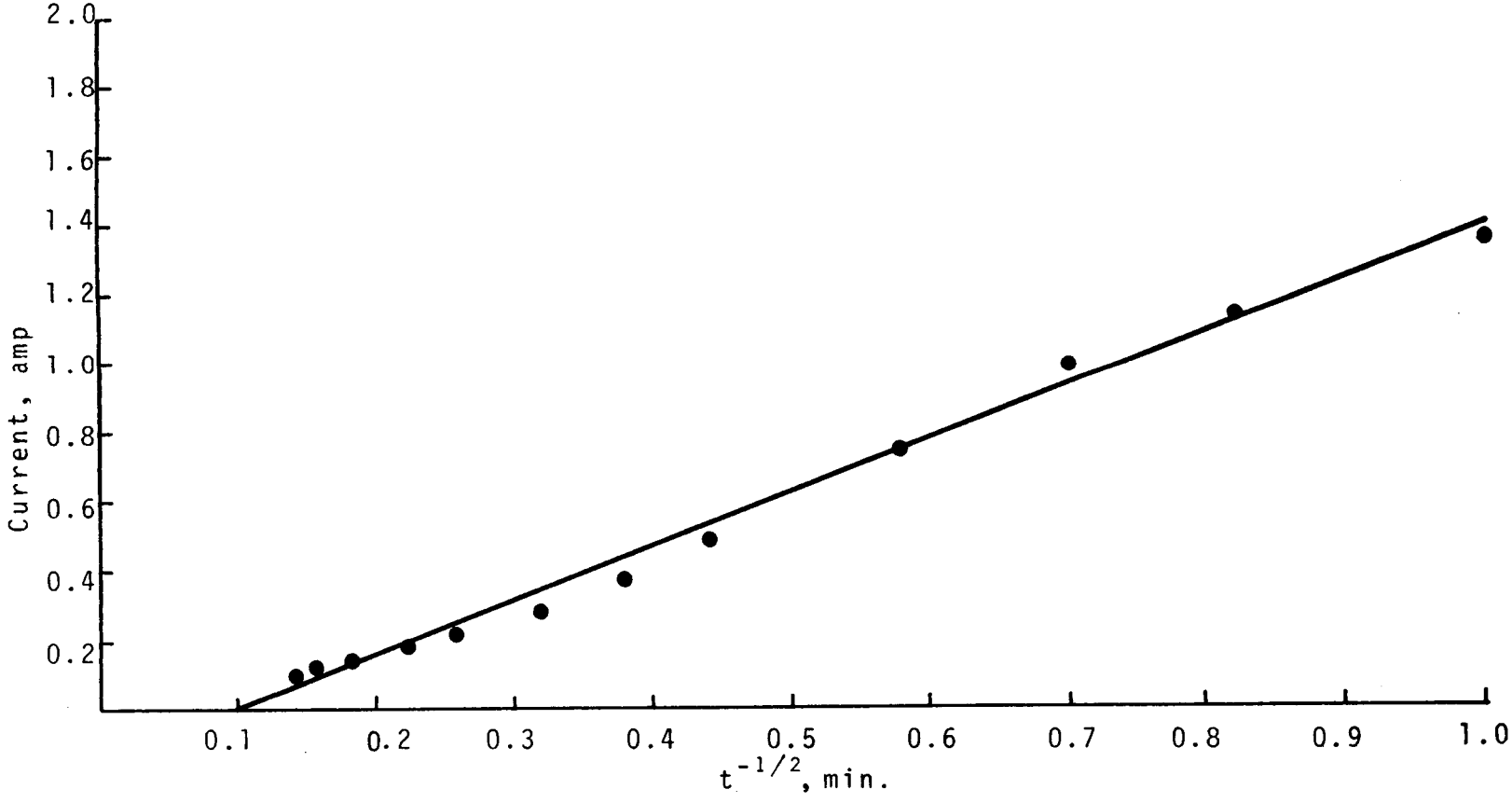

Figure 8. Analysis of Mg/ACL-85 Discharge Data (Cell 90015-4, 2.1 volt).

2. Lithium Anode Research

The standard anode in the non-aqueous program has been 15-mil lithium ribbon packed under argon.

Several etch solutions were tried on this 15-mil strip lithium. Of these, the best was a 1% HCl in DMF solution (Cells 90840, 42, 44-51). This solution caused moderate gassing and a darkened lithium surface. No obvious film was formed. The darkened surface may be indicative of a higher surface area. The cell discharges using this lithium (Cell 90840 and 90847) were similar to those with the unetched lithium (Cell 90843), versus an ACL-70 cathode.

Mechanical cleaning with a wire brush using a Dremel tool gave a shiny surface to the strip lithium. However, it is difficult to avoid gouging the lithium. The discharge using this lithium was slightly inferior to that of the unworked strip (Cell 90839 vs 90843). This technique was tried only once.

A lithium dispersion anode was prepared on a nickel screen (including 10% nickel powder)*. The metals were mixed in a hexane slurry and the slurry was rolled into the screen. The hexane was then removed under vacuum. The anode was tested versus a CuF_2 cathode. An open circuit voltage of 1.0 volt was obtained from this cell and no current could be drawn.

In general, a high surface area anode is not needed in methyl formate cells, and electrolyte retention is presumably a detrimental factor. At present we plan no further experiments with porous lithium anodes.

3. ACL-70 Cathode Research

a. General

The largest effort in this program has been placed on ACL-70 cathodes because of the results of early tests, and because this system has been capable of further improvement. These improvements have been mostly in mixing, packing, and generally improved electrolyte utilization. It is hoped that by optimizing the Li/ACL-70 system, we will also improve the general Li/$LiClO_4$(MF) non-aqueous system.

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* A. Lyall, H. N. Seiger, R. C. Shair, "Lithium Nickel Halide Secondary Battery Investigation", AFAPL-TR-65-128, March 1966.

Li/$LiClO_4$(MF)/ACL-70 cells were found to run most efficiently in the 3.0-3.2 volt range. Voltages were applied after the cell was activated and assembled. Initial currents seldom exceeded 0.2 amp/in.^{2} due, presumably, to the electrolyte resistance. Current decays were slower than in the aqueous cell, however.

Water and acetone were considered to be possible beneficial contaminants in the 144 watt-hr/lb cell reported (Quarterly Report No. 4). Hence, these materials were added in small quantities to several non-aqueous runs. Addition of acetone increased the initial current, but did not significantly improve overall tape performance (Cells 90822-3 compared to Cell 90819). This initial current increase with acetone is presumably not a function of conductivity although electrolyte conductivity with acetone is 1.33×10^{-2} ohm^{-1} cm^{-1} vs. 1.22×10^{-2} ohm^{-1} cm^{-1} for no acetone. The improvement in cell performance may be due to improved cathode wet-out. The effect of 1% water was negligible (Cell 90821 vs 90819).

b. The Effect of Carbon Type

Of all the carbon blacks tested on this program, Shawinigan acetylene black (SAB) has proven best. There are several SAB types, however, and some of these were given additional testing.

For normal packaging, SAB is compressed by 50 or 100%. The 50 per cent compressed material has been used in our standard cathode mixes. A sample of uncompressed SAB was tested (90877). The bulk density of this material is very low and more electrolyte than usual was required to make the cell run. The cell ran poorly compared to those prepared with 50 per cent compressed SAB.

Another type of carbon (NL) was tested because of its reported high absorptive properties. The data from this test were similar to the standard tape discharge (Cell 90879, vs 90875).

c. Separator Research

(1) Thickness

Separator materials are a problem since the standard 3-mil polypropylene separator is porous, and, if the cathode is too wet, the cell appears to short due to carbon saturating the separator. Also, it has been difficult to avoid shorting at the edges since the present cell design does not allow any overlap of separator. The best method to compensate for this defect was to use two separators, wetting one on the cathode and wrapping the

other around the lithium. In this way cells 90881 and 90883 gave 159 and 150 watt-hrs/lb and a heavier cathode (cell 90884) gave 169 watt-hr/lb. This separators shorting problem will probably not be significant in the final design; hence, two separators or a thicker separator will be used to develop the cells in static tests. In the final design it is possible that one 3-mil separator can be used.

(2) Type

Although several separator materials could be used in our tape cell, we have used one to three layers of 3-mil polypropylene in our nonaqueous work. This material has an open structure. Resistance losses have been shown to be very small (Quarterly Report No. 2, p. 21). The elctrolyte retention is slight, which may or may not be an advantage. For comparison, a glass fiber paper (H903E Hollingsworth-Vose) was used as the separator in a Li/ACL-70 cell. This material is 16 mils thick and absorbs large quantities of electrolyte. Thinner glass fiber materials are not readily available. Slicing this material in half gave a separator comparable to the standard polypropylene separator . The glass fiber separator showed no apparent advantages (Cell 90841 vs 90843).

d. Effect of Blending Methods

Several cathodes were prepared by Waring blending the entire mix (90855-62, 90864-66, 90872). Another large group of cathodes (90868, 90873-84) was prepared by Waring blending the SAB and carbon fiber (CF) and tumble mixing in the ACL-70 for 5 minutes. Both methods appear to give comparable performance. The tumble mix is used at present because the all-glass apparatus will not decompose ACL-70. In one test (90863), the entire mix was ground with mortar and pestle. The resulting cathode was dense and required less electrolyte than the standard tapes for equal apparent witness (1.1 ml vs 1.8 ml). However, the discharge was poor. Another tape was prepared from a trichloroethylene slurry (standard tapes are prepared dry). The comparison with the standard tapes indicates no significant differences.

The SAB was Waring blended with the CF because the CF forms aggregates and gives lumps in the tapes unless violent dispersion is used. The effect of Waring blending on the SAB, however, was unknown, in terms of performance. Hence, tapes were run without CF, in order to assess the effect of Waring blending of SAB. The performance was almost identical

(90870-1). The density of the Waring blended SAB cathode was lower since the blender broke the primary agglomerates (see Figure 2). It is also of interest to note that the results of these tests are better than those (90869) in which fibers were used, replacing an equal weight of SAB.

In the tumble mixing of ACL-70 into SAB-CF, some aggregates of ACL-70 remain in the mix. To avoid this, the ACL-70 was ground in a mortar and pestle in the dry box for Tape 90873-88. This did not appear to change the primary particle size (Figure 3) but did improve the performance of the mix.

e. Li/ACL-70 Energy Densities

The high energy densities in the non-aqueous system is achieved only by long discharge times, as compared to aqueous systems. The initial currents seldom exceed 0.20 amp/in^2, and the current decay is slower than in the aqueous system. Figure 9 shows the current and energy density as a function of discharge time. Such curves could be used to predict the penalty of frequent stop-start operation. The figure shows 169 watt-hr/lb at a 12-hour rate, 161 watt-hr/lb at an 8-hour rate, and on down to 105 watt-hr/lb at a 2-hour rate.

Also of great importance is the fact that efficiencies of greater than 50% are now being obtained. This shows that both chlorine atoms on the ACL-70 molecule are electro-active.

Energy densities are given in Table A-2 for many of the cells run this quarter.

f. Analysis of Constant Voltage Discharge Curves

It was found that an i vs $t^{-1/2}$ relationship was followed for aqueous tape discharge (Mg/ACL-85), thus indicating a mass transport limitation. The same type of dependence is found for the non-aqueous discharge. Figure 10 shows dependence for our best cell (cell 90884). The slope of the line is much less than for the aqueous cells, since the current decay is slower.

4. CuF_2 Cathode Research

Because of the importance of water to the solubility of CuF_2 and its discharge in non-aqueous cells, we dried and purified some CuF_2 by grinding and heating it at 150°C in an argon stream. This was followed by heating the CuF_2 to 450°C in a fluorine stream. This treatment should give a powdered material

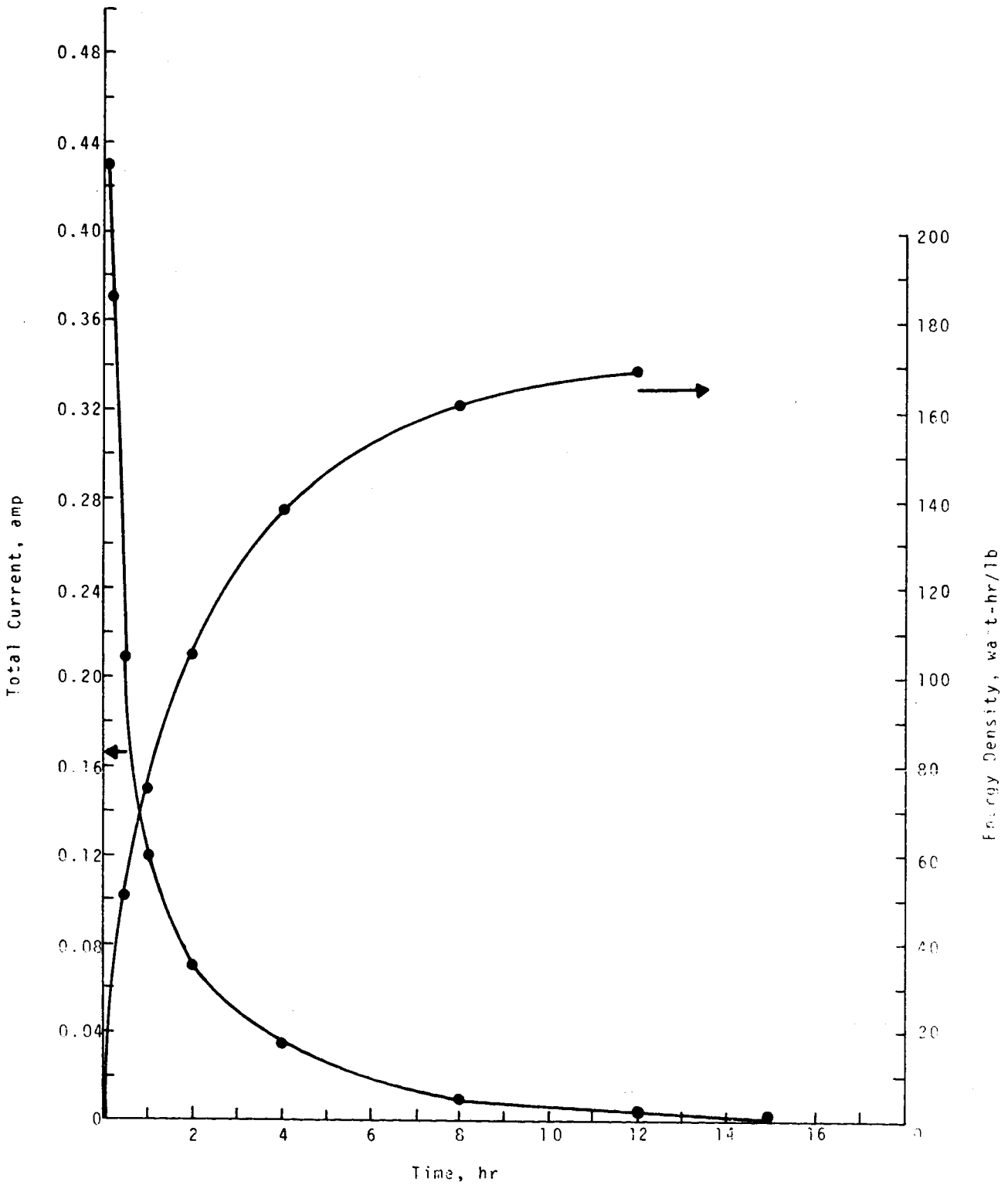

Figure 9. Current and Energy Density of Li/$LiClO_4$(MF)/ACL-70 as a Function of Discharge Time (Cell 90884-3in²).

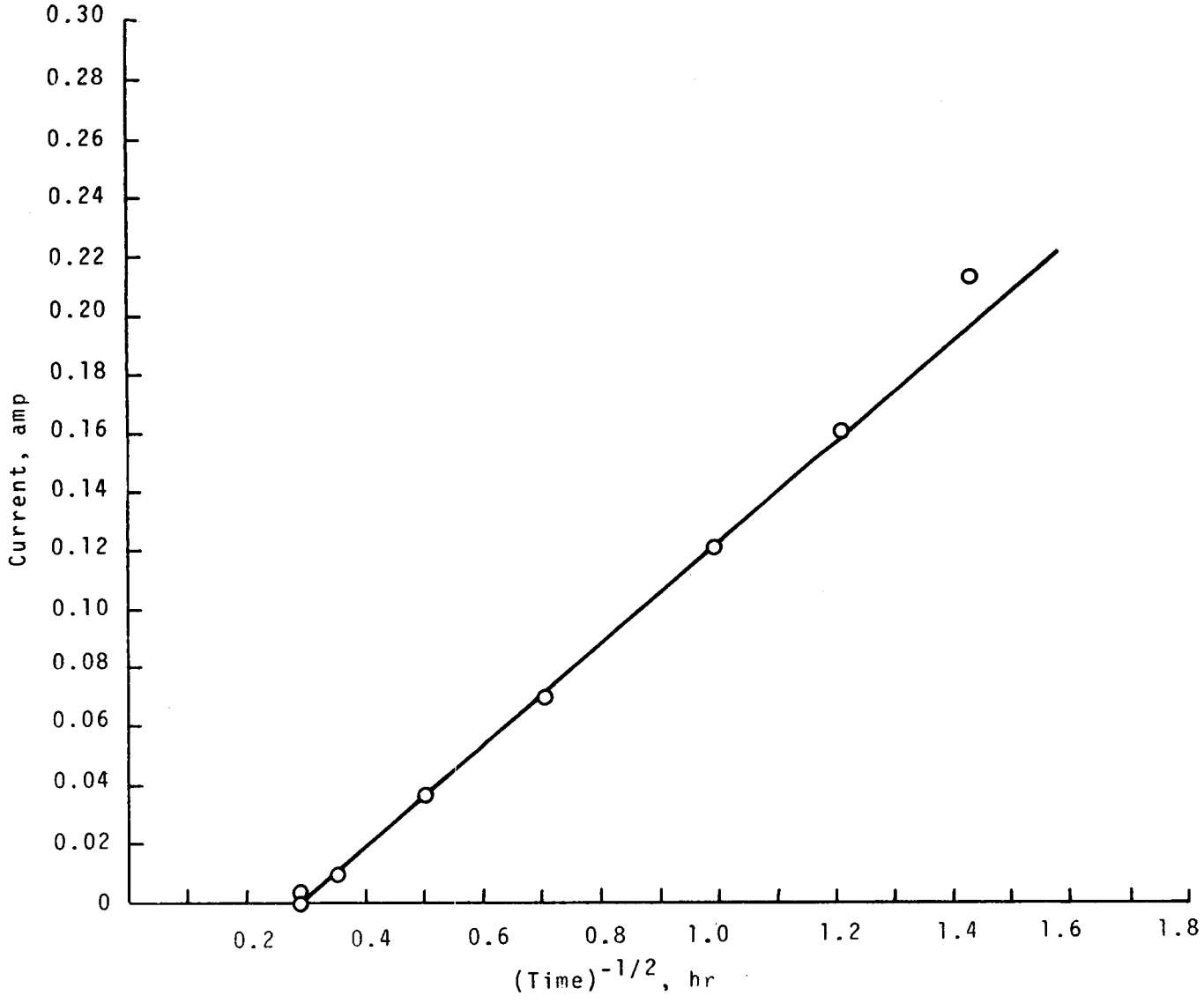

Figure 10 Current-Time Relationship for Non-Aqueous Discharges at Constant Voltage

of a standard high purity, to which water could be added if necessary. A comparison of tapes prepared with CuF_2 (fluorine treated) showed very little difference (Cells 90833-4). The grey color imparted by 150°C heating in argon was elimated by the fluorination, however.

5. LiOCl Cathode Research

A sample of 70% LiOCl had been procured and tested as a cathode in a manner similar to the ACL-70 cathode (Quarterly Report No. 4). The advantage of LiOCl is its presumably simple and total discharge. Also, the 70% sample has an ACL number of 84. The problem with this compound has been one of chemical decomposition.

A series of chlorine analysis were maded on LiOCl, SAB and MF mixtures pressed on glass, platinum, and carbon plates. The analyses were made after 5 minutes stand using 0.1g LiOCl and 0.3 ml of $LiClO_4$(MF). With electrolyte but without SAB, the ACL number was reduced by 23%. With SAB and no MF, the loss is 2%. However, with SAB and MF the loss is 32%. Pressing this mixture on glass, graphite or platinum plates appeared to make no significant difference. However the scatter of data is very large. Hence, there appears to be a decomposition of LiOCl in the electrolyte.

Because of the ability to utilize the second chlorine on ACL-70 in a battery system, and the generally encouraging results of the Li/ACL-70 system little emphasis is currently being placed on the LiOCl system.

6. Electrolyte Studies

a. Nonaqueous Electrolyte Resistance

Using the values for Tape 90875, a 66% electrolyte-filled volume is calculated (thickness cathode, 35 mil, separator, 4 mil and 1.3 ml of electrolyte). Using an electrolyte conductivity of 1.2×10^{-2} ohm^{-1} cm^{-1}, the electrolytic conductivity can be calculated using the formula in Table 4. This cathode mix conductivity is 0.0064 ohm^{-1} cm^{-1}. The resistance from the anodeto the collector is 0.82 ohm, and at 0.4 amperes the IR loss is 0.33 volt which is 33% of the overpotential. This is an unusually high current (obtained only initially), however, since the average current over a four hour period is 0.079 amperes. Using thiscurrent, the IR loss is 6.5% of the overpotential.

b. Methyl Trifluoroacetate as an Electrolyte

Methyl formate has been found to be the best non-aqueous electrolyte for relatively high drain rate applications with lithium. Ethyl formate and methyl acetate have also been tested, but these have shown less favorable performance. Methyl trifluoroacetate was tested this quarter with $LiClO_4$ because it appeared logical that the solvating power of MF is in the ester group and the electronic effect of $-CF_3$ is in the direction of -H rather than $-CH_3$. However, the solubility of $LiClO_4$ in CF_3COOCH_3 was only 5×10^{-2} molar, and the conductivity was 6×10^{-6} ohm^{-1} cm^{-1}. No discharge was attempted.

III. TASK II. TAPE CELL PREPARATION

A. PREPARATION OF MACHINE-MADE ACL-85 CATHODE

1. General

During this report period, an attempt was made to optimize ACL-85 cathode characteristics. Mix variables, including the effect of binders, were studied in machine-made cathodes. The purpose of these experiments was twofold: (1) improvement of mechanical properties, and (2) improvement of electrical characteristics.

The modification of the slurry addition apparatus on the tape making machine has allowed the preparation of 5 foot ACL-85 cathodes. These cathodes were of a quality at least the equal of the carefully standardized 3 $in.^2$ hand-made tapes used in static tests. Small sections (3 $in.^2$) of the machine-made tapes were run statically (Cell 90048). Even though these were the initial tape-making attempts, good electrochemical properties were obtained.

2. Cathodes with Low (67%) ACL-85 Loading

Several binder screening tests were carried out on machine-made cathodes of the following composition:

ACL 85	66.8%
SAB	30.4%
Carbon Fiber	2.8%

The dry mix was blended in a Patterson-Kelly apparatus. The slurry was hand-mixed with trichloroethylene in a non-metallic system. The tapes were prepared on the tape making machine employing a vibrating spreader. The average thickness of the tapes in these tests was 35 mils, including the 4.5-mil inch Dynel separator. The spreader is adjustable allowing the preparation of cathodes of various thicknesses.

Since the tape manufacturing procedure had not been refined, long term runs were not obtained. Sufficient data were obtained, however, to interpret the effect of two binders.

The tape made without binder gave a current density of 0.051 amp/in.^{2} at 2.0 v, 0.185 in/min tape speed, and 2M $MgBr^2$ electrolyte.

Polyvinyl formal (PVF) and polyvinylpyrrolidone (PVP) were investigated as binders in the above mentioned cathode mix. Early in the dry tape work, PVF had been found to improve the strength of the cathode mix. It appeared, however, to be oxidized by ACL-85 (Quarterly Report No. 2).

A saturated solution of PVF in trichloroethylene (5 g/l) was added to the tape cathode. The binder concentration was 7 per cent of the cathode mix. This tape had the following characteristics:

-- Electrical - poor; current density 0.013 amp/in.^{2} at 1.5 volts and 0.25 in/min tape speed.

-- Mechanical - fair; adhesion to the separator was better than with the cathode without binder. A slight separation of the mix and separator occurred when the tape was rolled around a one-half inch rod. The mix did not adhere to the current collector.

-- Conclusion - the addition of PVF binder reduced the electrical output of the tape, but improved its mechanical properties.

When PVP binder was used in the cathode mix, identical electrical characteristics were obtained, but poorer mechanical properties resulted.

3. Cathodes with High (80%) ACL-85 Loading

After having established the cathode manufacturing and testing procedures, the effect of PVF binder on cathodes with greater ACL-85 loading was examined.

The dry mix was composed of:

ACL-85	80%
SAB	16%
Paper Pulp	4%

This mix required less trichloroethylene for the proper slurry density than the 67% mix.

A tape (92453) of the above composition (with no binder) had the following characteristics;

-- Electrical - good; current density 0.10 amp/in.^{2} at 2.1 volts and 0.25 in/min tape speed.

-- Mechanical - fair; the tape was bent around a 0.5-inch rod with some separation and cracking of the cathode mix. The mix did not adhere appreciably to the collector during the 50-minute dynamic run.

An identical tape (92454) with 0.8% of PVF binder added gave the following data:

-- Electrical - poor; tape ran dynamically for less than 5 minutes at 0.1 amp/in.^{2} and 2.2 to 1.1 volt.

-- Mechanical - good; tape easily bent around a one-half inch rod with only slight cracking. Little adhesion to the current collector plate.

-- Conclusion - the PVF binder reduced the electrical output of the tape but improved its mechanical characteristics.

Further refinements of the tape manufacturing procedure are underway. Testing of various PVF concentrations are desirable in order to find the best compromise between electrical output and mechanical strength.

B. TAPE SYSTEMS WITH OXYGEN CATHODES

1. General

A program was undertaken to obtain preliminary data on the applicability of the dry tape concept to the oxygen cathode battery system. Dynamic tests were conducted on an apparatus specially designed for this work (Figure 11). This system consisted of the following components:

(a) A proprietary MRC oxygen electrode.

(b) A block anode.

(c) A moving 1-mil Dynel separator.

(d) An aqueous electrolyte added to the separator just before the anode.

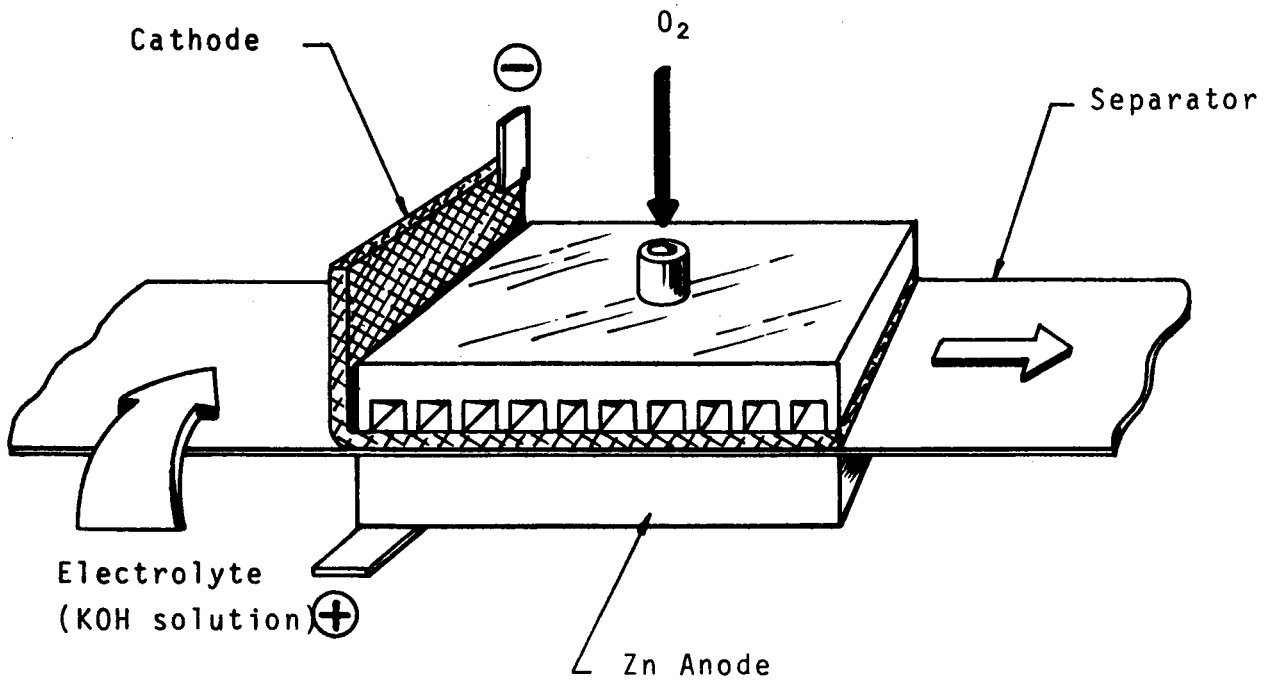

Figure 11 Dynamic Zinc/KOH/Oxygen Tape System

2. The Zinc-Oxygen System

The highest energy density obtained under non-optimized conditions was 127 watt-hr/lb (Table 8). The weights used included the measured weights of electrolyte and separator, and the theoretical weights of oxygen and zinc consumed based on the output of the cell. A very slow tape speed (4.28 in./hr) and a saturated KOH solution were found to give the best results.

The $Zn/KOH/O_2$ system has excellent possibilities for future dry tape studies.

3. The Magnesium-Oxygen System

A single dynamic test was conducted with the Mg/2M $MgCl_2/O_2$ system on an apparatus similar to that described in Figure 11. The results were non-reproducible, presumably owing to the deterioration of the oxygen electrode under the reaction conditions. A modification of the cathode, therefore, would be necessary before any future work could be undertaken.

Table 8

ZINC/OXYGEN CELL CHARACTERISTICS
(Cell 90072b)

Tape (0.0145 g/in^2):	1 mil Dynel
Tape Speed:	4.28 in/hr
Current Collector Areas:	3.0 in^2
Electrolyte (d = 1.54 g/ml):	Saturated KOH
Electrolyte Used:	0.0365 g/in^2
Current Collector No. 1:	1.3 v @ 0.10 amp
Current Collector No. 2:	1.2 v @ 0.11 amp
Power:	0.262 watt
Measured Weight of Electrolyte:	0.468 g
Measured Weight of Separator:	0.147 g
Theoretical Weight of Zinc:	0.255 g
Theoretical Weight of Oxygen:	0.063 g
Total Cell Weight:	0.933 g

ENERGY DENSITY

$$\frac{(0.262 \text{ watt-hr})\ (454 \text{ g/lb})}{(0.933 \text{ g})} = 127 \frac{\text{watt-hr}}{\text{lb}}$$

IV. TASK III. SUPPORTING RESEARCH

A. ROLLING CATHODE CURRENT COLLECTOR

Evaluation of a carbon rolling current collector was begun this quarter. This device has a 2-inch diameter with 5.5 $in.^2$ being utilized to collect current. Tests showed that up to 1 $watt/in.^2$ could be maintained with $Mg/AlCl_3$/ACL-85 tapes, at least for limited periods. Electrolyte addition was manual. Adhesion of the cathode mix to the current collector was still a problem. The size of this collector was large enough to permit electrical evaluation, but too small to allow the addition of a scraper for removal of adhering carbon.

A six-inch diameter current collector was fabricated. The cathode adhesion was still apparent, even with scraping. At the present state of development, a static current collector appears more feasible than a rolling collector.

B. PRESSURIZED TESTING CHAMBER

The high volatility of methyl formate has led us to design a pressure chamber (Quarterly Report No. 4) which was tested this quarter. The chamber was pressurized to 20 psi with argon, and the cell was discharged in the chamber in the dry box. The cell appeared wetter than usual after 160-minute discharge was completed (Cell 90831).

The pressure cell has yielded erratic results. While several cells have given almost no discharge, some very good results also have been obtained from this apparatus (e.g. Cell 90844). A series of experiments was conducted in the pressure cell at high voltage to obtain a long, sustained discharge without evaporation. The results show 3.0 volts to be preferred to 3.2 or 3.5 volts.

This cell will be useful for the quantitative determination of cell gassing.

V. FUTURE PLANS

A. AQUEOUS SYSTEMS

1. The effect of surfactants on ACL-85 cathode performance will be studied.

2. The effect of $MgBr_2$ electrolyte molarity on performance will be evaluated.

3. Machine-made cathodes will be optimized for electical and mechanical properties.

4. Further studies will be carried out in the Mg/Br_2 liquid cathode system.

B. NON-AQUEOUS SYSTEMS

1. The effect of electrolyte concentration ($LiClO_4$-methyl formate) on cell performance will be determined.

2. Separators thicker than 3 mil polypropylene will be evaluated to reduce any possible cell shorting.

3. The difficulties encountered with the pressurized test chamber will be resolved.

4. The effect of cathode formation pressure will be studied.

Table A-1a

CONSTANT VOLTAGE STATIC DISCHARGE OF
Mg/ACL-85 AQUEOUS TAPES

Cell No.	Electrolyte Type	Electrolyte Volume ml	Voltage v	Coulombic Efficiency %	Current (amp) at Time (min) 1	2	5	10	20	50	Final Time min	Final Current amp	Theoretical Capacity (amp-min)	Comments
					Tape 90033									
	(67 parts ACL-85, 30 SAB, 3 paper pulp - Waring Blendor, 2 min - 6% ACL loss in processing)													
1	2M $MgBr_2$	2.00	2.0	27	1.10	0.83	0.43	0.27	0.16	0.10	50	0.10	33.0	
2	2M $MgBr_2$	1.74	2.0	31	1.18	0.85	0.41	0.25	0.16	0.10	50	0.10	28.4	
3	2M $MgBr_2$	2.12	2.0	24	0.97	0.79	0.40	0.22	0.14	0.08	50	0.08	34.7	
4	2M $MgBr_2$	2.00	2.0	28	0.95	0.76	0.40	0.24	0.16	0.09	50	0.09	33.2	
5	2M $MgBr_2$	1.83	2.0	29	0.82	0.65	0.34	0.21	0.14	0.08	50	0.08	30.1	
9	2M $MgBr_2$	1.77	2.0	22	0.63	0.46	0.24	0.17	0.10	0.07	50	0.07	28.9	
10	2M $MgBr_2$	1.75	2.0	25	0.67	0.49	0.31	0.20	0.12	0.08	50	0.08	28 7	
					Tape 90037									
	(67 parts ACL-85, 30 SAB, 3 Carbon Fiber - Waring Blendor, 45 sec)													
1	1.5M $AlCl_3$+ 0.5M $MgCl_2$	1.87 +0.7	2.4	42 48	2.1	2.23	0.89	0.24	0.10		33 52	0.06 0.10	30.7	
2	1.5M $AlCl_3$+ 0.5M $MgCl_2$	1.74 +0.8	2.4	41	0.38	0.64	1.08	0.52	0.12		34 50	0.06 0.08	28.6	
3	1.5M $AlCl_3$+ 0.5M $MgCl_2$	3.86	2.4	41	0.99	1.17	1.17	0.61	0.13		30	0.06	31.6	3.4 ml/g
4	2M $MgBr_2$	1.94	2.0	43 78	1.95	1.20	0.67	0.42	0.21	0.10	161	0.06	31.7	
5	2M $MgBr_2$	1.82 +0.5	2.0	45 60	1.89	1.20	0.70	0.46	0.23	0.10	126	0.06	29.8	Pressed before testing, 25 psi - 30 sec.
6	2M $MgBr_2$	2.3	2.0	55 66	1.70	1.38	0.91	0.61	0.37	0.16	93	0.06	35.9	Pressed before testing, 25 psi - 30 sec.
					Tape 90039									
	(67 parts ACL-85, 30 SAB, 3 paper pulp - Waring Blendor, 90 sec - 3% ACL loss in processing)													
1	2M $MgBr_2$	1.76	2.0	34	0.99	0.72	0.44	0.26	0.17	0.11	50	0.11	28.9	
4	2M $MgBr_2$	1.60	2.0	46	1.14	0.90	0.50	0.31	0.20	0.12	50	0.12	27.3	Pressed at 200 psi for 30 sec.
10	2M $MgBr_2$	1.77	2.0	40	1.03	0.77	0.52	0.31	0.20	0.11	50	0.11	28.9	Pressed at 425 psi for 30 sec.
12	2M $MgBr_2$	1.82	2.0	32	0.97	0.75	0.45	0.28	0.17	0.10	50	0.10	29.8	
7	2M $MgBr_2$	1.77	2.0	30	1.23	0.75	0.36	0.22	0.15	0.09	50	0.09	29.1	200 psi - 30 sec. Wet thru cathode
9	2M $MgBr_2$	1.60	2.0	30	1.06	0.73	0.36	0.23	0.13	0.09	50	0.09	27.2	200 psi - 30 sec. Wet thru cathode

Table A-1a (continued)

CONSTANT VOLTAGE STATIC DISCHARGE OF
Mg/ACL-85 AQUEOUS TAPES

Cell No.	Electrolyte Type	Electrolyte Volume ml	Voltage v	Coulombic Efficiency %	Current (amp) at Time (min) 1	2	5	10	20	50	Final Time min	Final Current amp	Theoretical Capacity (amp-min)	Comments
					Tape 90042									
					(67 parts ACL-85, 30 SAB, 3 paper pulp - 45 sec Waring Blendor)									
1	2M $MgBr_2$	2.09	2.0	44	1.38	1.18	0.70	0.45	0.25	0.12	50	0.12	34.3	
10	2M $MgBr_2$	1.76	2.0	46	1.89	1.41	0.64	0.38	0.20	0.10	50	0.10	28.9	
12	2M $MgBr_2$	1.75	2.0	49	1.35	0.91	0.52	0.32	0.20	0.08	50	0.08	24.3	2 ml/g
11	2M $MgBr_2$	1.96 +0.5	2.0	38 55	1.50	1.06	0.48	0.28	0.17	0.11	50 115	0.11 0.08	32.0	Wet thru cathode
					Tape 90044									
					(65 parts ACL-85, 32 SAB, 3 paper pulp - stir slurry with glass, 3 min - 5% ACL loss in processing)									
1	2M $MgBr_2$	1.40	2.0	54	2.08	1.59	0.76	0.41	0.20		45	0.06	22.3	Voltage set before activation from here on
5	2M $MgBr_2$	1.32	2.0	60	2.36	2.10	0.79	0.36	0.13		45	0.06	1.98	
6	2M $MgBr_2$	1.52	2.0	74	2.46	2.31	1.07	0.48	0.18		37	0.06	24.1	Pressed at 200 psi for 2 min.
					Tape 90047									
					(65 parts ACL-85, 32 SAB, 3 paper pulp - stir slurry 3 min)									
1	2M $MgBr_2$	2.20	2.0	59 65	1.60	2.07	1.24	0.56	0.28	0.12	81	0.06	34.9	
2	2M $MgBr_2$	2.26	2.0	68 85	2.01	2.80	1.05	0.53	0.31	0.15	91	0.06	35.9	
3	2M $MgBr_2$	2.32	2.0	53 69	1.08	2.52	0.84	0.52	0.26	0.15	103	0.06	36.9	Pressed at 200 psi for 2 min.
5	2M $MgBr_2$	2.22	2.0	60 63	1.12	2.40	1.06	0.57	0.28	0.09	62.75	0.06	35.3	Pressed at 400 psi for 2 min.
					Machine-Made Tape 90048									
1	2M $MgBr_2$	2.10	2.0	70	0.45	2.55	1.71	0.86	0.31		38	0.06	33.2	
2	2M $MgBr_2$	2.25	2.2	55 66	0.90	1.80	1.05	0.51	0.31	0.12	93	0.06	35.8	

Table A-1a (continued)

CONSTANT VOLTAGE STATIC DISCHARGE OF
Mg/ACL-85 AQUEOUS TAPES

Cell No.	Electrolyte Type	Electrolyte Volume ml	Voltage v	Coulombic Efficiency %	Current (amp) at Time (min) 1	2	5	10	20	50	Final Time min	Final Current amp	Theoretical Capacity (amp-min)	Comments
					Tape 90049									
					(65 parts ACL-85, 32 SAB, 3 paper pulp - stir slurry 3 min - 3% ACL loss)									
1	2M $MgBr_2$	2.05	2.0	56 66	0.90	1.81	0.91	0.52	0.22	0.12	89	0.06	32.6	
3	2M $MgBr_2$	2.05	2.0	55 63	1.85	1.74	1.99	0.40	0.22	0.12	87	0.06	32.4	
4	2M $MgBr_2$	2.23	2.2 2.0	47 75	1.31	1.41	0.89	0.35	0.19	0.12	162	0.06	35.4	200 psi for 2 min. 2 volts set at 20 min.
8	2M $MgBr_2$	1.88	2.2 1.5	63 78	0.83	1.45	0.68	0.61	0.30	0.15	85	0.06	29.8	200 psi for 2 min.
6	2M $MgBr_2$	2.07	2.0	60 68	1.77	2.01	1.06	0.47	0.23	0.12	76	0.06	32.9	
					Tape 90051									
					(65 parts ACL-85, 15 SAB, 3 paper pulp - stir dry 2 min, stir slurry 3 min)									
2	2M $MgBr_2$	1.76	2.2	48 61	0.69	1.27	0.76	0.42	0.25	0.11	98	0.06	33.5	1.7 ml/g 200 psi for 2 min.
3	2M $MgBr_2$	1.51	2.2	48	0.96	0.97	0.85	0.46	0.25	0.08			32.6	1.5 ml/g 200 psi for 2 min.
4	2M $MgBr_2$	1.83	2.0	61 67	1.83	1.84	1.00	0.63	0.34	0.09	79	0.06	34.8	1.7 ml/g 200 psi for 2 min.
5	2M $MgBr_2$	2.39	2.0	50 62	0.94	2.10	1.57	0.75	0.36	0.13	113	0.06	51.6	1.5 ml/g 200 psi for 2 min.
6	2M $MgBr_2$	2.37	2.2	32 54	0.30	1.10	0.76	0.48	0.27	0.13	157	0.06	51.2	1.5 ml/g 200 psi for 2 min.
1	2M $MgBr_2$	1.52	2.0	59 65	0.69	1.92	0.96	0.56	0.28	0.11	74	0.06	32.5	1.5 ml/g 200 psi for 2 min.
8	2M $MgBr_2$	1.20	2.0	69	1.57	1.92	1.12	0.54	0.25	0.06			25.9	1.5 ml/g 200 psi for 2 min.
7	2M $MgBr_2$	1.38	2.0	69	1.80	1.76	1.05	0.63	0.37	0.06			26.3	1.7 ml/g 200 psi for 2 min.

Table A-1b

CONSTANT VOLTAGE STATIC DISCHARGE OF
Mg/ACL-85 AQUEOUS TAPES

Cell No.	Electrolyte 2M $MgBr_2$ Volume (ml/g Cathode)	Operating Voltage	Coulombic Efficiency	Current (amp) at t(min) 1	2	5	10	20	50	Final* T min	Final* I amp	Theoretical Capacity amp min	Notes
				Tape 90054-1									
				(65 Parts ACL-85, 15 SAB, 3 Paper Pulp - Mix 2 min Dry and 3 min Wet - Pressed 200 psi for 2 min)									
1	1.5	2.2	56	1.02	1.15	0.48	0.30	0.20	0.07	53	0.06	20.5	
2	1.3	2.2	49	0.90	1.16	0.49	0.22	0.13	0.07	51	0.06	23.8	
3	1.5	2.0	62	1.71	1.92	0.79	0.46	0.19		43	0.06	24.7	
4	1.3	2.0	59	2.25	1.70	0.76	0.39	0.17		43	0.06	25.8	
5	1.5	2.0	53 61	1.86	1.95	1.05	0.60	0.31	0.10	50 82	0.10 0.06	40.9	
6	1.3	2.0	56 59	1.05	2.13	1.26	0.67	0.31	0.08	50 67	0.08 0.06	38.8	
				Tape 90054-2									
				(65 Parts ACL-85, 32 SAB, 3 Paper Pulp)									
7	1.7	2.2	48 63	0.45	1.40	1.68	0.45	0.17	0.08	50 102	0.08 0.06	26.0	
8	1.5	2.2	47 60	0.48	1.38	0.60	0.24	0.11	0.08	50 101	0.08 0.06	24.9	
9	1.7	2.0	72 73	1.83	1.42	0.76	0.41	0.23	0.08	50 58	0.08 0.06	25.1	
10	1.5	2.0	55 59	1.05	1.86	0.66	0.37	0.21	0.08	50 65	0.08 0.06	26.0	
				Tape 90054-3									
				(65 Parts ACL-85, 10 SAB, 3 Paper Pulp - 3% ACL Loss in Processing)									
11	1.5	2.0	50 55	1.11	1.41	0.61	0.38	0.22	0.09	50 65	0.09 0.06	28.2	
12	1.3	2.0	37 44	1.68	1.00	0.55	0.35	0.22	0.09	50 83	0.09 0.06	37.6	
13	1.5	2.0	47	1.05	0.61	0.34	0.22	0.13		42	0.06	17.9	
14	1.3	2.0	44	1.05	0.63	0.33	0.22	0.11		39	0.06	17.7	
15	1.3	2.0	33 36	1.21	0.73	0.50	0.31	0.19	0.08	50 76	0.08 0.06	38.6	
17	1.5	2.0	45	0.96	0.67	0.42	0.27	0.18	0.07	58	0.06	24.6	Punched Mg Anode

Table A-1b (continued)

CONSTANT VOLTAGE STATIC DISCHARGE OF
Mg/ACL-85 AQUEOUS TAPES

Tape 90058-1

(65 Parts ACL-85, 15 SAB, 3 Paper Pulp - No dry Mixing, Stir Slurry 3 Min)

2	1.5	2.2	53 59	1.53	1.15	0.70	0.43	0.25	0.10	50 76	0.10 0.06	31.6	
4	1.5	2.2	42 47	1.02	1.27	0.59	0.34	0.19	0.10	50 83	0.10 0.06	32.2	Punched Mg (etched)
3	1.5	2.0	63	1.50	2.26	0.99	0.57	0.27	0.07	55	0.06	31.3	
1	1.5	1.9 2.2	51 73	1.06	1.59	1.80	0.89	0.38	0.19	50 170	0.19 0.06	57.6	

Tape 90058-2

(65 Parts ACL-85, 32 SAB, 3 Paper Pulp - Slurry Mixed for 3 Min at 10°C)

5	1.7	2.0	52 60	0.14	0.33	1.37	0.61	0.22	0.08	50 87	0.08 0.06	32.5	Add Electrolyte 1/2 first, 1/2 at 3 min.
7	1.7	2.0	56 60	0.30	0.51	0.63	0.33	0.46	0.13	50 88	0.13 0.06	33.8	Add Electrolyte 2/3-first, 1/3 at 10 min.
6	1.7	2.0	62 71	0.90	1.80	1.51	0.58	0.26	0.13	50 86	0.13 0.06	35.3	
8	1.5	2.0	40 59	0.27	1.35	1.25	0.60	0.21	0.10	50 159	0.10 0.06	42.4	1% $LiCrO_4$
9	1.5	2.0	41 54	0.96	1.26	1.06	0.42	0.22	0.11	50 124	0.11 0.06	41.4	1% Acetone

Tape 90061

(65 Parts ACL-85, 15 SAB, 3 Paper Pulp - Slurry Mixed 1.5 Min)

1	1.5	2.0	61 64	2.29	1.95	1.05	0.54	0.22	0.08	50 84	0.08 0.06	31.1	
5	1.5	2.0	49 61	1.59	2.40	1.06	0.47	0.65	0.18	50 117	0.18 0.06	55.3	Add Electrolyte 2/3 first, 1/3 at 15 min.
2	1.3	2.0	58	1.87	2.10	1.20	0.55	0.23	0.07	56	0.06	35.9	
6	1.2	2.0	41 54 65	0.90	2.30	1.46		0.30	0.23	38 126 188	0.06 0.06	62.7	0.3 ml at 38 min, 0.4 ml at 126 min Anode corrosion extreme
3	1.2	2.0	50 53	1.50	2.19	1.04	0.49	0.24	0.08	68	0.06	37.8	
4	1.2	2.0	57	2.30	2.36	1.20	0.50	0.19		44	0.06	33.5	1% Acetone

Table A-1b (continued)

CONSTANT VOLTAGE STATIC DISCHARGE OF
Mg/ACL-85 AQUEOUS TAPES

Tape 90064

(65 Parts ACL-85, 15 SAB, 3 Paper Pulp - Mix Slurry 1.5 Min)

1	1.0	2.0	44	1.90 2.47 1.16 0.51	0.24 0.08	50 0.08	47.5	1% Acetone	
			47			69 0.06			
			60			117 0.06		0.35 ml added	
			67			151 0.06		0.30 ml added	
2	1.0	2.2	35	1.22 2.07 1.67 0.52	0.23 0.10	50 0.10	51.9	1% Acetone	
			40			79 0.06			
			53			140 0.06		0.3 ml added	

Tape 90065

(65 Parts ACL-85, 15 SAB, 3 Paper Pulp - Mix 10 Min, Tumbled Dry and 1.5 Min in Slurry)

1	1.0	2.0	34	1.14 2.08 0.64 0.41	0.20 0.08	50 0.08		1% Acetone	
			39			85 0.06			
			53			155 0.06		0.36 ml added	

*Time used for calculation of efficiency

Table A-1

$Mg/MgBr_2$/ACL-85® AQUEOUS STATIC TESTS
Constant Voltage: 2.0 volts

Cell	Electrolyte Molarity	Electrolyte Quantity[a] (ml/g)	Theoretical Capacity (amp-min)	Cathode Thickness (mils)	Time (min)	Efficiency (%)	Energy Density (watt-hr/lb)	Remarks
			Reference 90091					
	80% ACL-85, 8% SAB, 8% Spheron 6 (granhite), 4% Paper Puln, Cathodes Pressed at 300 lb.							
4	2	1.2	35.6		50	37	58	
					106	55	86	
			Reference 90094					
	80% ACL-85, 16% SAB, 4% Paper Pulp, Cathodes Pressed at 300 lb.							
10	2	1.1	35.0	28	60	45	73	1% Triton X-100
9	2	1.1	40.2	33	60	51	85	No Triton X-100
8	2	1.1	35.7	31	60	60	99	0.1% Triton X-100
7	2	1.1	34.0		60	66	106	0.01% Triton X-100
6	2	1.1	35.9		60	63	103	0.001% Triton X-100
5	1	1.1	31.3		60	49	81	
4	0.5	1.1	35.8		60	29	52	
3	1.5	1.1	32.8		60	63	103	
1	4.3	1.1	31.7	27	60	55	78	
2	3	1.1	30.2	28	60	59	89	

Table A-1c (continued)

$Mg/MgBr_2/ACL\text{-}85^{®}$ AQUEOUS STATIC TESTS
Constant Voltage: 2.0 volts

Cell No.	Electrolyte Volume (2M $MgBr_2$) ml/g Cathode	Operating Voltage Volts	Coulombic Efficiency %	Current (amp) at time (min) 1	2	5	10	20	50	Final(1) T min	Final(1) I amp	Theoretical Capacity amp min	Cathode Thick. (mils)	Cathode Resist.(2) (ohms)	Energy Density (w-hr/lb)	Notes
Tape 90073 (80% ACL-85, 16% SAB, 4% Paper pulp - Slurry stirred 1.5 min. - Discharge 4 psi)																
1	1.2	2.0	46	1.17	1.98	0.71	0.46	0.23	0.10	50	0.10	40.0			71	
	+0.3 (7)		63							105	0.06				86	
6	1.5	2.0	52	1.80	1.92	1.26	0.63	0.27	0.10	50	0.10	40.1			75	
			60							79	0.06				87	
	+0.2 (7)		69							119	0.06				94	
4	1.2	2.0	50	2.31	1.47	0.93	0.57	0.29	0.12	50	0.12	42.2			80	1% acetone
			61							97	0.06				96	
	+0.2 (7)		68							129	0.06				98	
5	1.5	2.0	49	1.06	1.01	0.84	0.62	0.41	0.20	50	0.20	46.3	46		72	(5)
			76							148	0.06				110	
	+0.2 (7)		82							190	0.06				115	
3	1.2	2.0		1.23	0.93	0.47	0.35					37.1	36		69	
	+0.6		44					0.35	0.14	50	0.14				89	
			56												84	
2	1.5	2.0	60	0.90	1.82	1.29	0.72	0.42	0.13	50	0.13	41.5	45		96	
			68							98	0.06				97	
	+0.2		75							130	0.06					
Tape 90075 80% ACL-85, 16% SAB, 4% Paper pulp																
5	1.5	2.0	57	1.23	1.72	1.35	0.78	0.45	0.15	50	0.15	45.9	40	50	83	
			65							84	0.06				94	
	+0.3		69							102	0.06				91	
7	1.5	2.0	48	0.96	1.17	0.81	0.54	0.33	0.15	50	0.15	39.5			69	(4)
			61							103	0.06				87	
8	1.5	2.0	54	1.16	1.56	1.04	0.66	0.39	0.18	50	0.18	44.5	41	47	68	(5)
			70							110	0.06				102	
9	1.5	2.0	55	1.17	1.47	0.86	0.558	0.38	0.17	50	0.17	40.2	38	57	79	(6)
			68							96	0.06				97	
2	1.5	2.0	56	1.17	1.53	1.08	0.67	0.41	0.20	50	0.20	43.4	42	59	82	
			72							105	0.06				104	
	+0.4		78							145	0.06				97	
4	1.5	2.0	62	1.50	1.89	1.17	0.70	0.48	0.16	50	0.16	42.2			89	
			70							86	0.06				100	
6	1.2	2.0	60	1.23	1.68	1.76	0.77	0.46	0.17	50	0.17	45.3			98	1% acetone
			71							99	0.06				117	
12	1.2	2.0	52	1.06	1.93	1.07	0.70	0.37	0.15	50	0.15	45.3			85	1% acetone
1	1.2	2.0	49	0.56	1.23	0.97	0.58	0.31	0.11	50	0.11	38.6			78	1% acetone
			55							81	0.06				88	
	+0.3		65							124	0.06				90	

Table A-1c (continued)

$Mg/MgBr_2/ACL\text{-}85^{®}$ AQUEOUS STATIC TESTS
Constant Voltage: 2.0 volts

Cell No.	Electrolyte Volume (2M $MgBr_2$) ml/g Cathode	Operating Voltage Volts	Coulombic Efficiency %	Current (amp) at time (min) 1	2	5	10	20	50	Final(1) T min	Final(1) I amp	Theoretical Capacity amp min	Cathode Thick. (mils)	Cathode Resist.(2) (ohms)	Energy Density (w-hr/lb)	Notes
11	1.2	2.0	43	0.75	1.66	0.35	0.45	0.29	0.14	50	0.14	43.5			70	1% acetone
			54							101	0.06				88	
	10.3		63							142	0.06				90	
10	1.2	2.0	45	0.90	1.55	0.85	0.57	0.31	0.14	50	0.14	41.5	39	46	72	1% acetone
			54							84	0.06				87	
	+0.4		71							152	0.06				99	
				Tape 90077-1												
				80% CDB-85, 16% SAB, 4% Paper pulp												
3	1.2	2.0	33	0.26	1.02	0.61	0.39	0.19	0.13	50	0.13	43.7	47	72	52	1% acetone
			47							112	0.06				76	
4	1.3	2.0	37	1.16	1.19	0.63	0.40	0.25	0.13	50	0.13	43.2	46	76	58	
			55							131	0.06				86	
				Tape 90077-2												
				80% ACL-85, 16% SAB, 4% Paper pulp, Discharge at 8 psi												
7	1.2	2.0	57	1.32	1.70	1.12	0.61	0.35	0.13	50	0.13	37.8	39	53	70	1% acetone
			63							79	0.06				99	
12	1.1	2.0	47	1.14	2.05	1.24	0.61	0.29	0.13	50	0.13	46.3	45	47	81	0.1% Triton x-100
			54							82	0.06				94	
	+0.2		77							480	0.007				118	
9	1.2	2.0	49	1.23	2.13	1.65	0.68	0.37	0.14	50	0.14	41.4	45	52	79	0.1% DDBSA-94
			62							83	0.06				100	
	+0.4		78							143	0.06				107	
10	1.2	2.0	59	1.20	1.47	1.16	0.62	0.35	0.13	50	0.13	37.9	37	59	94	0.1% Zonyl A
			66							81	0.06				105	
	+0.4		83							240	0.010				108	
8	1.1	2.0	57	0.26	0.45	1.50	0.72	0.38	0.12	50	0.12	38.7			97	0.1% Triton x-100
			66							82	0.06				111	
			76							240	0.007				126	
				Tape 90086-1												
				80% ACL-85, 12% SAB, 4% Micro-6 graphite, 4% Paper pulp												
1	1.2	2.0	48	1.38	1.80	1.16	0.66	0.38	0.14	50	0.14	49.7			80	
			55							91	0.06				91	
	+0.3		73							240	0.022				108	
2	0.96 (7)	2.0	46	1.36	1.19	0.75	0.48	0.26	0.10	50	0.10	37.3	32	67	81	
			52							75	0.06				96	
	+0.5		65							129	0.06				95	

Table A-1c (continued)

$Mg/MgBr_2$/ACL-85® AQUEOUS STATIC TESTS
Constant Voltage: 2.0 volts

Cell No.	Electrolyte Volume (2M $MgBr_2$) ml/g Cathode	Operating Voltage Volts	Coulombic Efficiency %	Current (amp) at time (min) 1	2	5	10	20	50	Final(1) T min	Final(1) I amp	Theoretical Capacity amp min	Cathode Thick. (mils)	Cathode Resist.(2) (ohms)	Energy Density (w-hr/lb)	Notes
				Tape 90086-2												
				80% ACL-85, 8% SAB, 8% Micro-6, 4% Paper pulp												
4	1.05 (7)	2.0	34	0.64	0.90	0.64	0.42	0.25	0.13	50	0.13	43.9	35	89	86	
			42							95	0.06				73	
	+0.6		59							174	0.06				88	
5	1.2	2.0	42	1.32	1.17	0.82	0.51	0.31	0.16	50	0.16	41.2	35	107	73	
			55							108	0.06				88	
				Tape 90086-3												
				80% ACL-85, 16% Micro 6, 4% Paper pulp												
7	1.2	2.0	10	0.37	0.23	0.11	0.07	0.04	0.03	121	0.013	45.2	33	625	21	
				Tape 90088												
				80% ACL-85, 16% SAB, 4% Paper pulp												
5	1.2	2.0	57	1.08	1.68	1.02	0.65	0.35	0.09	50	0.09	35.7	36	47	90	
			60							63	0.06				95	
			66							240	0.007				104	
1	1.1	2.1	57	0.95	0.99	0.97	0.56	0.28	0.07	50	0.07	31.9			96	0.1% Triton x-100
			59							58	0.06				99	
			69							240	0.005				116	

Table A-2a

CONSTANT VOLTAGE STATIC DISCHARGE OF NON-AQUEOUS
Li/$LiClO_4$-METHYL FORMATE/ACL-70 TAPES

Ref. No.	System and Weight: Active Cmpd	(wt)	SAB	CF	Cathode: Volt	Eff.	At Min.	Volume ml	I (A) @ Time (min): 1	2	5	10	20	40	80	160	Final: A	Time	Theoretical Capacity amp min	No. of Sep.	LOAD (POUNDS)	Notes
90814	ACL-70	0.65	0.15	0.05	3.0	45.5	@ 70	1.2	.480	.460	.350	.220	.120	.065	.030		.015	142	20.3	1	10	
90815	ACL-70	0.65	0.15	0.05	3.0	48.5	@ 70	1.2	.470	.450	.390	.280	.160	.065	.020		.020	97	20.3	1	10	
90816	ACL-70	1.30	0.30	0.10	3.0	42.2	@120	2.2	.400	.380	.320	.290	.265	.140	.070		.040	152	40.6	1	10	
90817	ACL-70	1.30	0.30	0.10	3.2	31.1	@110	2.2	.420	.380	.270	.215	.165	.115	.060		.040	114	40.6	1	10	
90818	ACL-70	1.30	0.30	0.10	3.0	37.3	@110	1.8	.450	.410	.365	.315	.235	.120	.065		.040	114	40.6	1	10	
90819	ACL-70	1.30	0.20	0.10	3.0	32.0	@100	1.9	.330	.350	.270	.330	.230	.100	.060		.045	101	40.6	1	10	
90820	ACL-70	1.30	0.30	0.10	3.0	35.1	@110	1.9	.190	.190	.230	.330	.250	.110	.055	.040	.040	163	40.6	1	10	Poor contact at start. Stopped and restarted.
90821	ACL-70	1.30	0.30	0.10	3.0	32.4	@ 90	1.9	.295	.300	.400	.310	.210	.105	.035		.010	90	40.6	1	10	1% H_2O added to electrolyte.
90822	ACL-70	1.30	0.30	0.10	3.0	42.2	@110	1.9	.710	.700	.570	.330	.210	.130	.085		.055	119	40.6	1	10	1% acetone.
90823	ACL-70	1.30	0.30	0.10	3.0	35.8	@110	1.9	.900	.650	.450	.310	.190	.100	.060	.035	.020	205	40.6	1	10	5% acetone.
90824	ACL-70	1.30	0.30	0.10	3.2	47.4	@160	1.8	.390	.410	.400	.360	.260	.140	.080	.055	.040	230	40.6	1	10	Cathode mix made w/o metal contact.
90825	ACL-70	1.21	0.28	0.09	3.2	35.5	@110	1.6	.400	.430	.420	.350	.200	.080	.050		.040	140	37.8	1	10	Preformed cathode w TCE.
90827	ACL-70	1.30	0.30	0.10	3.2	51.6	@160	1.9	.250	.290	.360	.360	.290	.140	.070	.040	.035	205	36.2	1	10	
90828	ACL-70	1.30	0.30	0.10	3.2	35.9	@110	1.9	.425	.425	.420	.325	.230	.135	.085		.070	110	40.6	3	10	
90829	ACL-70	1.30	0.30	0.10	3.2	29.1	@110	1.9	.270	.270	.275	.220	.130	.090	.060		.050	125	40.6	3	10	Added 0.3 ml after 20 min.
90830	ACL-70	1.30	0.30	0.10	3.2	36.2	@110	2.2	.345	.345	.335	.295	.235	.130	.070	.050	.045	180	40.6	3	10	Rigid steel plate under springs to press cell.
90831	ACL-70	1.30	0.30	0.10	3.2	48.4	@160	2.2	.340	.335	.310	.270	.210	.150	.090	.050	.040	215	40.6	3	10	Used press. chamber @ 20 psi argon.
90833	CuF_2	1.00	0.25	0.10	2.8	55.3	@110	2.3	.340	.350	.265	.365	.285	.185	.060		.025	150	33.0	2	10	
90834	CuF_2	1.00	0.25	0.10	2.8	51.8	@110	2.4	.395	.395	.380	.360	.260	.190	.050		.020	140	33.0	2	10	CuF_2 dried, F_2 450°C.

Table A-2b

CONSTANT VOLTAGE STATIC DISCHARGE OF NON-AQUEOUS
Li/$LiClO_4$-METHYL FORMATE/ACL-70 TAPES

Ref. No.	Cathode System (g) Active Cpd.	(Wt)	SAB	C.F.	Operating Voltage	Cathode Efficiency	W-hr/lb at min		Electrolyte Volume (ml)	Current (amp) at Time (min) 1	2	5	10	20	40	80	160	Final Amp	Final Min	Theor. Capacity (A-min)	Load (lb)	Notes [a]
90835	CuF_2	1.0	0.25	0.10	2.8	40.1	66.7	100	(min) 2.2	0.18	0.22	0.26	0.255	0.25	0.14	0.06		0.04	100	33.0	10	
90836	CuF_2	1.0	0.25	0.10	2.8	18.1	26.7	110	2.8	0.15	0.15	0.16	0.15	0.07	0.04			0.01	110	33.0	10	
90839	ACL-70	0.65	0.15	0.05	3.0	42.2	77.1	80	1.2	0.37	0.37	0.35	0.24	0.09	0.065	0.04		0.04	105	20.3	10	Wire brushed Li
90840	ACL-70	0.65	0.15	0.05	3.0	53.8	98.2	80	1.2	0.47	0.50	0.45	0.25	0.14	0.09	0.05		0.02	135	20.3	10	Etched Li (HCl-DMF)
90841	ACL-70	0.65	0.15	0.05	3.2	42.5	60.7	80	2.0	0.73	0.64	0.37	0.18	0.10	0.05	0.025		0.015	115	20.3	10	Li from roll, glass fiber separator
90842	ACL-70	0.65	0.15	0.05	3.2	50.3	87.6	80	1.5	0.81	0.72	0.40	0.165	0.10	0.09	0.05		0.05	90	20.3	10	Glass fiber separator
90843	ACL-70	0.65	0.15	0.05	3.0	54.6	99.4	80	1.2	0.50	0.47	0.39	0.26	0.11	0.085	0.04		0.035	85	20.3	10	
90844	ACL-70	0.65	0.15	0.05	3.0	64.1	117	80	1.2	0.48	0.46	0.39	0.30	0.17	0.11	0.05		0.05	80	20.3	10	c
90845	ACL-70	0.65	0.15	0.05	3.2	40.9	79.8	80	1.2	0.23	0.22	0.21	0.19	0.13	0.075	0.045		0.045	80	20.3	10	c
90846	ACL-70	0.65	0.15	0.05	3.5	24.6	52.3	140	1.2	b	0.15	0.125	0.09	0.07	0.045	0.02		0.015	140	20.3	10	c
90847	ACL-70	0.65	0.15	0.05	3.0	56.5	103	80	1.2	b	b	b	b	0.21	0.135	0.055		0.055	80	20.3	10	c, Li-HCl+DMF etch
90848	ACL-70	1.0	0.2	0.10	3.2	38.7	81.5	140	1.8	0.32	0.28	0.21	0.19	0.145	0.08	0.065		0.04	140	31.5	10	
90849	ACL-70	1.0	0.15	0.05	3.2	39.9	94.9	140	1.5	0.44	0.41	0.32	0.27	0.16	0.065	0.05		0.04	130	31.5	10	
90850	ACL-70	0.65	0.10	0.05	3.0	50.4	93.6	80	1.2	0.44	0.425	0.35	0.25	0.15	0.085	0.045		0.03	110	20.3	10	
90851	ACL-70	1.30	0.30	0.10	3.2	27.8	66.2	120	1.9	b	b	b	b	b	b	b		0.03	120	40.6	10	one week old mix
90852	ACL-70	0.65	0.15	0.05	3.0	61.2	112	80	1.2	0.65	0.60	0.49	0.26	0.17	0.10	0.05		0.05	85	20.3	5	
90853	ACL-70	1.0	0.15	0.05	3.2	49.0	116.8	140	1.5	0.50	0.47	0.41	0.32	0.20	0.075	0.065		0.045	135	31.5	5	
90854	ACL-70	1.0	0.15	0.05	3.2	42.1	107.5	140	1.3	0.38	0.35	0.315	0.28	0.23	0.07	0.045		0.02	150	31.5	5	e
90856	ACL-70	1.0	0.15	0.05	3.2	34.9	86.2	140	1.4	0.35	0.36	0.36	0.29	0.22	0.055	0.025		0.02	140	31.5	5	f,g
90858	ACL-70	1.0	0.20	0.05	3.2	42.9	91.5	140	1.8	0.46	0.46	0.39	0.33	0.20	0.07	0.045		0.02	150	31.5	5	g
90859	ACL-70	1.0	0.20	0.05	3.0	59.2	118	140	1.8	0.51	0.52	0.44	0.32	0.20	0.12	0.08	0.05	0.04	185	31.5	5	g
90860	ACL-70	1.0	0.20	0.05	3.0	53.8	107.5	140	1.8	0.40	0.41	0.39	0.35	0.21	0.10	0.065	0.05	0.05	150	31.5	5	g, 1% acetone
90861	ACL-70	1.0	0.20	0.10	3.0	54.4	107	140	1.8	0.55	0.52	0.43	0.33	0.20	0.10	0.07	0.05	0.05	160	31.5	5	g
90862	ACL-70	1.0	0.20	0.05	2.8	61.1	114	140	1.8	0.51	0.47	0.43	0.37	0.24	0.135	0.085		0.035	140	31.5	5	g
90863	ACL-70	1.0	0.20	0.05	3.0	10.3	26.1	140	1.1	0.25	0.10	0.05	0.03	0.025	0.02	0.02	0.015	0.005	320	31.5	5	h
90864	ACL-70	1.0	0.20	0.05	3.0	57.4	126	140	1.5	0.49	0.49	0.45	0.37	0.20	0.12	0.075	0.07	0.025	220	31.5	10	g
90865	ACL-70	1.0	0.20	0.05	3.0	51.8	121.5	140	1.3	0.27	0.28	0.30	0.28	0.24	0.12	0.07	0.03	0.01	240	31.5	10	a
90866	ACL-70	1.0	0.20	0.05	3.0	43.2 51.9	89.1 106.5	140 240	1.7	0.50	0.46	0.39	0.28	0.15	0.08	0.06	0.03	0.015	270	31.5	10	g i
90867	ACL-70	0.959	0.191	0.048	3.0	59.5	127	240	1.5	0.35	0.32	0.32	0.30	0.21	0.09	0.07	0.04	0.02	240	30.2	10	
90869	ACL-70	1.0	0.15	0.05	3.0	49.1 58.5	109.2 130.2	140 240	1.5	0.34	0.35	0.35	0.30	0.18	0.11	0.07	0.04	0.02	240	31.5	10	
90870	ACL-70	1.0	0.20		3.0	52 62.2	115.7 138.2	140 240	1.5	0.35	0.37	0.38	0.31	0.20	0.11	0.07	0.04	0.01	280	31.5	10	j
90871	ACL-70	1.0	0.20		3.0	52.3 60.4	116.2 134.5	140 240	1.5	0.28	0.28	0.30	0.30	0.22	0.13	0.08	0.03	0.01	260	31.5	10	k
90872	ACL-70	1.0	0.15	0.05	3.0	40.8 49.2	90.8 106	140 240	1.5	0.36	0.37	0.35	0.28	0.14	0.08	0.05	0.03	0.016	260	31.5	10	g, 33 mil cathode

Table A-2b (continued)

CONSTANT VOLTAGE STATIC DISCHARGE OF NON-AQUEOUS
Li/LiClO$_4$-METHYL FORMATE/ACL-70 TAPES

Ref. No.	Cathode System (g) Active Cpd.	(Wt)	SAB	C.F.	Operating Voltage	Cathode Efficiency	W-hr/lb at min		Electrolyte Volume (ml)	Current (amp) at Time (min) 1	2	5	10	20	40	80	160	Final Amp	Min	Theor. Capacity (A-min)	Load (lb)	Notes [a]
90873	ACL-70	1.0	0.20	0.05	3.0	49.5 56.8 66	118 135.3 158	140 240 720	1.3	0.31	0.38	0.36	0.14	0.08	0.04	0.015	0.005	0.001	720	31.5	10	d,l, 38 mil
90874	ACL-70	1.0	0.20	0.05	3.0	53.3 61.2	127.5 146	140 240	1.3	0.34	0.40	0.35	0.14	0.10	0.05	0.014		0.014	240	31.5	10	d,m
90875	ACL-70	1.0	0.20	0.005	3.0	53.3 60.3 66.8	127.5 144 160	140 240 720	1.3	0.29	0.36	0.28	0.15	0.10	0.045	0.013	0.003	0.001	720	31.5	10	d, etch Li (HCl-DMF)
90876	ACL-70	1.0	0.15	0.05	3.0	43.1 49.3 58	108.4 124 146	140 240 720	1.2	0.30	0.35	0.35	0.13	0.07	0.025	0.015	0.005	0.002	720	31.5	10	d
90877	ACL-70	1.0	0.2	0.05	3.0	32.4 45.2 52.5	61.1 85.4 99.0	60 140 240	1.3+0.7	0.36	0.30	0.25	0.14	0.065	0.04	0.013		0.013	240	31.5	10	d, SAB Uncompressed Failed with 1.3 ml
90878	ACL-70	1.0	0.2	0.05	3.0	15.1 18.6 20.2	35.6 43.7 48.2	40 140 240	1.1+0.2	0.38	0.22	0.15	0.05	0.014	0.007	0.005	0.003	0.0015	720	31.5	10	34 mil Failed with 1.1 ml
90879	ACL-70	1.0	0.2	0.05	3.0	37.4 49.8 57.3	89.7 119 137.5	62 140 240	1.3	0.27	0.41	0.38	0.15	0.065	0.04	0.015		0.015	240	31.5	10	d, N.L.Carbon
90880	ACL-85	1.0	0.2	0.05	3.0	37.4 12.8	23.8 40.3	60 140	1.3	0.062	0.07	0.08	0.06	0.04	0.03			0.03	140	41.5	10	d, ACL-85
90881	ACL-70	1.0	0.2	0.05	3.0	40.2 56.0 65.2 69.4 71.2 72.5	88.5 123.0 143.1 152.2 156.5 159.5	60 140 240 360 480 720	1.5	0.25	0.35	0.37	0.16	0.10	0.05	0.017	0.003	0.001	720	31.5	10	n
90882	ACL-70	1.0	0.2	0.05	3.0	32.6	71.6	60	1.3+0.6	0.50	0.38	0.29	0.14	0.09				0.06	90	31.5	10	p
90883	ACL-70	1.0	0.2	0.05	3.0	32.8 55.0 64.9 71.7 72.8	67.7 113.8 134.0 146.7 150.2	60 140 240 480 720	1.3+0.4	0.32	0.31	0.28	0.15	0.11	0.058	0.017	0.003	0.002	720	31.5	10	n, Failed with 1.3 ml
90884	ACL-70	1.5	0.3	0.075	3.0	21.1 30.9 43.2 56.4 66.2 69.5	51.1 74.7 105.0 137.5 161.2 169.0	30 60 120 240 480 720	2.0	0.43	0.40	0.37	0.21	0.12	0.07	0.036	0.009	0.004 (0.002	720 900)	47.25	10	n, 58 mil cathode

a two polypropylene separators unless otherwise specified

b current unsteady

c pressure cell at 20 psi

d one polypropylene separator

e SAB+CF Waring blended. Add ACL-70 and mix in glass tube with baffles

f "C" clamp used to compress dry mix in cell from here down

g entire mix Waring blended

h entire mix ground in dry box with mortar and pestle

i trichloroethylene slurry used to make pre-formed tape

j SAB not Waring blended, high bulk density 38 mil cathode

k SAB Waring blended, 40 mil cathode

l CF+SAB Waring blend, and ACL-70 tumble mix from here down

m ACL-70 ground in mortar and pestle from here down

n Wrapped Li with one separator to avoid shorting on edges

p Wet cathode without separator in place - failed - added more electrolyte and separator

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