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UNIVERSITY OF MICHIGAN
ANN ARBOR

DEVELOPMENT OF A NEW-TYPE STORAGE BATTERY FOR MILITARY USE

September 15, 1947, to December 31, 1953

By

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Director of Project

ERI PROJECT M743
for
U.S. WAR DEPARTMENT, ORDNANCE DEPARTMENT
Contract W-20-018-ORD-13024, Project 610

ERI PROJECT M875
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SUMMARY

This report covers the accomplishments during the period June 30, 1953, to December 31, 1953.

For the benefit of those who wish to manufacture lead-plated aluminum-grid storage batteries, a more detailed account of the manufacturing techniques and production controls required is given in this report, with data based on our pilot-plant controls.

Design data are given for the production of a 12-volt 65-A.H. automobile starting battery.

Inspection data on batteries which have been tested at Wright Field and Yuma Test Station are included, and summaries of these inspections are listed under their appropriate headings.

Personnel of ERI Projects M743, M875, and 2018

ERI Project M743, September 1947, to November 15, 1949.

L. L. Carrick, Project Supervisor	September 1947, to November 15, 1949
B. Agruss, Full-time investigator	February 1, 1948, to November 15, 1949
J. M. Stapleton, Full-time investigator	February 1, 1948, to November 15, 1949
H. H. Hicks, Jr., Part-time laboratory assistant	December 10, 1947, to March 1948
Don Church, Part-time laboratory assistant	December 16, 1948, to November 15, 1949

ERI Project M875, November 15, 1949, to January 1, 1952.

L. L. Carrick, Project Supervisor	November 15, 1949, to January 1, 1952
B. Agruss, Full-time investigator	November 15, 1949, to January 17, 1950
J. M. Stapleton, Full-time investigator	November 15, 1949, to January 1, 1952
F. J. Prieskorn, Full-time laboratory assistant	January 30, 1950, to January 1, 1952
D. M. Braun, Full-time laboratory assistant	February 5, 1950, to January 31, 1951
E. J. Groff, Full-time laboratory assistant	November 6, 1950, to January 1, 1952
Carl F. Cooper, Full-time laboratory assistant	May 1, 1950, to January 1, 1952
Don Church, Part-time laboratory assistant	November 15, 1949, to February 1, 1951
Don E. Kory, Part-time laboratory assistant	February 12, 1951, to May 1, 1951
Sam Dreisback, Part-time laboratory assistant	June 2, 1951, to October 30, 1951
William Elliot, Part-time laboratory assistant	February 13, 1951, to October 30, 1951

ERI Project 2018, January 1, 1952, to December 31, 1953

L. L. Carrick, Project Supervisor	January 1, 1952, to December 31, 1953
J. M. Stapleton, Full-time investigator	January 1, 1952, to December 24, 1952
Carl F. Cooper, Full-time laboratory assistant	January 1, 1952, to June 1, 1953
F. J. Prieskorn, Full-time laboratory assistant	January 1, 1952, to December 31, 1953
E. J. Groff, Full-time laboratory assistant	January 1, 1952, to December 31, 1953
John Altman, Part-time laboratory assistant	June and July 1952
Patrick Doyl, Part-time laboratory assistant	August and September 1952
Larry Wilkinson, Part-time laboratory assistant	June 15, 1953, to December 31, 1953
Gene Zerlaut, Part-time laboratory assistant	September 24, to December 31, 1953

Reports Issued During Duration of ERI Project M743, M875, and 2018 and Covered in This Final Report

Project No.	Date Issued	Period Covered
M743	March 1948	September 15, 1947, to March 1, 1948.
M743	30 June 1948	March 1, 1948, to June 30, 1948.
M743	17 August 1948	Special Report.
M743	30 September 1948	June 30, 1948, to September 1, 1948.
M743	31 December 1948	September 1, 1948, to December 31, 1948.
M743	31 May 1949	December 31, 1948, to May 31, 1949.
M743	30 August 1949	May 31, 1949, to August 30, 1949.
M743	31 December 1949	August 30, 1949, to December 31, 1949.
M875	24 April 1950	December 31, 1949, to April 1, 1950.
M875	July 1950	April 1, 1950, to July 1, 1950.
M875	31 December 1950	July 1, 1950, to December 31, 1950.
M875	15 April 1951	December 31, 1950, to April 1, 1951.
M875	December 1951	April 1, 1951, to December 1, 1951.
2018	June 1952	December 1, 1951, to June 30, 1952.
2018	July 1952	Special Report on Lead Burning.
2018	January 1953	June 30, 1952, to December 31, 1952
2018	31 December 1953	A final resume of the above reports emphasizing the techniques to be observed in manufacturing of lead-plated aluminum-grid batteries.

THE DEVELOPMENT OF A NEW-TYPE STORAGE BATTERY FOR MILITARY USE

OBJECTIVE

This work was directed toward the development of a new-type storage battery for military use employing, if such can be discovered or developed, a more satisfactory substance as a substitute for lead and, if none can be found, to find desirable means of improving the performance of lead batteries.

The desired battery is to be a 24-volt battery which will have a volume under 2 cubic feet and a weight under 100 lbs, will operate satisfactorily over a temperature range from -70° to 165°F with a 300-ampere discharge for one minute at -70°F with an end voltage of 1 volt per cell. This battery is to be waterproof for submersion, under a minimum external or internal pressure of 6 psi.

INTRODUCTION

Since it has become evident during the past few years that lead may become a scarce metal, it is increasingly desirable to find a substitute for lead in storage batteries. It is imperative that battery performance be improved, since the low electrochemical efficiency of the commercial alkaline batteries and their poor performance at low temperatures make them unsatisfactory for military use.

Willihnganz, in a paper presented before the Association of American Battery Manufacturers, has shown from theoretical considerations that only a few electrode combinations besides lead are possible. Use of these combinations required considerable research and theoretically appeared very limited. Hence, most improvements have been obtained from studies of plate thickness and paste mixes. The tendency has been toward thinner plates, more plates per cell, and the use of various extenders or addition of agents in the paste. By these means more porosity and greater active area were obtained. Even though cold performance was improved, the objective set forth above has not been reached.

One of the greatest disadvantages of the lead battery has been its weight, which is particularly striking when it is realized that only a small percentage of the lead in a battery is necessary for energy production, the rest being excess in the form of oxides, grids, and conductors. Because of the poor electrical and heat conductivity and low strength of lead, there is a tendency for the grids to buckle and warp under charge of discharge conditions, especially at high rates, and they become brittle when cold. Several investigators have suggested the use of lead-coated light metals such as copper or aluminum for grid materials, but summarily dismissed them as possibilities because of local cell action.

It is true that one pinhole in the coating will cause local self-discharge, but in view of the rapid advances that have been made in modern metal finishing and electroplating this suggestion deserves a much more careful examination. Widespread commercial acceptance of electroplates on aluminum was unheard of ten years ago.

In addition, the capture of a German battery with lead-coated aluminum plates that were reported to have withstood 1000 cycles substantiates the assertion that such plates should be thoroughly investigated. The long life (1000 cycles) suggests the use of Planté-type plates. It is well known that the Planté battery had a longer life and a higher capacity than other batteries, especially at low discharge and with regard to current drain per unit plate area. However, it was discarded in favor of the Faure-type plate because of its extreme weight and bulkiness and because, at the same time, the plates were more prone to buckle and warp. It is noteworthy that the modern trend in battery design has been toward the Planté type in that thinner plates are used to give greater active surface area. Planté plates had thin layers of active material covering large areas.

Since it has been conceded that lighter-weight grids would be a boon to the industry and that the trend is toward thinner layers of active material, it would appear that this is the propitious moment for an extensive investigation of lead-coated aluminum plates. The high electrical and heat conductivity of aluminum coupled with its greater strength (compared to lead) should allow the use of much thinner plates without the danger of overheating and buckling, and should provide also a greater active surface area per unit volume or per unit weight. Such an increase in active surface area per unit weight will tend to increase not only the ampere-hour capacity but also the life of the battery.

PLAN OF INVESTIGATION

Because of the above considerations, it was decided that the primary objective would be the development of a lead-acid storage battery containing lead-coated aluminum grids, and that the development of other electrode systems would be a secondary objective. To some extent, the lead-coated aluminum system may be considered as a substitute for the major portion of the lead in the standard lead-acid battery.

The proposed plan of investigation is tabulated below:

1. Develop a suitable technique for plating lead on aluminum, testing each type of plate for continuity of coating, porosity, local cell action, metal diffusion.
2. Develop methods of "forming" active material on lead-coated grids.
3. Assemble test cells and determine their capacity, life, maximum current density, self-discharge, charge and discharge rates, temperature efficiency, etc.
    a. Correlate test data with methods of plating and with the formation of active positive and negative grid surfaces.
    b. Ascertain optimum plating, forming, and assembling conditions.
    c. Specify raw material to meet the aluminum-lead system requirements.
4. Reduce lead-plated aluminum grid elements in the assembled battery so that the final voltage of the fully charged aluminum grid battery will equal the voltage of the fully charged lead-antimony-grid six-element battery, in order to utilize the existing charging equipment in use today.

THE ALUMINUM GRIDS

Storage of Aluminum

The aluminum stock should be stored in an atmosphere free from acid fumes, since acid fumes tend to pit the surface of aluminum and create an uneven plating surface.

The aluminum stock should also be stored in an even-temperature atmosphere where the grease on the surface will not be removed. Excessive oxidation of the aluminum suface may also result in pitting of the grids as they pass through the cleaning solutions, and adhesion is dependent to some extent on the condition of the aluminum surface and the extent of oxide removal. Any atmosphere which tends to increase the thickness of the aluminum oxide film on the stock aluminum should be avoided.

Pitting may cause blisters and loss of adhesion of the lead electroplate when it is heated or placed in service, especially at elevated temperatures.

Type of Aluminum Employed

We have plated all the aluminum alloys listed in Table 1. The composition is quite variable but all accept a coherent, nonporous, and continuous electroplate of lead.

Only the alloys EC, 2S, 3S, and 52S have a satisfactory chemical composition. When the copper content exceeds 0.20% we have found that the copper will diffuse through nickel and lead electroplate, migrate from the positive plate, and deposit as an electroplate of copper on the negative plate. Thus copper promotes self-discharge of the battery; hence, it is kept at a minimum.

Alloys like 2SO, 3SO, 52SO, have sufficient hardness to pierce satisfactorily in the production of the aluminum grid. The hardness also assists in holding the aluminum rigid during movement in the plating tank. The cold-rolled aluminum seems to possess a nonuniform surface hardness; hence, it has been found advantageous to anneal the aluminum grids after degreasing to produce a uniform surface structure which facilitates alkali cleaning and deposition of a satisfactory lead electroplate. Proper hardness in the aluminum is also conducive to the production of clean-cut edges on the aluminum grids. Depending on the type of piercing die and the

TABLE 1

CHEMICAL COMPOSITION LIMITS FOR WROUGHT ALUMINUM ALLOYS (ALUMINUM COMPANY OF AMERICA)
Composition given is a maximum unless shown as a range; the remainder is aluminum.

Alloy	Copper, %	Silicon, %	Iron, %	Manganese, %	Magnesium, %	Zinc, %	Chromium, %	Nickel, %	Titanium, %	Other Elements Each	Other Elements Total
EC			99.45% minimum aluminum content								
2S*	0.20	**	**	0.05	-	0.10	-	-	-	0.05	0.15
2SH14	0.20	**	**	0.05	-	0.10	-	-	-	0.05	0.15
2SH18	0.20	**	**	0.05	-	0.10	-	-	-	0.05	0.15
3SO	0.20	0.60	0.70	1.0-1.5	-	0.10	-	-	-	0.05	0.15
14S	3.9-50	0.5-1.2	1.0	0.4-1.2	0.2-0.8	0.25	0.10	-	***	0.05	0.15
18S	3.5-45	0.90	1.0	0.20	0.45-0.9	0.25	0.10	1.7-2.3	0.05	0.05	0.15
24SO	3.8-49	0.50	0.50	0.3-0.9	1.2-1.8	0.10	0.10	-	-	0.05	0.15
24ST4	3.8-49	0.50	0.50	0.3-0.9	1.2-1.8	0.10	0.10	-	-	0.05	0.15
52SH38	0.10	****	****	0.10	2.2-2.8	0.10	0.15-0.35	-	0.15	0.05	0.15
61ST4	0.15-0.40	0.4-0.8	0.70	0.15	0.8-1.2	0.20	0.15-0.35	-	0.15	0.05	0.15
61ST6	0.15-0.40	0.4-0.8	0.70	0.15	0.8-1.2	0.20	0.15-0.35	-	0.15	0.05	0.15

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*Minimum aluminum content is 99%.

**Iron plus silicon is maximum of 1%.

***Usually contains no titanium.

****Iron plus silicon is maximum of 0.45%.

hardness of the aluminum stock, the stock aluminum may vary from 1/2 0 to 0 and up in hardness.

Aluminum in the grid maintains flexibility of the plate during cold weather. Conductivity or resistance of the aluminum stock is important in maintaining a high discharge voltage (see Table 2), low development of heat during charge and discharge, reduction of internal resistance at all temperatures and especially its effect on cold-temperature operation.

TABLE 2

THERMAL CONDUCTIVITY AND ELECTRICAL RESISTANCE
OF ALUMINUM USED IN BATTERY GRIDS
(Metals Handbook. 1948 Edition)

Aluminum Type	Thermal Conductivity at 25°C cal/sq cm/cm/°C/sec	Electrical Resistivity at 20°C, micro-ohm-cm
EC	0.50	2.6548
2S-0	0.53	2.922
2S-H18	0.52	3.025
3S-0	0.46	3.448
14S-0	0.46	3.448
18S-0	0.46	3.448
24S-0	0.45	3.448
24S-T4	0.29	5.747
52S-H38	0.33	4.926
61S-T4	0.37	4.310
61S-T6	0.37	4.310

All aluminum, whether it is 2S or any other designated commercial type of aluminum, is manufactured to meet certain specifications as to minimum and maximum alloy content of iron, silicon, manganese, etc. It is interesting to note that some manufacturers adhere to the lower limit of impurities in their manufacturing operations while others seem to use the upper limits as their manufacturing guide. These types of aluminum require a different concentration of conditioning solutions. This will be discussed further in connection with dipping solutions.

Thickness of Aluminum to Employ in Grids

The thickness of the aluminum is dependent on (1) whether a positive or a negative grid is to be produced, (2) the type of service expected of the lead-plated aluminum grid, and (3) the type of battery desired.

The positive grids to withstand 12 S.A.E. overcharge cycles should have an electroplate of 0.015 inch of lead. Thus a 0.075-inch plated grid may carry 0.045 inch of aluminum stock.

The negative grids to withstand 12 S.A.E. overcharge cycles need not have over 0.010 inch of lead electroplate. Thus a 0.030-inch-thick grid may carry 0.010 inch of aluminum. We have run 12 S.A.E. overcharge cycles on grids that have 0.0075-inch-thick lead plate on 0.015-inch-thick aluminum. The 0.010-inch-thick lead plate is a safety factor, not a necessity if a good lead plate has been deposited.

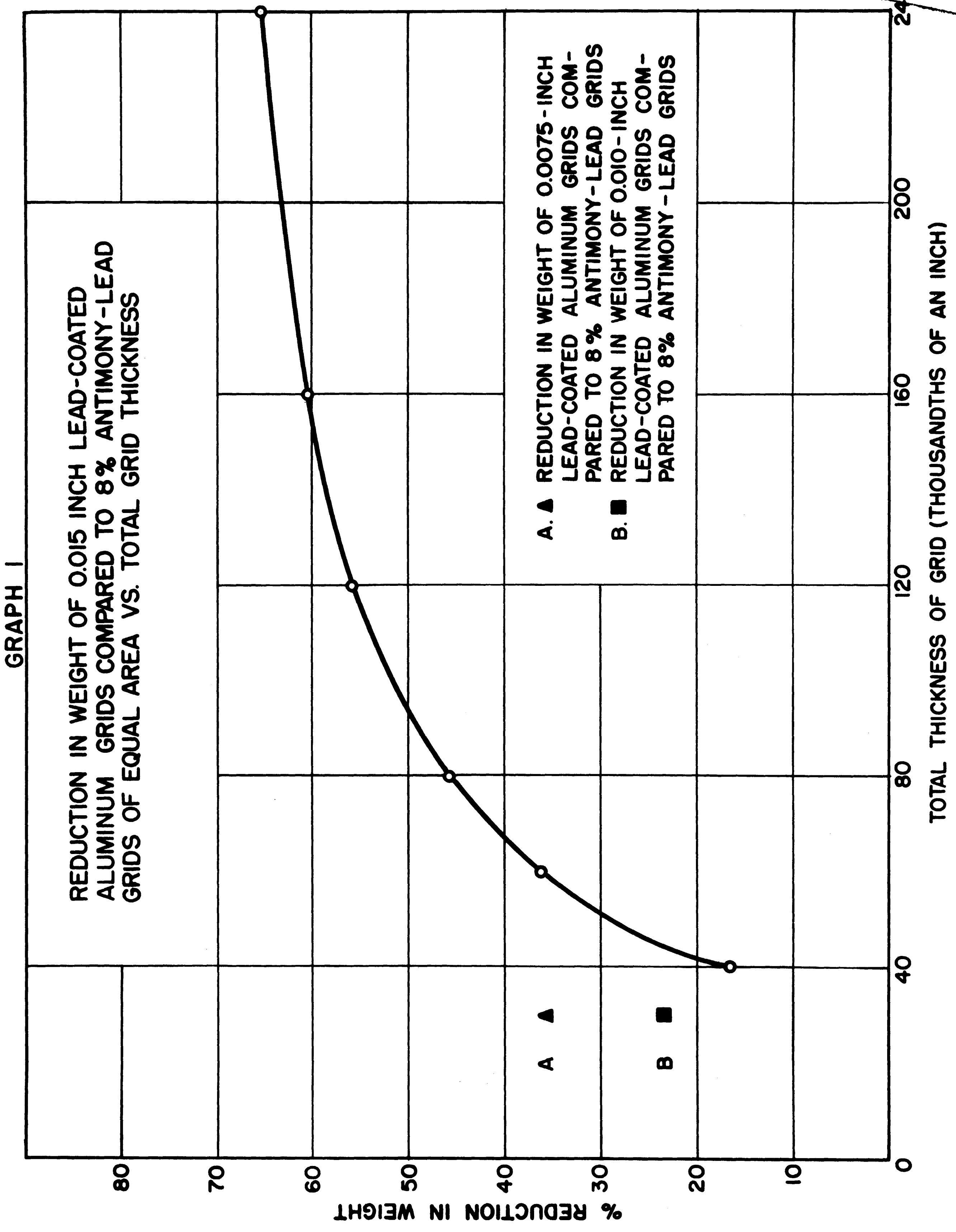
Since the sloughing of reaction products is primarily on the positive plate, it is advisable to give it a heavier electroplate. We have experimented with electroplates from 0.005-inch to 0.025 inch thick. For starting batteries, we consider 0.015-inch-thick lead electroplate for positive and 0.010-inch-thick lead electroplate for negative grids ample to meet all normal requirements or demands.

For standby batteries, which usually must carry much thicker plates, an electroplate 0.020 inch thick for positive and 0.015 inch thick for negative grids is ample. The balance of the thickness of the grid may be aluminum.

Graph 1 gives the relation between the weight of lead-plated aluminum grids which have a 0.015-inch-thick lead electroplate and a similar grid made of 100% lead-antimony alloy (8%Sb). This saving in weight is dependent on the grid design. Hence it should not be taken as the ratio of weights between lead-plated aluminum grids that we use and lead-antimony alloy grids (commercial grids of today) of equal thickness.

Stamping of the Grids

In stamping the aluminum it should be remembered that the stamping operation cold-works the aluminum stock. Cold-working will tend to



GRAPH I

REDUCTION IN WEIGHT OF 0.015 INCH LEAD-COATED ALUMINUM GRIDS COMPARED TO 8% ANTIMONY-LEAD GRIDS OF EQUAL AREA VS. TOTAL GRID THICKNESS harden the stock to some extent, but such hardening is not necessarily detrimental.

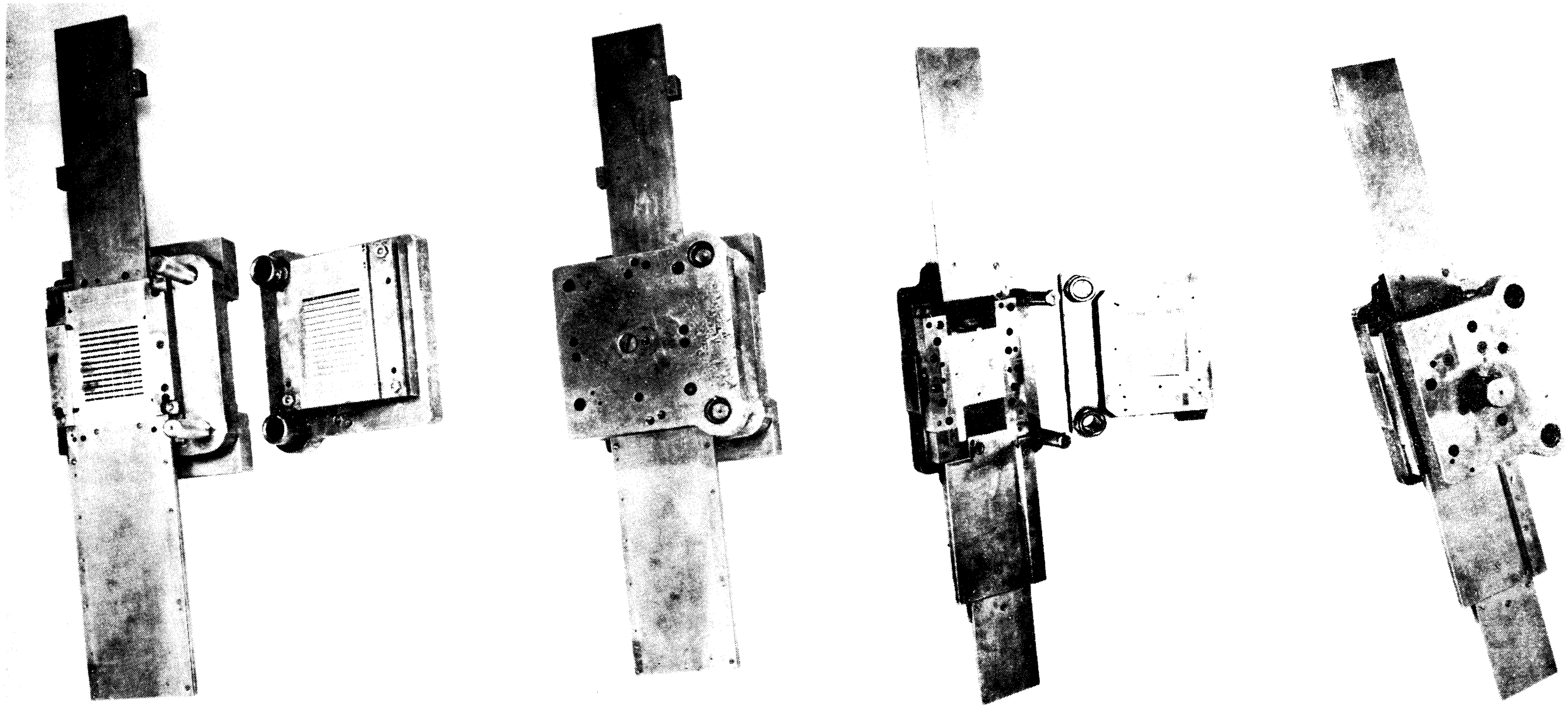
We have experienced the greatest difficulty in the type of lubricant used in the stamping operation. Any lubricant which will react with the aluminum under pressure and temperature and form rather stable compounds with the aluminum should be avoided. Many lubricants that form stable compounds are not detrimental, however, as they may be removed by solvent action during the degreasing operation. On the other hand, some of these compounds are difficult to remove in either the degreasing operation or the cleaning operation. Such compounds left on the aluminum are likely to cause lack of adhesion or blistering or both of the electroplate when the aluminum is subjected to heat, as during assembly burning.

It has been our experience that a good grade of kerosene free from lubricating oil makes an excellent lubricant for the stamping die. No synthetic turpentine should be used; turpentines do not seem to function as well as kerosene or mineral spirits.

The grid die is shown in Photograph 1. Photograph 1(a) shows the piercing die with the inside of the two halves exposed, while Photograph 1(b) shows the piercing die assembled for action. Photograph 1(c) shows the two halves of the blanking die which outlines the grid, and Photograph 1(d) shows the blanking die assembled for action.

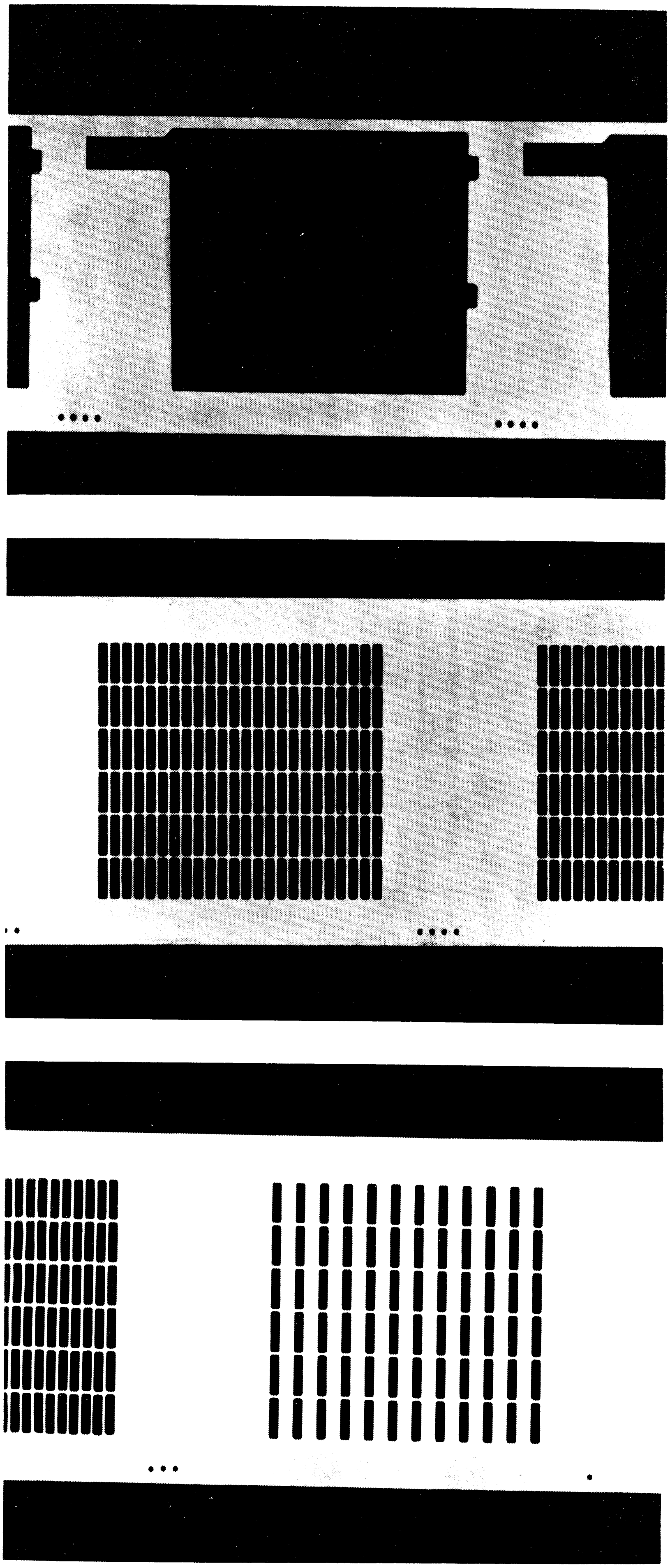
The grid production operations are shown in Photograph 2, depicting the three steps required in using our piercing and blanking die to produce aluminum grids. The three round holes in the upper left-hand corner, Photograph 2(a), and the one round hole in the lower left-hand corner are the result of the first operation, which pierces one-half of the grid openings. These two groups of holes will govern the position of the second stamping operation as shown in Photograph 2(b). The grid is advanced one hole in the upper left-hand corner; this pushes the aluminum stock through the die at just the proper distance so that the second operation removes the unpierced area between the existing openings and leaves the grid ribs as shown in Photograph 2(b). It should be noted that at this stage there are four holes in the upper left-hand corner and four in the lower left-hand corner. When all the aluminum has been pierced as shown in Photograph 2(b), the aluminum ribbon is passed through the blanking die, Photograph 1(d). Here the ribbon is guided by the four holes in the upper left-hand corner, Photograph 2(b), and the four holes in the lower left-hand corner of the same photograph and the grid is blanked, outlining the completed grid in the form shown in Photograph 2(c).

A die of this type has been used to pierce over 100,000 grids from aluminum stock ranging in thickness from 0.010 inch to 0.030 inch in



(a) (b) (c) (d)

Photograph 1. Grid Die: (a) Piercing die open; (b) Piercing die closed ready for action. (c) Blanking die open; (d) Blanking die closed ready for action.



(a) (b) (c)

Photograph 2. Operations in Grid Production: (a) Operation 1; (b) Operation 2; (c) Operation 3.

thickness. We also have used this die to pierce copper, iron, and brass 0.010 inch thick. There have been some minor repairs and sharpening, but on the whole the die is in excellent condition.

In the construction of piercing dies, the die should be designed to pierce only one thickness of aluminum stock, such as 0.015 inch, 0.030 inch, etc. In this way, less clearance is required and the ribs may be reduced in width, thus reducing the total weight of the grids and the total lead consumed, while maintaining the resistance and conductivity of the grid so that it will be better than a solid lead-antimony-alloy grid. The hardness of aluminum stock to use in each die will depend on the clearance and the sharpness of the die.

Degreasing

The degreasing operation should come before the removal of aluminum hairs and also before annealing of the aluminum, since annealing of the aluminum may cause decomposition of some of the lubricating compounds, thus depositing carbon in the pores of the aluminum which will be almost impossible to remove and difficult to bridge with subsequent conditioning solutions or electroplates.

If degreasing has preceded the removal of aluminum hairs and annealing of the aluminum, it is not necessary to be concerned about any grease that may be deposited on the aluminum grid through handling, especially if the handler will use clean cotton cloths. Any small amount of human grease from the hands is not likely to cause serious harm, as it will be removed by the cleaning solution.

Degreasing is done in a vapor degreaser. Trichlorethylene is employed as the degreasing agent.

Inspection of Grids and Removal of any Aluminum Hairs

The grids that come from the stamping die may have aluminum hairs attached to ribs or edges of the grids. Such aluminum hairs are produced if the die is not sharp or if the second stamping operation is not properly synchronized or spaced with the first stamping operation. Should there be an overlapping in the second operation, this will generally produce aluminum hairs.

If the aluminum hairs are excessively fine, they may be removed in the cleaning operation by the action of the alkali and subsequent acid dips. Should the hairs be too heavy for such cleaning, however, then they should be removed by some mechanical means such as wire brushing. The wire brushing should be done after the grids have been degreased, to prevent the burning of any of the lubricant into the pores of the aluminum.

Annealing of the Aluminum

Not all types of aluminum need annealing to be satisfactorily electroplated, but should there seem to be areas on some types of aluminum which do not accept electroplate and these areas cannot be cleaned either by degreasing or passage through the cleaning solution, it is recommended that these grids be annealed at a temperature of 500°F for a period of 30 minutes in order to release any stresses or strains resulting from cold-working during the stamping operation. Such areas under stress or strain are likely to receive electrodeposit at a different rate or under different conditions than those which are not subject to such stresses or strains (see photomicrographs in Photograph 3).

It has been our experience that it is not necessary to anneal 2S aluminum grids, as the cold-working does not seem to affect the deposition to any serious extent with this stock.

LEAD-PLATING OF ALUMINUM GRIDS

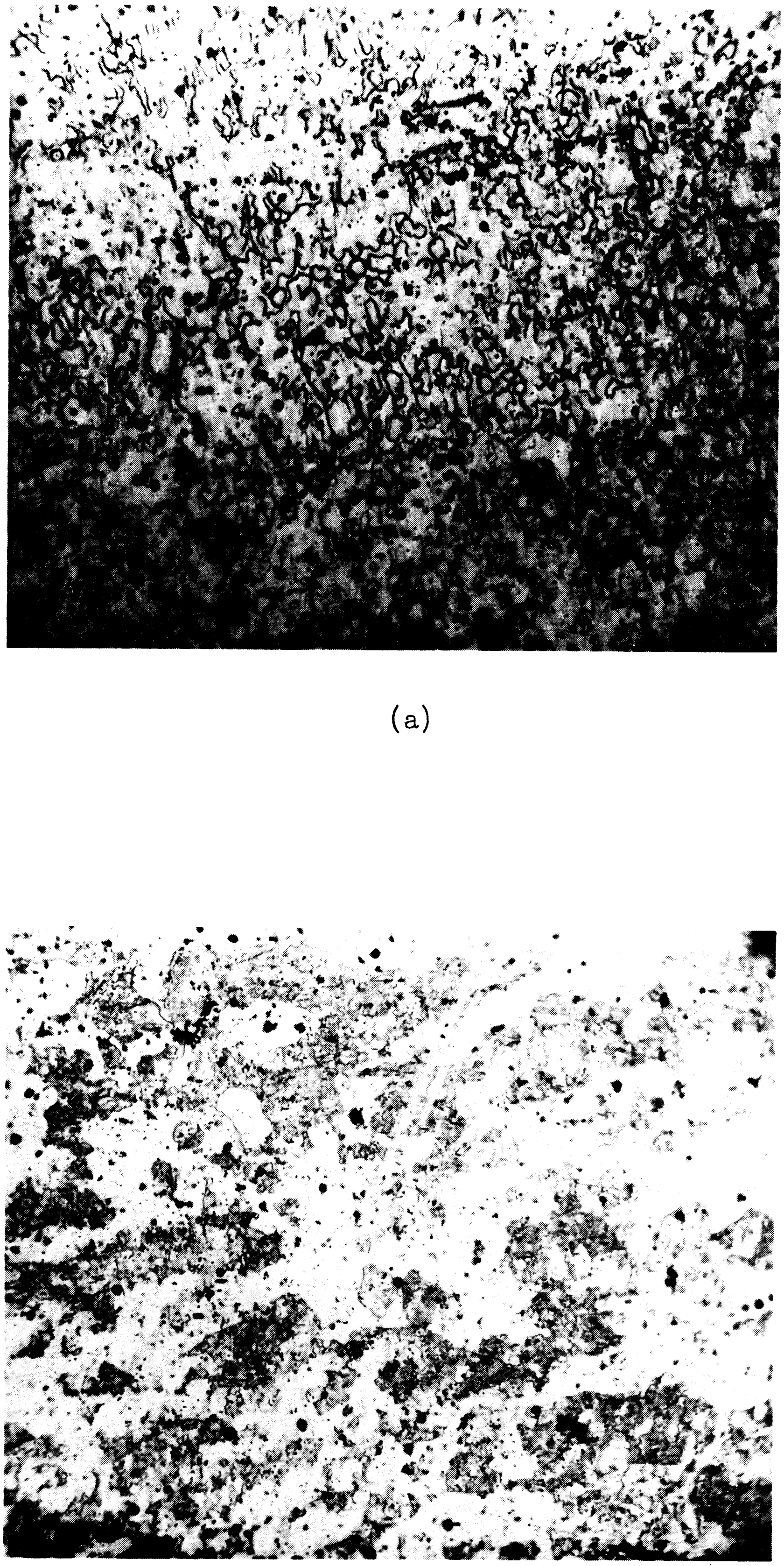
Flow Sheet for Production of Lead-Plated Aluminum Grids

The electroplating of aluminum comprises a total of seventeen steps. A flow sheet for the production of lead-plated aluminum grids is given in Table 3. Steps 1, 2, and 3 of the process have been discussed on pages 7, 12, and 13 respectively.

Alkali Cleaning of Grids (Step 4)

The first step after the grids have been degreased and annealed is the alkali cleaning, which removes small traces of grease and the film of aluminum oxide on the surface of the grid. This film of aluminum oxide is approximately 0.5×10^{-6} inch thick when the stock is received from the mill.

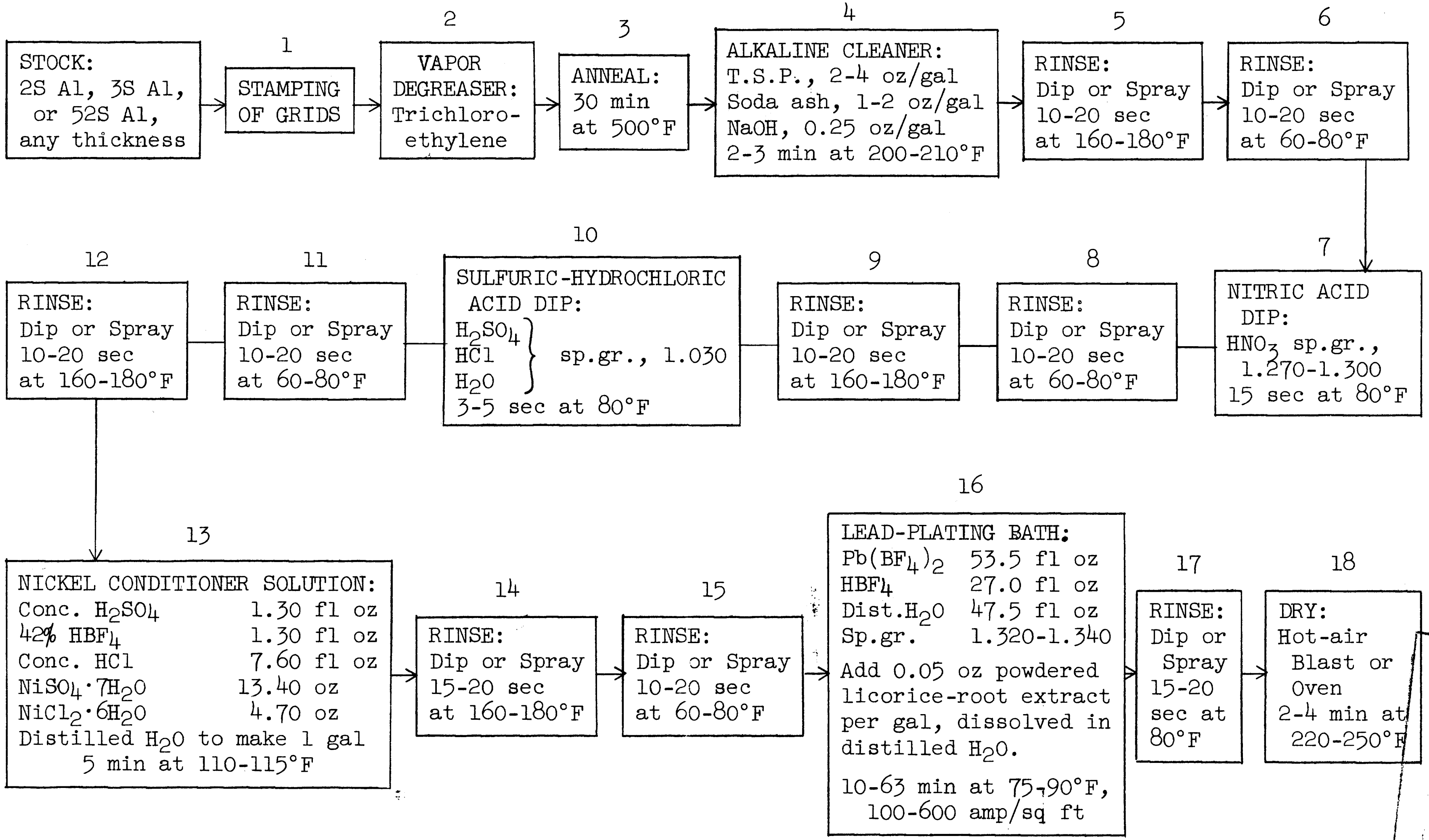
An alkali cleaning solution which has been found to be quite satisfactory is composed of the following ingredients:



Photograph 3. Photomicrographs of 2S Aluminum, 200X:
(a) Aluminum grid as received from the piercing operation;
(b) Aluminum grid heated at 500°F for 30 minutes.

TABLE 3

FLOW SHEET FOR THE PRODUCTION OF LEAD-PLATED ALUMINUM GRIDS



Trisodium phosphate	2-4 oz/gal
Soda ash	1-2 oz/gal
NaOH	0.25 oz/gal

This cleaning bath operates well if the temperature is between 200 and 210°F.

The time required for cleaning will depend on the nature of the 2S aluminum, i.e., whether it meets the highest purity standards or meets only the lowest ASTM purity standards for the manufacturing of 2S aluminum. Aluminum which has been covered with a heavy film of aluminum oxide will need to remain in the alkali cleaner for a longer period, or it may be necessary to dip it in the alkali cleaner more than once. Should there be a large amount of iron in the aluminum, the cleaning period may be reduced to what it is for 2S aluminum which meets the lower limit of manufacturing impurities.

Water Rinses and Acid Dips for Alkali-Cleaned Aluminum (Steps 5-12 and 14-15)

The grid will turn black due to the precipitation of impurities, and these impurities must be removed in an acid rinse or dip. Should the acid dip be composed of nitric acid, there seems to be a tendency toward pacification of the surface of the aluminum; hence, such a dip is usually followed by a sulfuric acid - hydrochloric acid dip. If the iron content is excessively high, we have found that a dilute solution of hydrochloric acid (5-10%) may be substituted for the sulfuric acid - hydrochloric acid dip or for both the nitric acid and the sulfuric acid - hydrochloric acid dips.

In going from the alkali cleaner to the acid dip, the aluminum grid should be rinsed in hot water (160-180°F) for 10 to 20 seconds to remove excess alkali as drag-out from the cleaning tank. This rinse may be either a dip (with agitation) or a spray operation, or a combination of both.

The acid dip following the alkali cleaner and water rinse is generally composed of nitric acid 1.270-1.300 specific gravity heated to a temperature of 80°F. The grid is usually allowed to remain in this solution for approximately 15 seconds; this time interval will vary depending on the type of aluminum and the degree of pacification desired. Should little or no pacification be desired, the hydrochloric acid dip of 5-10% hydrochloric acid is quite satisfactory.

Following the acid dip tank, the grid is rinsed by dipping or spraying with water at a temperature of 60-80°F to close the pores of the grid and squeeze out any acid that may remain in it. The cold-water rinse, dip or spray, is followed by a hot-water (160-180°F) rinse, dip or spray, in which the pores are opened and water absorbed which will dilute any acid remaining and if allowed to remain 15-20 seconds should reduce the acid retained in the grid to a minimum.

Thus, once the aluminum grid has passed the alkali cleaner (Step 4) it is hot-water rinsed (160-180°F). This hot-water rinse opens the pores of the metal and dilutes any alkali that may be in the pores. It is followed by a cold-water rinse (60-80°F) which contracts the pores and ejects the water and alkali. The first acid dip, called the nitric acid dip, is at 80°F. As the metal comes in contact with the 80°F water rinse, the pores tend to remain closed and exclude much of the acid, but sufficient acid enters to neutralize the alkali. The nitric acid dip is followed by a cold-water rinse or spray (60-80°F), during which the pores in the aluminum remain closed. This washes off the excess acid from the surface of the grid and suspends further chemical action on the cleaned aluminum. The cold-water rinse or spray is followed immediately by a hot-water rinse or spray, which expands the pores of the aluminum, drawing in water to dilute any acid that may have entered and be retained in the pores, thus neutralizing retained alkali.

The hot-water rinse or spray is followed immediately by dipping in a sulfuric acid - hydrochloric acid dip at a temperature of 80°F. This procedure squeezes out any water, diluted nitric acid, or salts which may have been retained in the pores and converts any nitric acid salts present to sulfuric acid salts, thus removing all the nitric acid from the grid. The hydrochloric acid in this bath is added to assist in preparing the aluminum for the nickel conditioner by activating the aluminum surface. The hydrochloric acid seems to create considerable effervescence, thus helping to reduce any aluminum oxide left on the grid and form water-soluble salts. The hydrochloric acid also helps to promote adhesion of the nickel conditioner to the aluminum. The sulfuric acid - hydrochloric acid dip is followed by a cold-water and a hot-water washing cycle as described above. The aluminum goes directly from the last hot-water dip in the expanded condition to the nickel conditioning solution at 110-115°F. This causes a slight contraction of the pores, squeezing out any acid that may remain but at the same time assisting the deposition of nickel on the surface of the aluminum.

Example of Nitric Acid Dip

Nitric acid (sp.gr., 1.42 C.P.)	36.2 lb or 11,375 ml, or about 5.17 7-lb bottles.
Distilled water	23,245 ml
Specific gravity of mixture:	1.165-1.170 (33.9% HNO_3); operate at 80°F.

The addition of nitric acid will be necessary from time to time in 100-ml quantities as the activity is reduced by formation of aluminum nitrate.

The grids should remain in the nitric acid dip for 20-25 seconds. The time factor depends on the type of aluminum, 2S, 3S, or 52S, etc. The object of this dip is to remove all discoloration from the aluminum surface left by the alkali cleaner.

Example of Sulfuric-Hydrochloric Acid Dip

Sulfuric acid (sp.gr., 1.84 C.P.)	2.12 lb, or 520 ml	Sp.gr., 1.020-1.025
Distilled water	8 gal, or 30,280 ml	
Hydrochloric acid (sp.gr., 1.19 C.P.)	3.06 lb or 1,165 ml	
Distilled water	2,320 ml	
Specific gravity of mixture:	1.030	

If the specific gravity is below 1.030, add H_2SO_4 and HCl in the ratio of 2.12 lb to 3.06 lb (or 10 ml H_2SO_4 to 22.5 ml HCl) until the specific gravity recovers a value of 1.030. The specific gravity may increase to not over 1.040 without affecting the operation of the acid dip.

Operate at 80°F. The time of dip varies with the type of aluminum, from 2-5 minutes.

If the bath becomes inactive, the addition of 5 ml of HCl (sp.gr., 1.19) to a 1-gal bath usually restores its activity. In stubborn cases, 10 ml of HF acid added will probably restore activity. If this fails to renew the activity of the bath it should be dumped. The bath should also be dumped if it becomes cloudy.

Conditioner Solution (Step 13)

The nickel conditioner solution is very important for good adhesion of the lead electroplate, which is important because a loss of adhesion may cause blistering of the lead electroplate.

The conditioner solution to be used on the aluminum grid just following the acid dip and subsequent hot-water rinse may be composed of iron ions as follows:

Iron Conditioner Dip

$FeCl_2 \cdot 4H_2O$	757 grams
HCl	757 ml
H_2O	3028 ml

Operate 30 seconds at 100-120°F

Conditioner solutions may also be made from chromium ions or nickel ions.

We have found that a most effectual dip and one easy to operate is the conditioner solution made from nickel ions according to the formula given below.

Conditioner Solution No. 1

Conc. H_2SO_4(sp.gr., 1.84)	1.30 fl oz
HBF_4 (42%)	1.30 fl oz
Conc. HCl (sp.gr., 1.19)	7.60 fl oz
$NiSO_4 \cdot 7H_2O$	13.40 oz
$NiCl_2 \cdot 6H_2O$	4.70 oz
Distilled H_2O	To make 1 gal

A nickel dip made according to the above formula is generally maintained at a temperature of 110-115°F. The dipping time will vary in accordance with the chemical composition of the aluminum and whether it has been pacificated in the acid rinses. While we recommend 5 minutes, this may be adjusted downward to as little as 2 minutes.

Two cases will illustrate the variations desired in the conditioner solution: (1) with aluminum which meets the lower manufacturing limits for ingredients other than aluminum in 2S, 3S, and 52S aluminum and (2) with aluminum which meets the upper manufacturing limits for ingredients other than aluminum.

Conditioner solution No. 1a, below, is used when the aluminum meets the lower manufacturing limits for ingredients other than aluminum (Case 1). This solution may be used to provide the only barrier coat between the aluminum base and the top coat of lead electroplate. This specific formula may be varied as required to meet changes in the aluminum alloy composition.

Conditioner Solution No. 1a

Nickel sulfate ($NiSO_4 \cdot 7H_2O$)	18.3 oz
Nickel chloride ($NiCl_2 \cdot 6H_2$)	18.3 oz
Sodium chloride (NaCl)	2.8 oz
Nickel fluoborate ($Ni(BF_4)_2$ - 44%	9.9 fl oz
Hydrochloric acid (HCl, sp.gr., 1.18-1.19)	2.2 fl oz
Sulfuric acid - water solution (H_2SO_4, sp.gr., 1.270)	6.5 fl oz
Ammonium Hydroxide (30 parts NH_4OH, sp.gr. 0.9, and 70 parts of water)	1.9 fl oz
Distilled water	To make 1 gal

This conditioner is operated at a temperature of 80-90°F. After degreasing and removal of surface oxides, the article is placed in the conditioner for 2 to 3 minutes and on removal from the conditioner any adhering solution is removed by rinsing in hot and cold running water. The nickel electroplate is deposited directly on the nickel container deposit, which serves as a barrier coat for the top coat of nickel, chromium, lead, nickel-chromium, or nickel-lead electroplate.

A conditioner solution suitable for aluminum which most nearly approaches the upper manufacturing limits of ingredients other than aluminum (Case 2) is Nickel Conditioner Solution No. 2.

Conditioner Solution No. 2*

Nickel chloride ($NiCl_2 \cdot 6H_2O$)	9 lb
**Hydrochloric acid (sp. gr., 1.19 C.P.)	1400 ml
Distilled water	to make 39,000 ml
***Hydrofluoboric acid	added as needed
Temperature	110-115°C.

It has been determined by calculations and verified in practice that 10 grams of nickelous chloride salt ($NiCl_2 \cdot 6H_2O$) will coat 700 2HN aluminum grids of 0.030-inch thickness. The coating of nickel is approximately 0.0001 inch thick or 0.24 g of nickel per grid as calculated by the nickel removed from the bath.

A typical cleaning operation prior to the nickel conditioner solution is as follows:

Alkali cleaner: 2 to 3 minutes.

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*See p. 46 for controls to be applied.

**Hydrochloric addition depends on the aluminum stock; more than 1400 ml may be required. The hydrochloric acid is added until the bond to the aluminum is satisfactory (i.e., until it melts and flows on the surface of the aluminum without loss of adhesion or the formation of blisters). Should blisters or loss of adhesion occur during the operation of the bath, hydrochloric acid is added in 5-ml amounts (in a 1-gal-capacity bath) until the defects are eliminated.

***Should pinholes occur in the lead surface during lead plating, 25 to 50 ml of 42% hydrofluoboric acid (HBF_4) is added per gallon of bath, or until pinholing stops. This addition may have to be made each day, as the HBF_4 and HCl are lost during operation. The quantitites of hydrochloric and hydrofluoboric acids suggested above are only approximate; the correct amounts depend on the operation of the conditioner solution. Usually pinholes do not occur in electroplate on new aluminum.

Hot- and cold-water rinse in running water.
Nitric acid rinse: 15 seconds or until aluminum is cleaned.
Cold- and hot-water rinse in running water.
Sulfuric-hydrochloric acid cleaner: 2 to 5 minutes or until aluminum is cleaned.
Cold- and hot-water rinse in running water.

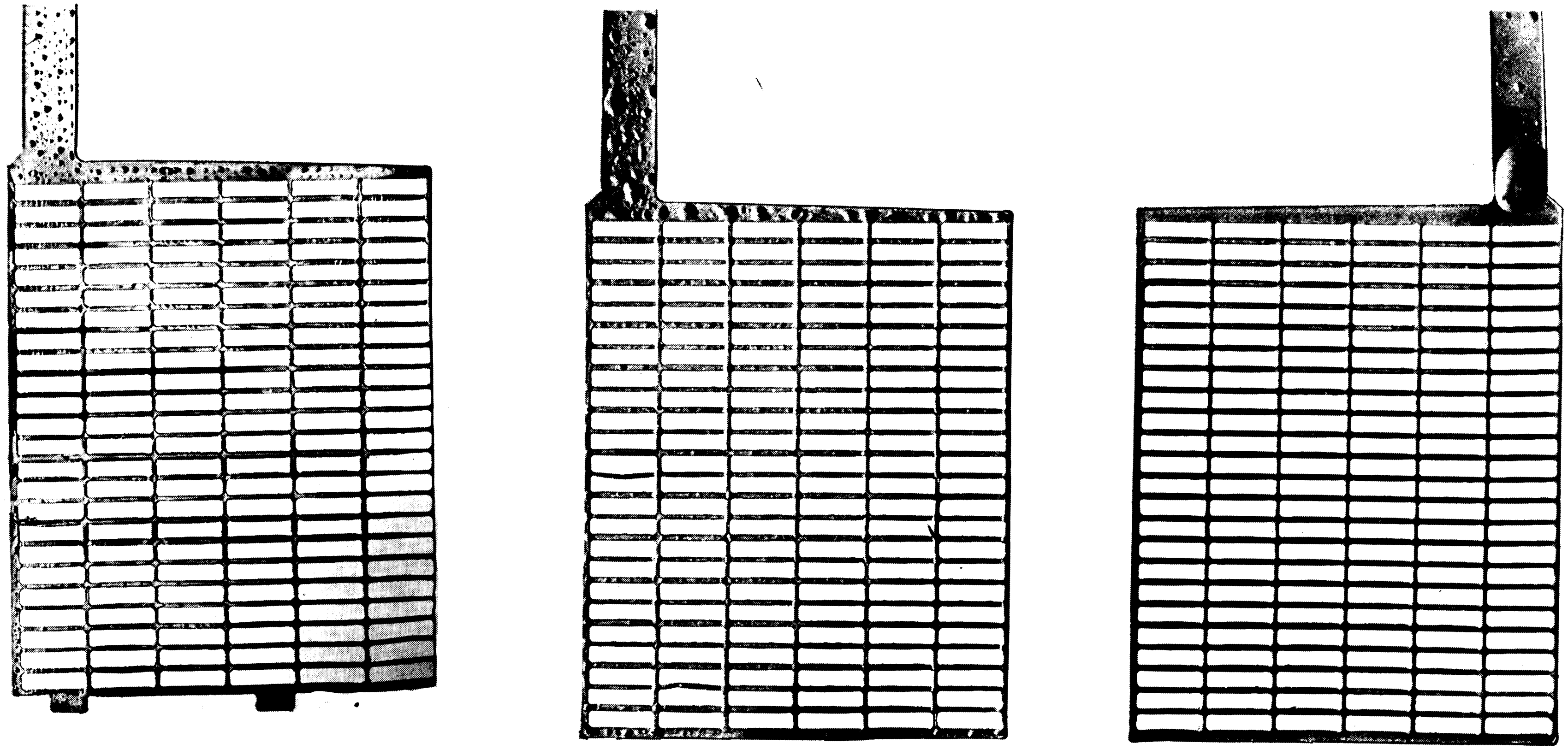
The hydrochloric acid and hydrofluoboric acid generally need replacement every day, as the concentration of each acid is changed due to (1) air agitation, (2) drag-in, (3) drag-out, and (4) temperature of the bath operation, etc.

Photographs 4a, b, and c, illustrate the effect of imperfect concentration of the above acids in the conditioner solution in which the aluminum grids are dipped, while Photograph 4d shows a satisfactory lead plate. The loss of these acids has been traced and found to produce certain definite undesirable characteristics of the aluminum surface. Thus, a deficiency in hydrochloric acid and chloride ions in the conditioner solution causes blistering. The size of the blisters is roughly proportional to the deficiency of hydrochloric acid. Thus in Photograph 4a there is a deficiency of hydrochloric acid but the blisters are small. In Photograph 4b there is a greater deficiency of hydrochloric acid and the blisters are larger and more widely distributed. In Photograph 4c there is not such a deficiency of hydrochloric acid, even though a large blister has occurred; this blister seems to be the result of oil acquired from handling. Fine blisters indicate a slight deficiency of hydrochloric acid. Photograph 4d shows a satisfactory electroplate in which the hydrofluoboric and hydrochloric acids are properly balanced.

The amount of hydrochloric acid required to be added each day is dependent primarily on the volume of the bath, the temperature of the bath, the rate of aeration or agitation, and the number of grids conditioned. What has been said above in regard to the addition of hydrochloric acid to the conditioner solution will apply equally as well to the addition of hydrofluoboric acid to the lead-plating bath.

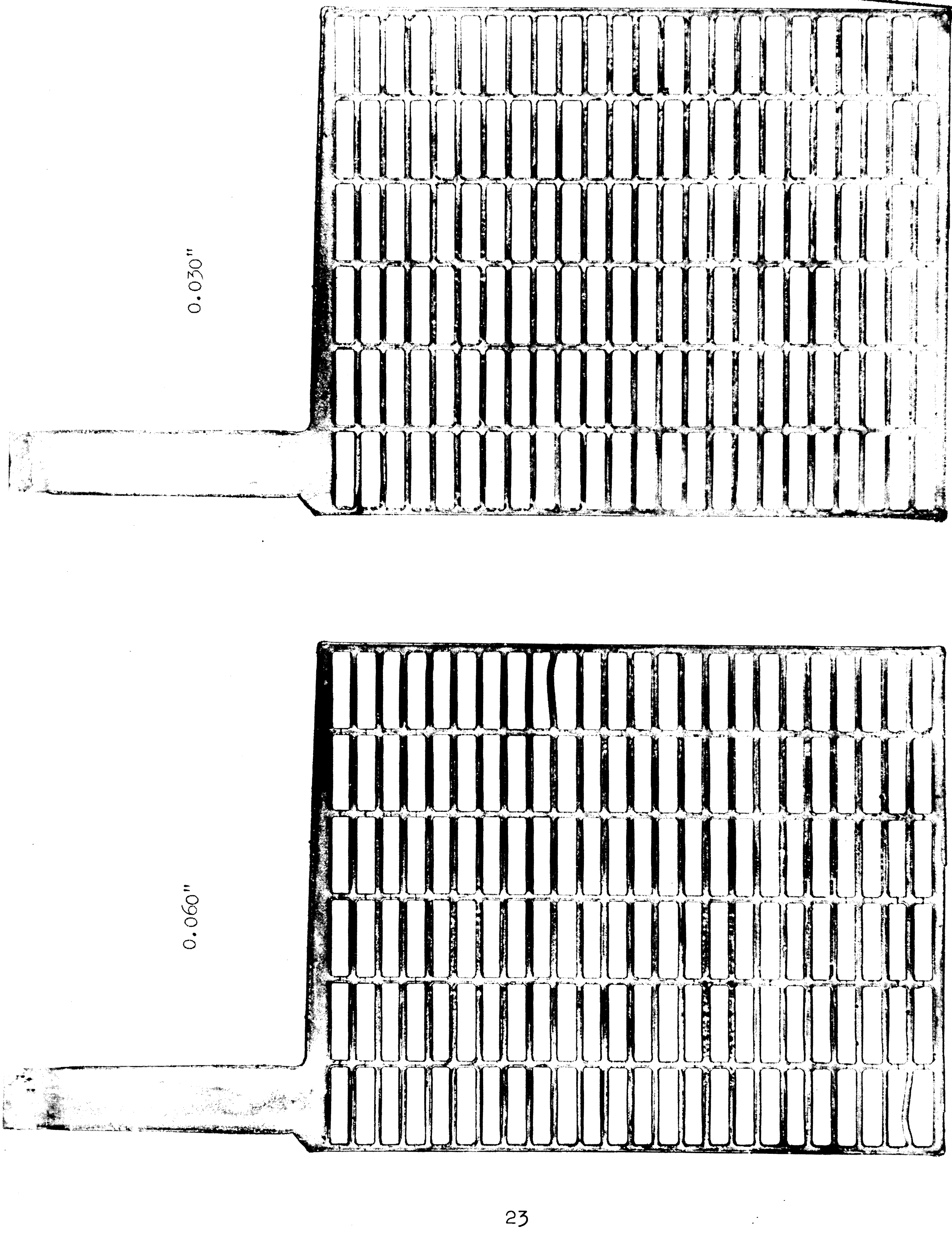
In the 34-liter conditioner solution we are using, it has been found necessary to add approximately 100-150 ml of hydrochloric acid (sp.gr., 1.19) for each 24 hours that the bath is operated and maintained at 110-115°F.

Photograph 5 illustrates the formation of pits in the surface of lead-plated aluminum grids which have been attributed to a deficiency of hydrofluoboric acid in the conditioner solution. A deficiency of hydrofluoboric acid in the lead-plating bath may also cause pits, but the primary cause of pitting is found in the conditioner solution. We have found that the addition of approximately 100 ml of 42% hydrofluoboric acid, to a

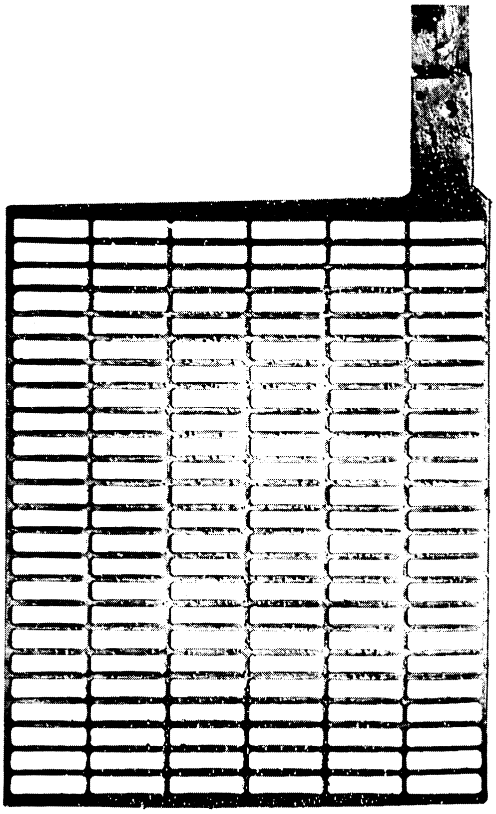


(a) (b) (c)

Photograph 4. Effect of Hydrochloric Acid Concentration in the Conditioner Solution on Heated Lead Electroplate: (a) Small deficiency of hydrochloric acid, manifested as small blisters; (b) A large deficiency of hydrochloric acid; (c) The blister is larger than 4(b), but there are not as many. A less deficiency of hydrochloric acid than in 4(b); (d) See page 23.



Photograph 4d. A Satisfactory Lead Electroplate on 0.060 inch and 0.030 inch Aluminum Grids.



Photograph 5. Effect of Hydrofluoboric Acid Concentrations in the Conditioner Solution on Grids as They Came from the Lead-Plating Bath.

34-liter conditioning bath is required for each 24 hours of operation at a temperature of 110-115°F.

Lead-Plating Bath (Step 16)

The lead-plating bath is a lead fluoborate bath which has been modified slightly from that generally used in the industry. The composition of the bath as we have been using it is given below:

$Pb(BF_4)_2$ (50%)	485 ml/l
HBF_4 (42%)	92 ml/l
Distilled water	To make 1 liter
Specific gravity	1.320-1.390

Agitation of the Bath. The agitation of the grids attached to the movable cathode in the bath has been found helpful in reducing the treeing of lead deposits, especially with high current densities. In addition to the agitation of the cathode, it has been found that additional air agitation of the bath in and around the anodes will help prevent channeling between the anodes and cathodes. The air bubbling may be at such a rate as to produce a slight foam on the surface of the bath. The foam does not seem to interfere with the deposition of the lead.

Temperature of the Bath. A temperature of 75-90°F is recommended. We have plated at higher and lower temperatures, but the higher and lower temperatures were not intentional, but rather were the result of environmental conditions. We would recommend that the tanks be equipped to maintain the temperature indicated (75-90°F).

Hydrogen Ion Concentration. The pH or acidity of the bath is regulated by addition at proper intervals of hydrofluoboric acid as the physical condition of the electroplate may require. This is necessary because some of the hydrofluoboric acid is lost by air drag-out or evaporates as the bath stands and even during operation. The pH is controlled by regulating the acidity as directed under controls for lead-plating bath, page 45. It seems that if the acidity drops below the value indicated, the deposit of lead is not as fine and free from imperfections as when the acidity is maintained at 92 ml/l of 42% HBF_4.

Density of the Bath. For ordinary lead-plating of grids to a thickness of 0.015 inch of lead in 20 to 30 minutes, a lead-plating bath having a specific gravity of 1.320 to 1.390 is recommended.

Should the current density employed be in the range of 300 to 500 amperes per square foot, we have found it advisable to maintain the specific gravity of the lead fluoboric bath at approximately 1.380, and also to increase the number of anodes which are in the bath.

Addition Agents. Water-soluble Canadian protein is recommended as the best addition agent. Since this type of protein is difficult to obtain, we have, by a series of extractions with water-immiscible solvents such as toluene and benzene, been able to isolate a water-soluble protein from the usual American proteins. However, we have found the processed protein manufactured by Canadian Packers Ltd. to be the best protein for our use; enabling us to plate the grids at a current density of between 200 and 500 amperes per square foot.

We have used many other types of additives but the one that comes the nearest to giving as satisfactory a lead plate as the Canadian protein is licorice-root extract, which is prepared by dissolving 5 grams of powdered extract of licorice root in 100 ml of water and filtering the licorice-root water extract. The licorice solution has to be added to the tank at periodic intervals to maintain a fine-grained, uniform deposition. The rate of addition depends primarily on the drag-out and drag-in of the tank in operation.

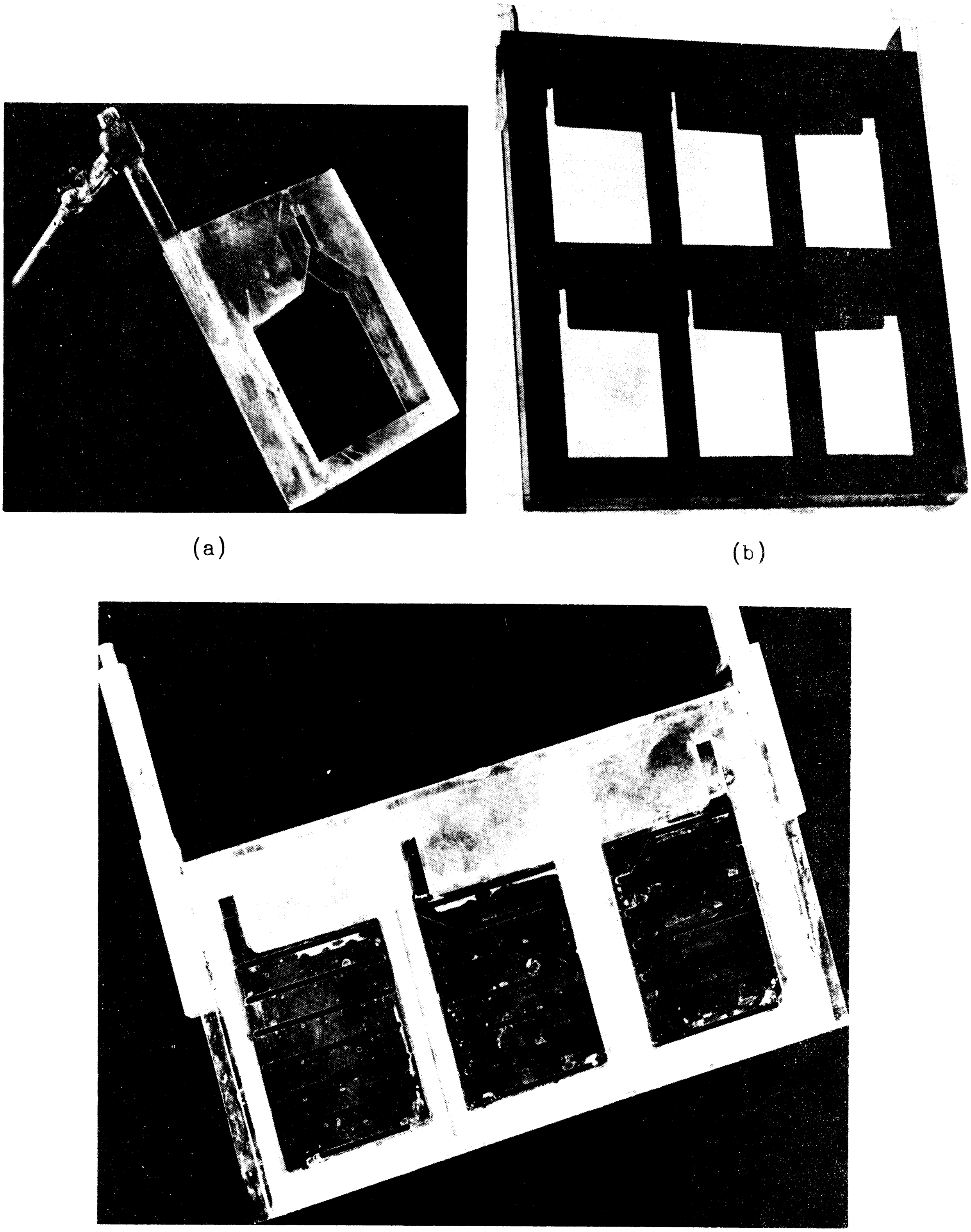
Shields for the Grids in the Plating Tank. It has been found necessary to use shields to reduce the treeing of the lead deposit on the grids. This, coupled with mechanical agitation, permitted us to lead-plate at 300 to 500 amperes per square foot without any visible trees. It has also aided us in securing a more uniform deposition of lead electroplate over all the surface of the grid. Pictures of the shields which we have used are shown in Photographs 6 and 11. Satisfactory operating current densities and the temperatures and times of deposition of a lead plate on 0.015-inch-thick aluminum stock are indicated.

Photograph 7 shows the effect of shields on the deposition of a continuous even-thickness electroplate without trees. The grids to the right in each view show the effect of using no shield.

Voltage. The voltage that is maintained in the lead-plating bath is between 3 and 6 volts. This produces a uniform deposition of lead.

Relation of Current Density Distribution to Character of Lead Deposited. Up to July 1952, lead-plating had been done at a constant grid current density from the beginning to the end of the lead deposition period for a given grid. This method of lead deposition favors the formation of spongy lead on the surface of the aluminum and a much less spongy lead deposit near the surface of the lead electroplate. The dense lead near the surface of the electroplate promotes sloughing of peroxide, due to expansion of lead when it changes to lead dioxide, while the spongy lead near the aluminum grid favors penetration of the lead plate by ions of the electrolyte and provides room for expansion as the lead dioxide is formed.

On discharge the formation of lead sulfate requires additional volume over and above that provided by the change from metallic lead to

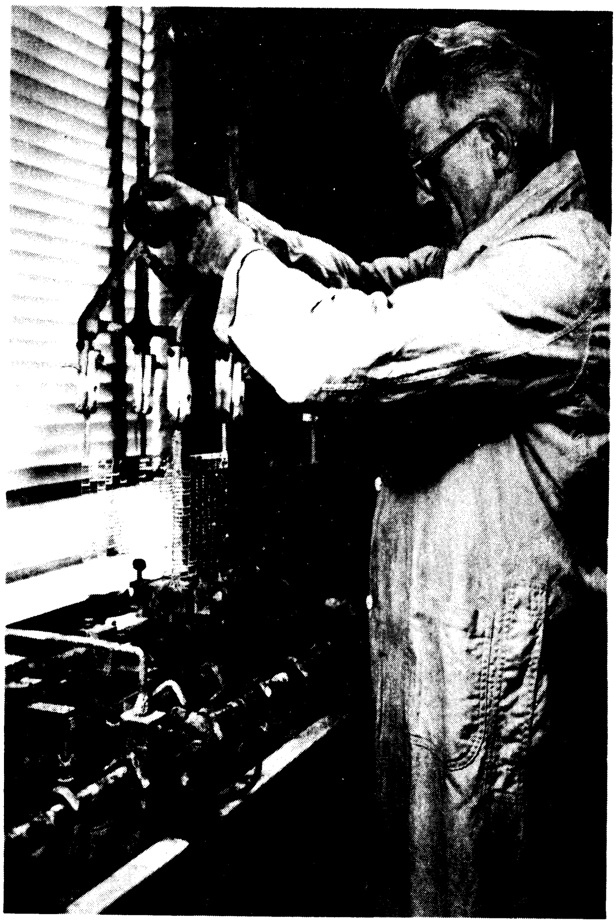


(a)

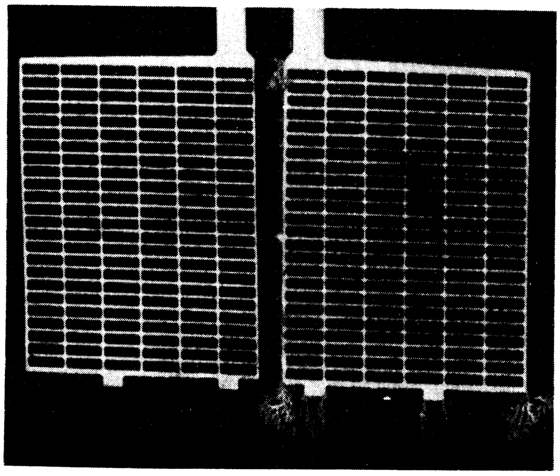
(b)

(c)

Photograph 6. Shields Shown in Previous Report.
a. Shields Used at the Beginning of Project to Help Deposit Lead on Aluminum Grids in 1949. b. Shield Used to Plate 6 Grids at a Time, Based on Shield Shown in Photograph 6a. c. Modified Shield Used in 1951 to Plate 3 Grids at a Time.



(a)



WITH SHIELD WITHOUT SHIELD
LEAD PLATED AT 300 AMP. SQ. FT.
TIME 8 MIN.

(b)

Photograph 7. Effect of Shields on Deposition of Lead Electroplate: (a) Note trees on lead grids held by the operator in left hand; (b) A closeup of one of the grids in 6(a).

lead dioxide; hence, any spongy lead on the surface would help reduce sloughing and provide better penetration and thus greater capacity.

In the following table are listed the active ingredients of a lead storage battery and the calculated volume and diameter of a molecule of each substance.

The volume of one molecule was obtained by dividing the molecular weight in grams by the density to give the gram molecular volume, and dividing that value by Avagadro's number (6.06×10^{23}). The diameter was calculated from the volume of one molecule by assuming that the molecule was a sphere.

These calculations are reasonably correct for this theoretical discussion. As a check, the x-ray data for lead show that its unit cell is a face-centered cube with parameter $a_0 = 4.92$ Å. From these data, the closest approach of any two atoms (which is the atomic diameter) is 3.48 Å. That value is reasonably close to the value (3.862) given in the table.

First let us assume, for the sake of simplicity, that the pores in the active material are cubes. (Any simple geometric figure will give the same results.) Although the pores are not simple geometric shapes, they must be figures with plane surfaces, since all the active materials crystallize in figures with plane surfaces. Hence, a cube may be considered as one of the pores. If the cube side is given the dimension "a", then the volume of the pore, V_p, is

$$V_p = a^3 \ .$$

The area of any one face, A, is

$$A = a^2$$

and the total surface area = $6a^2$.

Now let us assume that the reaction proceeds through only "t" molecular layers at the surface of the pore. This is justified since it has been established that only one-third of the active material is used in any plate. Then the volume of the molecules, V_R, reacting in this reaction layer is

$$V_R = 6a^2 tD \ ,$$

where D is the diameter of the molecule.

TABLE 4

VOLUME CHANGE OF ACTIVE COMPONENTS IN A BATTERY PLATE

Name	Substance Formula	Molecular Weight	Density, g/cm^3	Volume of one molecule x 10^{-23} v, cm^3	Diameter of one molecule x 10^{-8} D, cm
Lead Oxide	PbO	223.21	9.35	3.93	4.22
Lead Dioxide	PbO_2	239.21	9.375	4.2105	4.3163
Lead Sulfate	$PbSO_4$	303.27	6.2	8.0728	5.3619
Metallic Lead	Pb	207.21	11.337	3.0160	3.8620
Water (4°C)	H_2O	18.	1.	2.9703	3.8424
Ice (-20°C)	H_2O	18.	0.88	3.3754	4.0097
Sulfuric Acid (-20°C)	H_2SO_4	98.08	1.834	8.825	5.5239

The number of molecules involved in the reaction is

$$n = \frac{V_R}{v_m} ,$$

where v_m is the volume of the molecule reacting.

Let us first consider the positive plate. The pore here is surrounded by PbO_2 molecules. Then

$$V_{PbO_2} = 6a^2 \; t \; D_{PbO_2}$$

$$n = \frac{V_{PbO_2}}{v_{PbO_2}} \quad \frac{6a^2 \; t \; D_{PbO_2}}{v_{PbO_2}} \tag{1}$$

The reactions at the positive plate as given by Vinal are:

$$PbO_2 + 2H_2O \rightleftharpoons Pb\,(OH)_4 \rightleftharpoons Pb^{++++} + 4OH^-$$

$$Pb^{++++} + 2e \rightleftharpoons Pb^{++}$$

$$Pb^{++} + SO_4^{--} \rightleftharpoons PbSO_4$$

$$4OH^- + 4H^+ \rightleftharpoons 4H_2O .$$

The sum of these reactions is:

$$PbO_2 + H_2SO_4 + 2H^+ + 2e \rightleftharpoons PbSO_4 + 2H_2O .$$

For each molecule of PbO_2 consumed, there is produced one molecule of $PbSO_4$ and two molecules of H_2O, and one molecule of H_2SO_4 is consumed from the electrolyte. The H^+ for the reaction is supplied from the accumulated H^+ at the plate. Internally, the positive plate is the cathode and there will be an accumulation of H^+ there. The H^+ consumed will be rapidly replaced, since the H^+ has an extremely high transference number or migration velocity under a potential gradient. The modern concept is that the H^+ does not actually move through the solution but that a Grotthus-type transfer takes place between H_3O^+. That is, H^+ forms H_3O^+ with water and the H^+ jumps or transfers from one water molecule to the next, thus accounting for the rapid migration velocity. Hence, there will always be a preponderance of H_3O^+ or H^+ at the positive plate for the reaction to proceed. The SO_4^{--} associated with the $2H^+$ will be used in the reaction at the negative plate, to which it migrates.

The volume changes of the pore itself will involve only the PbO_2 and the $PbSO_4$ molecules. The PbO_2 is replaced by $PbSO_4$ and the change in volume of these moleucles will determine the change in volume of the pore in the active material. Electrolyte volume alterations will not influence the pore size, since the electrolyte is a liquid within the pore. However, the change in electrolyte volume in relation to the change in pore volume will dictate whether electrolyte flows into or out of the pore. The relation of electrolyte volume and pore volume will therefore be taken up after the change in pore volume is discussed.

Since only PbO_2 and $PbSO_4$ molecules are involved in the change in pore volume, this change for n molecules of PbO_2 reacting is:

$$\Delta V_p = V_{PbSO_4} - V_{PbO_2}$$

$$V_{PbSO_4} = n\ v_{PbSO_4}$$

$$V_{PbO_2} = n\ v_{PbO_2} \quad ;$$

therefore

$$\begin{aligned} \Delta V_p &= n\ (v_{PbSO_4} - v_{PbO_2}) \\ &= n \times 10^{-23}\ (8.0728 - 2.3105) \qquad (2) \\ &= 3.8623\ n \times 10^{-23} \end{aligned}$$

This means that the pore is being closed rapidly by the accumulated $PbSO_4$ molecules and that small pores are completely closed off from reacting further before all the available PbO_2 molecules have reacted. Thus available capacity has been reduced.

That small pores may be completely closed is seen from the following:

$$V_{pf} = V_{pi} - \Delta V_p = V_{pi} - n\ (\Sigma v_m) \quad ,$$

where V_{pf} = final pore volume and V_{pi} = initial pore volume = a^3.

$$\therefore \; V_{pf} = a^3 - n\,(\Sigma v_m)$$

$$100\,\frac{V_{pf}}{V_{pi}} = \%\text{ change} = 100\left[\frac{a^3 - n\,(\Sigma v_m)}{a^3}\right]$$

$$= \left[1 - \frac{n\,(\Sigma v_m)}{a^3}\right] 100 \qquad (3)$$

$$n = \frac{6a^2\,t\,D_{PbO_2}}{v_{PbO_2}} = K\,a^2\,t$$

$$\therefore \; 100\,\frac{V_{pf}}{V_{pi}} = \left[1 - \frac{Ka^2\,t\,(\Sigma v_m)}{a^3}\right] 100 = \left[1 - \frac{K_o t}{a}\right] 100,$$

since v_m is constant. Thus, as the pore size gets smaller the percent change becomes increasingly larger, so that small pores may be closed.

Another factor reducing capacity may be seen from the molecular dimensions given in the table. The $PbSO_4$ molecule is so much larger than the PbO_2 molecule that it blocks off or covers unreacted PbO_2 molecules, and prevents them from reacting, thus reducing capacity.

Hence, besides the closing of the pore, the available reactive material is blocked off. It is conceivable that many pores large enough to remain open are not reactive because the $PbSO_4$ molecules have covered the unreacted PbO_2 molecules. These are the reasons why only about one-third of the active material of the positive plate is utilized.

Another factor governing capacity and the reason for a spongy lead near the surface of the lead electroplate is acid concentration in the pore or at the reactive surface. The change in volume of electrolyte, ΔV_E, is

$$\Delta V_E = n\,v_{H_2SO_4} - 2n\,v_{H_2O} \qquad (4)$$

$$= n \times 10^{-23}\,(8.825 - 2 \times 2.9703) = 2.884\,n \times 10^{-23}\;.$$

As is observed in practice, the electrolyte volume shrinks. Thus, if a pore did not change in volume, fresh electrolyte would be forced into the pores, thereby aiding the process of diffusion. However, if the pore closed faster than the electrolyte volume shrank, acid would be forced out of the pore, inward diffusion would be hindered, and the acid density in the pore would decrease at an abnormal rate due to the accumulation of water.

Theoretically, then, what does happen in the pore being studied? From the above, it has been calculated that

$$\Delta V_p = 3.8623\, n \times 10^{-23} \qquad (2)$$

but

$$\Delta V_E = 2.8844\, n \times 10^{-23} \qquad (4)$$

Hence, the pore is closing about 1-1/2 times faster than the reduction in acid volume and the second category discussed above is operating, i.e., electrolyte is being forced out, inward diffusion is hindered, and abnormal acid dilution is taking place due to accumulated water. This means that capacity again is being abnormally reduced.

These calculations may be used to explain the difference in capacity at high and low current densities at room temperature. It has already been pointed out why such excess of active material must be present at low current densities. At high current densities, however, the pores are closing so rapidly that practically pure water is adjacent to the reactive surface, not only because diffusion is too slow to replace the acid, but also because any acid in the pore is being forced out so rapidly that inward diffusion is prevented.

The new plating technique deposits dense lead on the surface of the aluminum and spongy lead near the outer surface of the lead electroplate. The spongy lead does not slough off after it is changed to lead peroxide and the dense lead near the aluminum reduces ion penetration from the electrolyte. The spongy lead near the surface of the negative plate favors high negative- and positive-plate capacity, and the dense lead near the aluminum helps prevent ion penetration as indicated by the above study.

The initial lead deposition is done at a low current density, while the final lead deposition is done at a high current density. The time factor is not increased by using this plating technique. For an example of the current density used to plate one of the grids in 55 minutes, see Table 5.

TABLE 5

EXAMPLES OF PLATING SCHEDULE

Thickness of Aluminum Grid, in.	Total Area of Aluminum to be Plated, sq in.	Weight of Unplated Grid, Grams	Plating Schedule Amperes per Grid	Plating Schedule Time, Minutes	Weight of Lead Plated on Grid, Grams	Area of Surface of Lead-Plated Grid, sq in.
0.015	16.61	4.44	5.5	25	38-42	31.36
			11.0	15		
			16.5	15		
0.030	20.39	8.9	15	25	68-72	34.81
			36	15		
			60	15		

Such a plating schedule will deposit the same amount of lead on the grid as if the current density were set at 11.5 and 19.5 amperes per grid, respectively, for the duration of the entire plating cycle.

Filtration of the Bath. The bath should be filtered regularly to remove all specks of dirt which are the result of the solution of lead anodes, contamination from the air, or the introduction of grids, (drag-in) and grid holders in the lead-plating bath. The filtration is done by means of a stainless-steel filter pump which is equipped with felt filter pads. The bath should be filtered whenever the solution shows the presence of specks of any kind, at least once a week. The filtered solution should be clear and sparkling.

Anodes. The anodes in the lead-plating tanks are prepared by casting bar electrolytic lead into shapes 1 inch thick, 4 inches wide, and 12 inches long. These anode shapes are drilled and monel metal hooks are placed in the tops to suspend them from the anode.

We use 12 anodes in each 10-gal tank. They are suspended in 3 rows of 4 each and so placed that their corrosion will give the most uniform deposition of lead on the movable cathodes. There are two movable cathodes in each bath, suspended inside the shields, and the shields and cathodes move in unison between rows of anodes. This means that the middle row of anodes furnishes lead for cathodes on either side.

During the casting of the lead some lead is oxidized and some foreign matter may be included in the cast anode. The cast anodes require a sheathing of vinon cloth, either in the form of a sack or wrapped around the anode. The vinon cloth withstands the actions of the acids in the bath. We have used some of these vinon cloths for over two years.

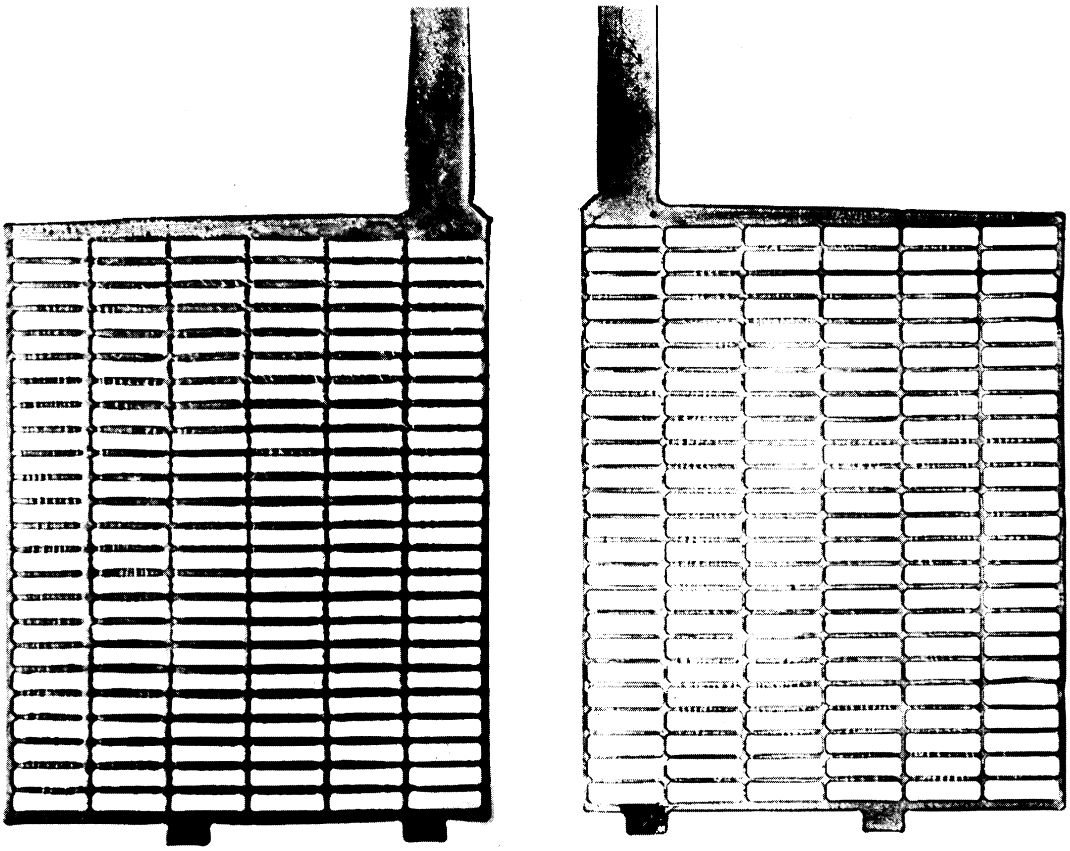
Due to the processing of the anode it may become contaminated with a layer of grease before it is ready to be placed in the lead-plating bath. Hence, we advise that it be degreased and handled subsequently with gloves until it is placed in the lead-plating bath, as grease does not function well in the lead bath.

Inspection of the Lead-Plated Grid. For Blistering and Adhesion of the Lead Plate: The lead-plated grid should be inspected as it comes from the lead-plating bath for trees, for uniformity of coat, and for tendency to blister when subjected to an elevated temperature.

We have found that if the grids, after coming from the lead-plating tank, are rinsed in water at 80°F and then placed in an electric oven at a temperature of 220-250°F for 2 to 5 minutes, they will develop blisters if blisters are likely to occur under the electroplate. This step is important because if they do not blister under the conditions cited above, they will take the lead-burning operation without failure.

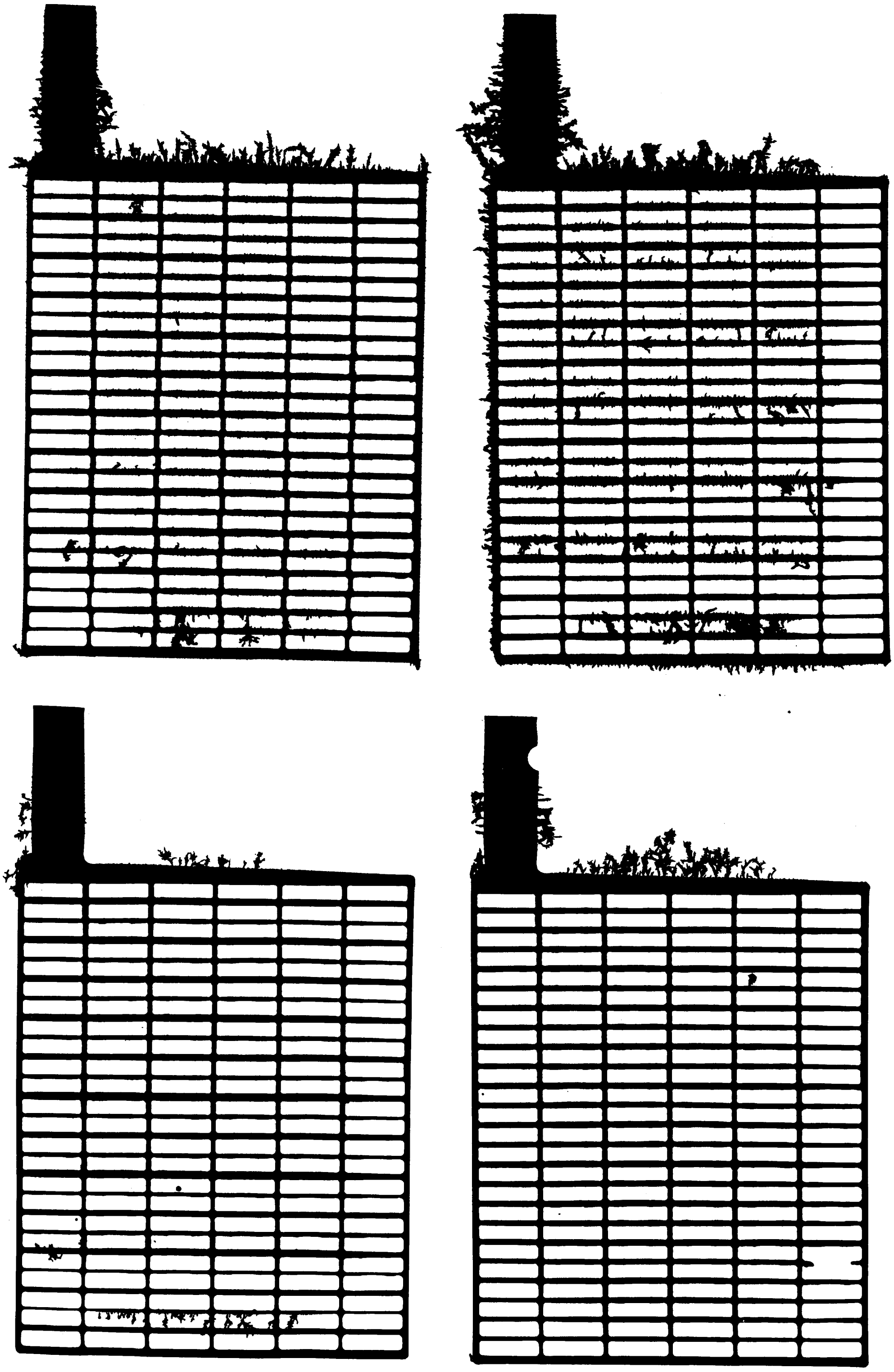
For Ripples in the Lead Plate: Ripples in the lead plate on aluminum grids are illustrated by Photograph 8. If the acidity and all other conditions of the bath are normal, ripples like these may occur if the agitation is not adequate. In order to correct this condition, we have found it necessary to agitate the lead-fluoboric bath with a current of compressed air. This agitation need not be too vigorous, but it should be sufficient to keep the lead-fluoborate thoroughly mixed. Otherwise there seems to be channeling of the lead from the anode to the cathode in spite of the presence of shields or motion of the cathode. This is especially true when plating with high current densities.

Relation Between Current Density and Addition Agent. The effect of licorice and current density on lead plating of battery grids was investigated. It was found that the specific gravity was not a critical factor, although at 150 am/ft^2 a specific gravity of 1.380 was slightly more conducive to lead treeing than a specific gravity of 1.300, as illustrated in Photograph 9. At each of the above specific gravities, holding the current density at 100 amp/ft^2, a decrease in lead treeing resulted from an increase in the licorice concentration. The effect of the licorice can be appreciated more by examining Photograph 10, where different types of shields were used.



Photograph 8. Ripples in Lead Electroplate Due to Improper Agitation.

Sp Gr. 1.300 1.380



No Licorice-Root Extract in Plating Bath

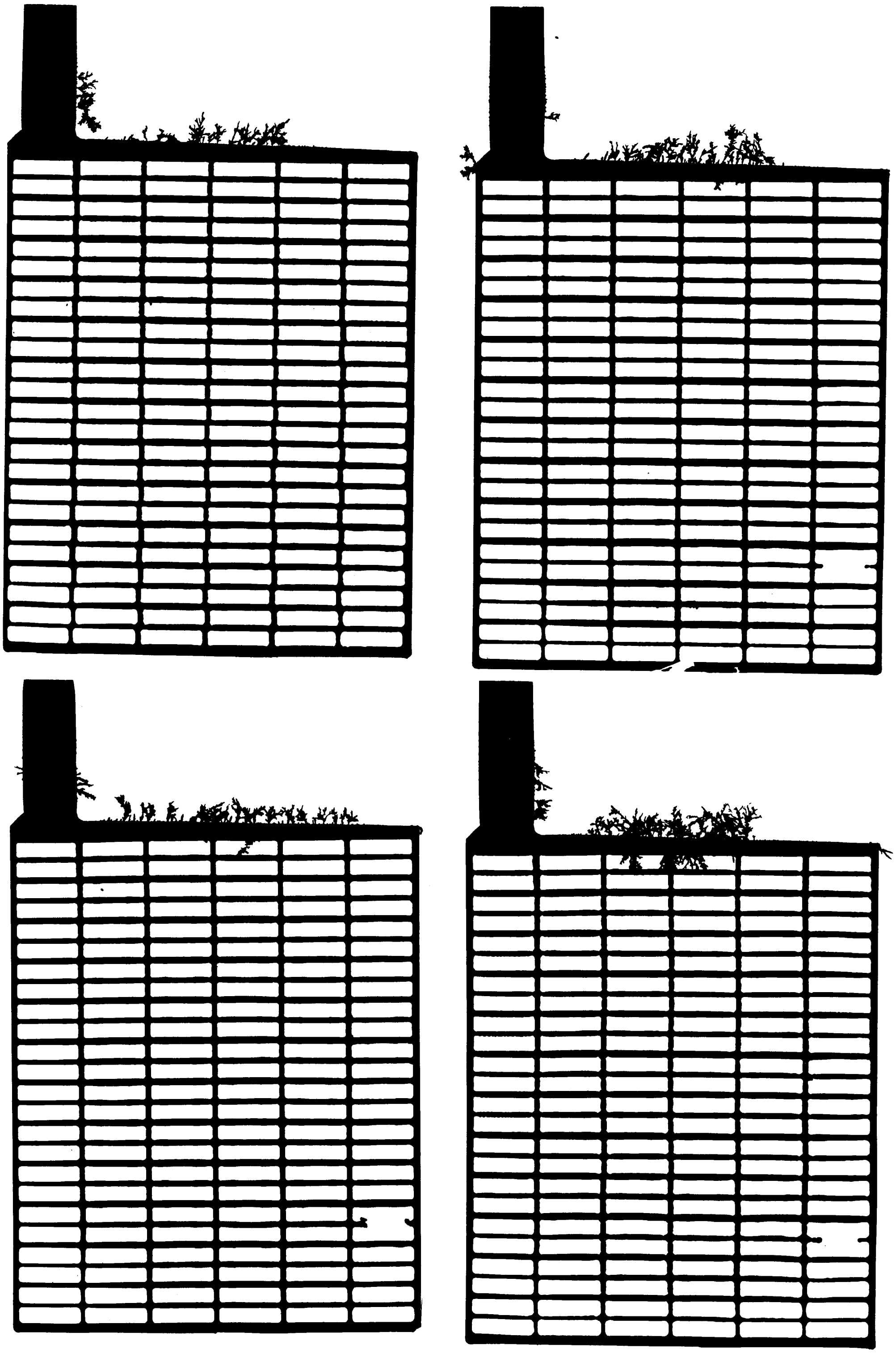
0.0625 g/1 Licorice-Root Extract in Plating Bath

Photograph 9. Effect of Licorice and Specific Gravity on Lead Electroplate. Conditions: Room temperature, Current Density 150 amps/sq ft, Type A Shield.

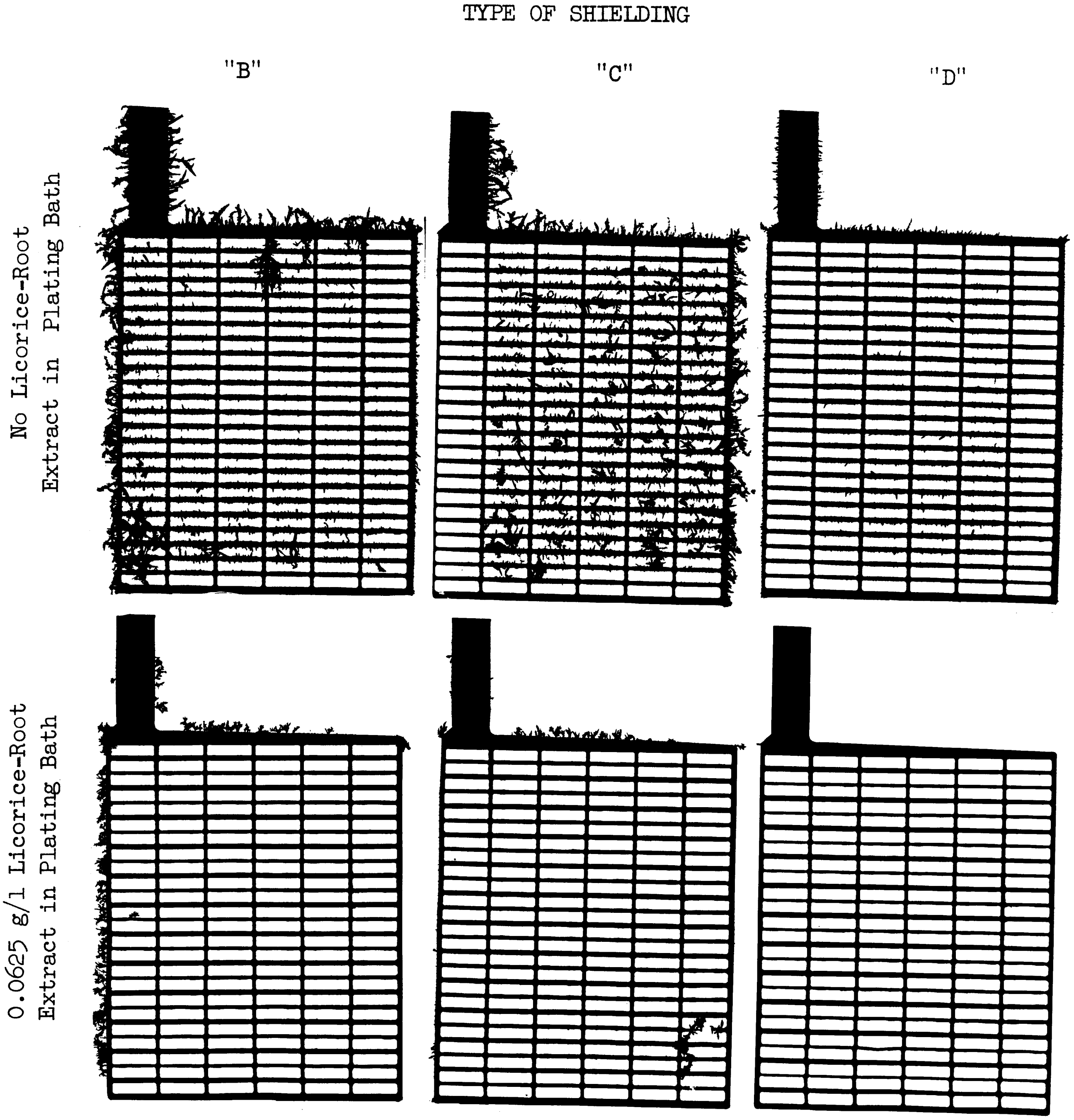
Sp Gr. 1.300 1.380

0.141 g/l Licorice-Root Extract in Plating Bath

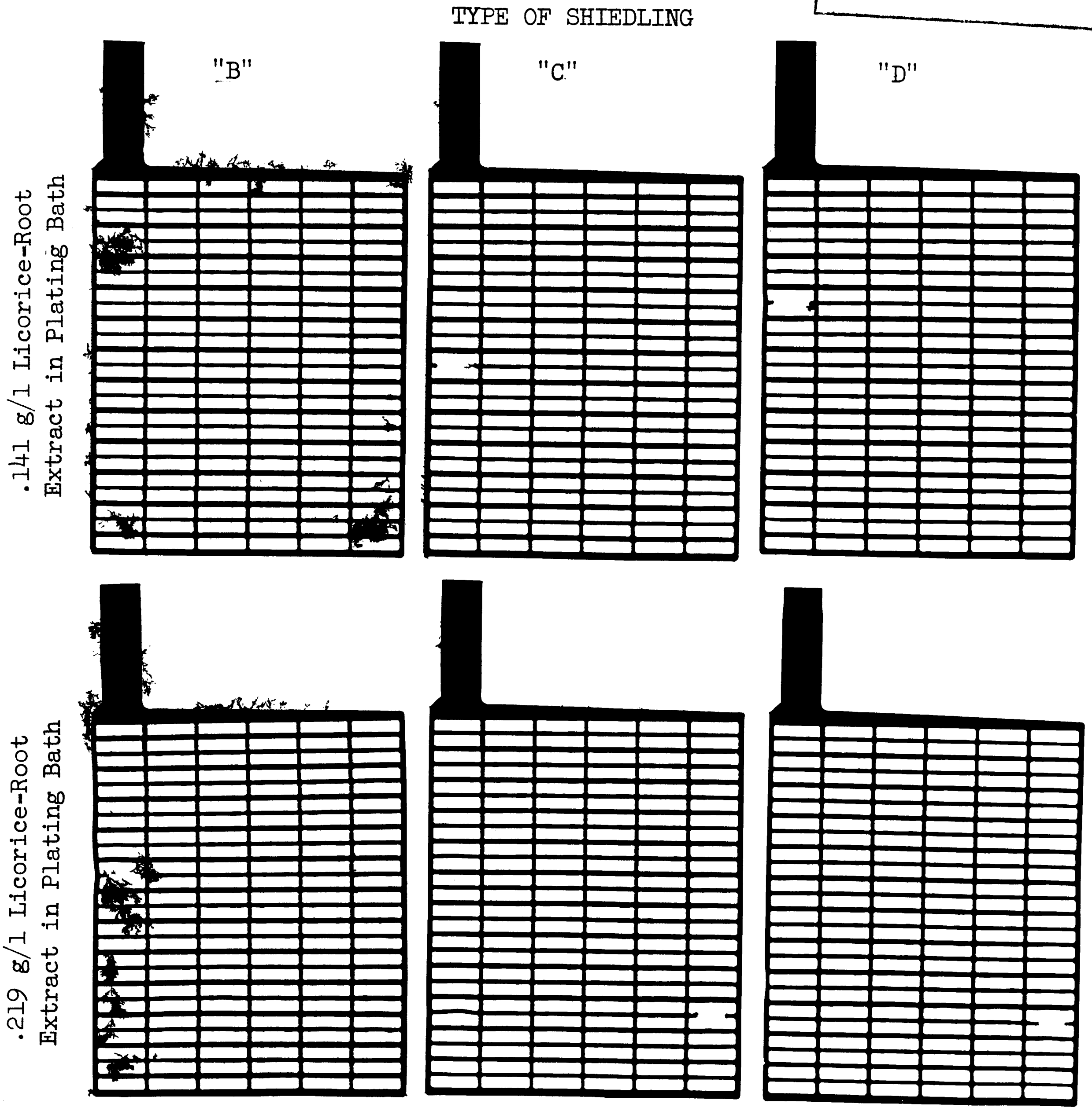
0.219 g/l Licorice-Root Extract in Plating Bath



Photograph 9. Continued



Photograph 10. Effect of Shielding and Licorice Content on Lead Electroplate. Conditions: Room Temperature, Specific Gravity 1.320, Current Density 200 amps/ft^2.



Type of Trees Formed in Licorice-Root Free Plating Bath

Type of Trees Formed in Plating Bath with 0.219 g/l Licorice

Photograph 10. Continued

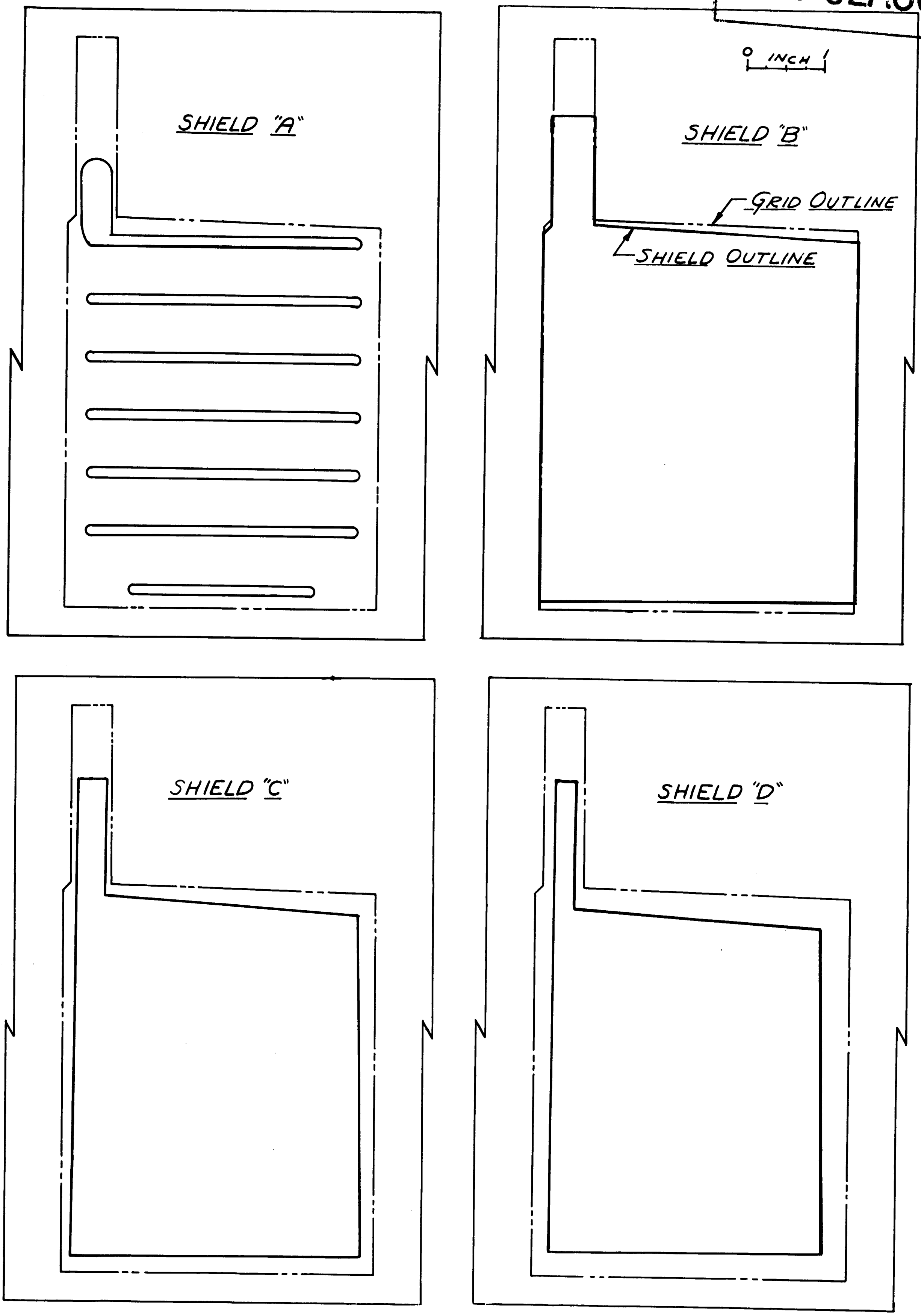
It should be noted at this point that the shield used for Photograph 9 is of the type A shown in Photograph 11 and even though the current density (150 amps/ft^2) is lower than that used for Photograph 10 (200 amps/ft^2), the treeing was more prevalent. As a result of this, shields of the type B, C, and D are recommended. One disadvantage of B, C, and D shields is that the location of the grid with respect to the shield is more critical than with the type A shield. For production work, locating blocks can be used to attain the proper location. For the grids plated in this investigation the location was judged visually, as evidenced by some instances in Photograph 10 where treeing is predominant on one edge and absent from the opposite edge, e.g., shield C with no licorice. As shown in Photograph 10, shield D is the most effective in preventing treeing. This is because the shield overlaps the profile of the grid. If excessive overlapping by the shield is permitted, however, the edges of the grids will be deprived of sufficient lead plate to protect the aluminum base from the battery acid. On the other hand, if the shield does not overlap the profile of the grid, the edges will have a greater tendency to tree as illustrated by the results with shield B in Photograph 10.

Various addition agents such as Canadian protein, protein hydrolysate, gelatin, sassafras-root extract, and licorice-root extract have been added to the lead-plating baths. The Canadian protein seemed to give the best results but it is no longer on the market. In lieu of this, the powdered extract of licorice root was used for this investigation. In order to prepare the powdered extract for addition to the plating bath, a 5% solution of licorice extract powder in water was first boiled and then filtered.

The effect of the licorice on the types of lead trees can be observed at the bottom of Photograph 10. In the absence of licorice the lead crystals grew to lengths of about 3 mm, whereas in the bath with licorice the crystal growth was stunted to about 0.3 mm. The size and shape of the lead trees might be used as a rough check of the concentration of the addition agent.

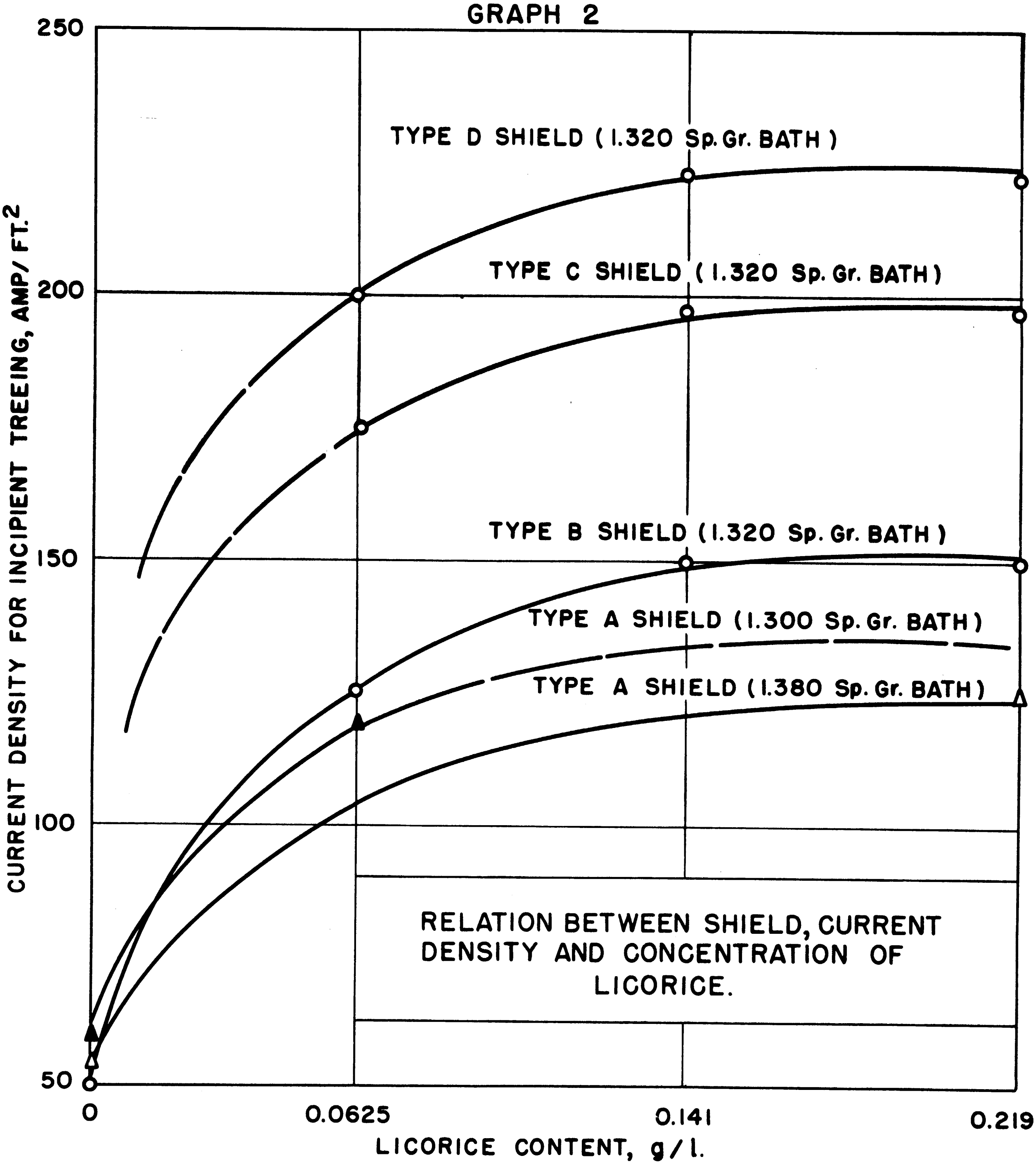
Graph 2 shows the maximum permissible current density per square foot allowable with various shields at different concentrations of licorice. It appears that the addition of more than 0.141 g/l of licorice has no effect on the lead treeing, but more addition agent may be used to insure its continued presence for a period of time. The consumption of the licorice has not yet been determined.

The aluminum grids used for this examination were grids rejected due to a faulty piercing operation to the extent that one or more ribs in the gridwork are missing. Some treeing occurred on the ends of the broken



Photograph 11. Different Shields Employed.

GRAPH 2



RELATION BETWEEN SHIELD, CURRENT DENSITY AND CONCENTRATION OF LICORICE.

ribs; therefore, the treeing at these points should be discounted as irrelevant to the investigation herein involved.

Controls Used to Maintain Optimum Working Conditions in the Lead-Plating Bath. The nominal composition of the lead-plating bath was as follows:

$Pb(BF_4)_2$, 50%	485	ml/liter
HBF_4, 42%	92	ml/liter
Specific gravity	1.380	
Tank capacity	64.0	liters

Total Acid: The total acid i.e., ml/l of HBF_4, may be controlled by titration with standard normal sodium hydroxide: Dilute a 10-ml sample of the bath to approximately 100 ml in a 250-ml Erlenmeyer flask. Titrate with 1N NaOH to the first trace of turbidity which remains on shaking. Record ml of 1N NaOH required and calculate the total acid as the ml/l of HBF_4:

$$A = B \times 18.4 ,$$

where

A = HBF_4, ml/l , and

B = ml, 1N NaOH required for titration.

Analyses should be made only when the tank is at standard working volume. A low tank will give high results, while a diluted tank will give low results.

Under full operation, a daily analysis of the total acid as HBF_4 is recommended. Any deficiency in HBF_4 should be corrected by equivalent additions. Calculate this addition as:

$$C = (92-A)D ,$$

where

C = ml HBF_4 to add,
A = ml/l HBF_4 found by titration,
D = capacity of tank, and
92 = ml/l of 42% HBF_4 of unused tank.

The major loss in HBF_4 seems to be due to dilution from drag-out and drag-in, in proportion to the number of grids plated. There may be some loss due to evaporation upon standing.

Lead Fluoborate ($Pb(BF_4)_2$): The lead fluoborate may be controlled by hydrometry. A specific gravity between 1.320 and 1.390 is satisfactory if taken when the HBF_4 concentration is at 92 ml/l and the tank is at standard working volume.

Our observations have shown that over a period of sixty days of operation, the specific gravity remained between 1.384 and 1.388. This may be accounted for by the fact that as the lead is plated from the solution, an equivalent amount of acid is liberated. This excess acid attacks the lead anodes, returning to the solution an amount of lead equivalent to that lost through plating. Thus, the balance is maintained as long as the total acidity (HBF_4) is kept constant (92 ml/l) by replacing that lost through dilution and evaporation.

Licorice: The licorice concentration, as mentioned on pages 26 and 42 of this report, can be roughly controlled by observation of the type of "trees" formed when plating at high current densities, i.e., 200 amp/ft^2. An excessive amount of licorice will cause black spots to appear on the surface of the plated lead.

Special Controls used with Conditioner Solution No. 2. The nominal composition of Conditioner Solution No. 2, page 20, is

$NiCl_2 \cdot 6H_2O$	100 g/l
HCl, sp gr. 1.19	35 ml/l
HBF_4, 42%	as needed; see below
pH	0.30
Specific gravity	1.055 (fresh tank)
Tank capacity	40.0 l

Analysis of Nickel as Nickel Chloride ($NiCl_2 \cdot 6H_2O$): Pipette a 25-ml sample into a 100-ml volumetric flask. Dilute to the mark with distilled water and mix thoroughly. Pipette a 5-ml sample of this solution into a 400-ml beaker, and dilute to 200 ml with warm H_2O. Dissolve 2-3 grams of either tartaric or citric acid in the solution; render ammoniacal with NH_4OH and heat to 150°F.

Add with stirring 15 ml of 2% dimethylglyoxime (dissolved in equal parts of acetone and ethyl alcohol). Allow the precipitate to separate and test the supernatent liquid for complete precipitation. When precipitation is complete, digest for 1/2 hour just below boiling. DO NOT BOIL.

Cool and filter through a tared Gooch crucible. Wash 10-12 times with small portions of warm 1% NH_4OH. Dry in an oven at 115°C for

30-40 minutes. Cool and weigh as $Ni(C_4H_7O_2N_2)_2$. Calculate as $NiCl_2 \cdot 6H_2O$ in g/l as follows:

$$A = 0.823 \times B \times C ,$$

where

$A = NiCl_2 \cdot 6H_2O$, g/l,
B = weight of precipitate,
C = 1000/ml in sample*

When adding dimethylglyoxime, care must be taken to insure only a slight excess. Dimethylglyoxime is insoluble in water, and an excess will crystallize out, producing high results.

Analyses should be made no less than once a week during full operation. The nickel chloride concentration should not be allowed to drop below 80 g/l. To determine the amount of nickel chloride to add, use the equation:

$$D = (100-A)E ,$$

where

D = grams nickel chloride to add,
A = g/l nickel chloride analyzed, and
E = tank capacity, l.

Tank makeup and HCl-HBF_4 Control: The tank is made up without initial hydrofluoboric acid. The correct amount of nickel chloride ($NiCl_2 \cdot 6H_2O$) is dissolved in distilled water with heat and filtered before addition to the tank; 1 liter of water will dissolve about 2500 grams of $NiCl_2 \cdot 6H_2O$.

With the initial 35 ml of HCl per liter present, the pH of the conditioner solution was found to be approximately 0.50. Our studies have shown that this pH is high for successful deposition. By adding to the tank both HCl and HBF_4 until a pH of 0.30 was reached, a satisfactory deposition was obtained. During the first seven days of operation of a new tank, during which 370 grids were plated, 850 ml of HCl and 755 ml of HBF_4 were added. The pH, after the above-mentioned additions, was found to be at 0.25.

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*As stated in procedure, a 25-ml sample is diluted to 100 ml, and 5 ml is taken for analysis. Thus

$$C = \frac{1000}{25/20} = \frac{4000}{5} = 800.$$

It is recommended that HCl and HBF_4 be added in nearly equal quantities until a pH of 0.30±0.05 is reached; and thereafter, at intervals necessary to keep the pH within the range 0.25-0.35. Due to drag-out, evaporation, and other factors depending on local conditions, considerable loss of acid concentration will occur. It is therefore necessary that daily pH readings be made, and in all probability it will be found advantageous to make small daily additions of both HCl and HBF_4.

Dissolved Aluminum: The deposition of nickel on aluminum is essentially a displacement reaction, and equivalent quantities of aluminum are displaced into solution by the deposited nickel.

There seems to be a point at which the displaced aluminum makes the satisfactory deposition of nickel very difficult if not impossible. It appears that as this point is reached, further additions of HCl and HBF_4 do not compensate for the diverse effect of the high aluminum concentration.

Observations have shown that when the specific gravity approaches 1.130, the nickel deposition becomes unsatisfactory indicating an excess of aluminum ions. At this time the only solution to this problem appears to be substitution of a fresh conditioner bath.

We have conditioned over 5000 aluminum grids in a dip tank which has a capacity of 40 liters.

ASSEMBLY OF LEAD-PLATED ALUMINUM PLATES INTO ELEMENTS AND THE PRODUCTION OF BATTERIES FROM THE ELEMENTS

In Table 6 is outlined the sequence of operations which we follow in the assembly of lead-plated aluminum grid elements and their subsequent assembly into various-sized batteries.

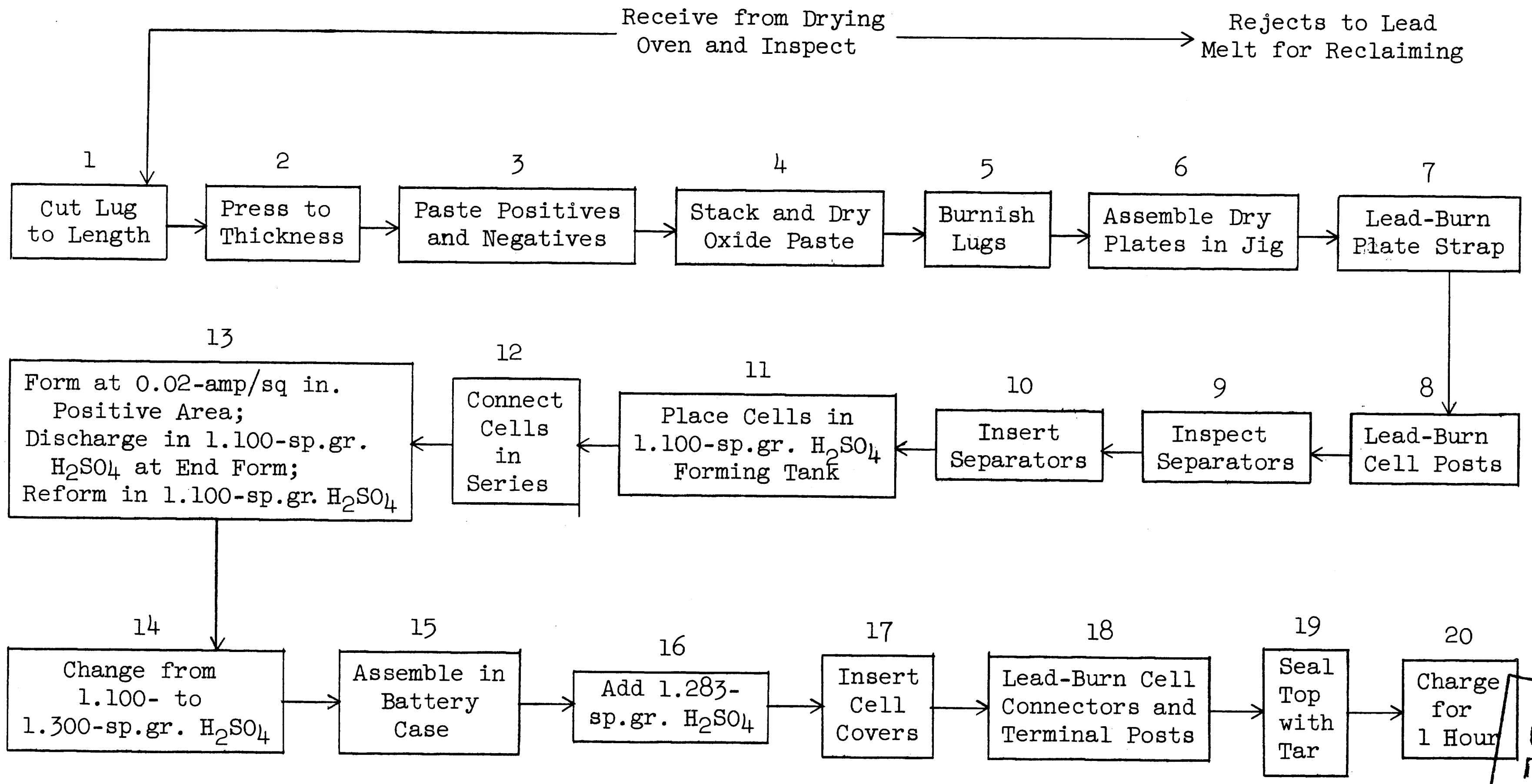
Some of these operations will not be discussed, as they are rather general and any type of equipment may be used to conduct the operation indicated. The only steps on this flow sheet to be discussed here are Steps 2, 6, 7, 8, 9, 13, 18 and 20. The other steps are self-explanatory.

Pressing Grids (Step 2)

In Step 2 the grids are pressed to a uniform thickness. If it is desired to produce a 0.060-inch-thick lead-plated aluminum grid from 0.030 inch-thick aluminum stock through the use of 0.015-inch-thick

TABLE 6

FLOW SHEET FOR ASSEMBLY OF LEAD-PLATED ALUMINUM-GRID BATTERIES



electroplate, the lead is plated approximately 0.016-0.017 inch instead of 0.015 inch. This procedure produces a uniform thickness for 0.015 inch and a slight excess of 0.001-0.002 inch on the edges of the ribs of the grid. The pressing of the grid to a 0.060-inch thickness by use of a spanking press set for a thickness of 0.060 inch will tend to form the edge of the ribs so that they have a V-notch on them, which will assist in holding the active material in place. Such a spanking and reduction in thickness does not seem to affect the adhesion of the lead electroplate.

Assembly of Dry Plates into Elements (Steps 6, 7, and 8)

The assembly of the dry grids in the burning jig (Photograph 12, Step 6) and the lead-burning of the plate strap and the cell posts into position (Steps 7 and 8 of the flow sheet) are discussed as one topic.

Lead Burning of Lead-Plated Aluminum Plates (Steps 7 and 8)

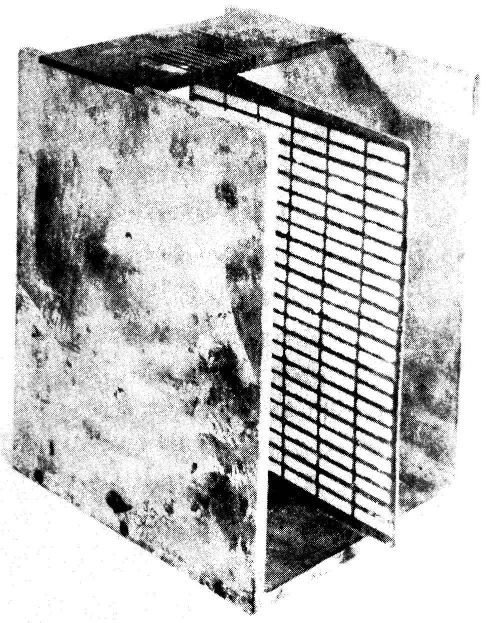
The burning techniques for lead-plated aluminum plates are little different from the burning techniques employed in the burning of cast antimony-lead alloy plates.

Flame. The burning may be done with either a gas-oxygen, hydrogen-oxygen, or acetylene-oxygen reducing flame. It is important that a reducing flame be used to prevent surface oxidation, i.e., formation of lead oxide. The molten pure lead flows and welds easily under a reducing flame. Regulate the size of the reducing flame to correspond to the size of the burning operation.

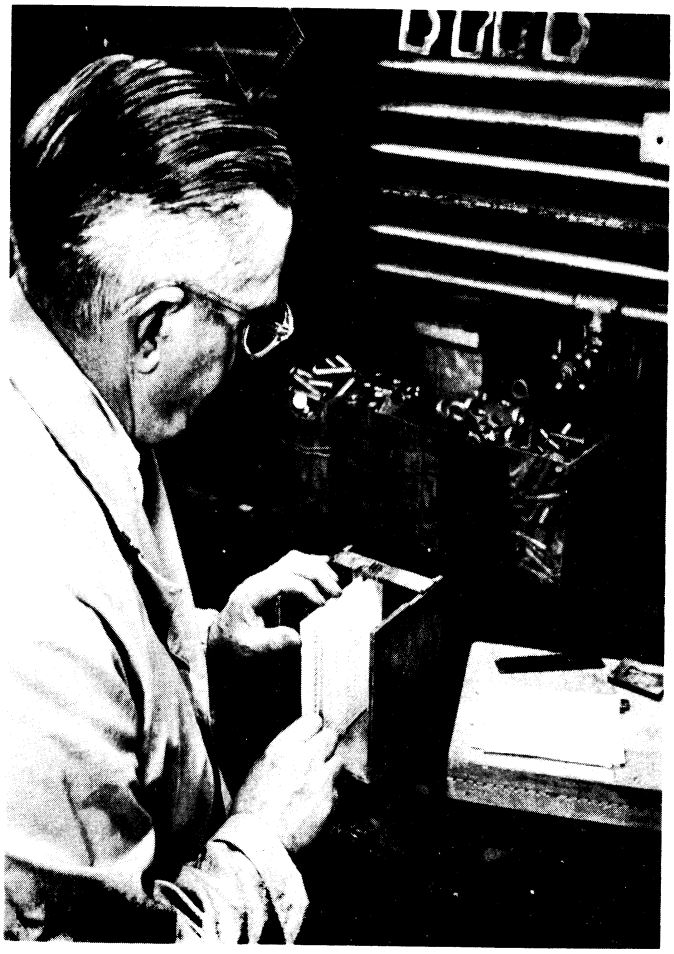
Plate Lugs and Plate Strap Assembly. Photographs 12 and 13 show the relative position of the plate lug and the burning comb. It has been found advantageous to use a mold of steel to form the plate strap (see Photographs 14 and 15).

The extension of the plate lug (Photographs 12 and 13) above the top of the comb should not exceed half the total final thickness of the plate strap. If the plate lug extends closer to the top of the plate strap, blisters or pinholes may occur in the plate strap which are difficult to remove.

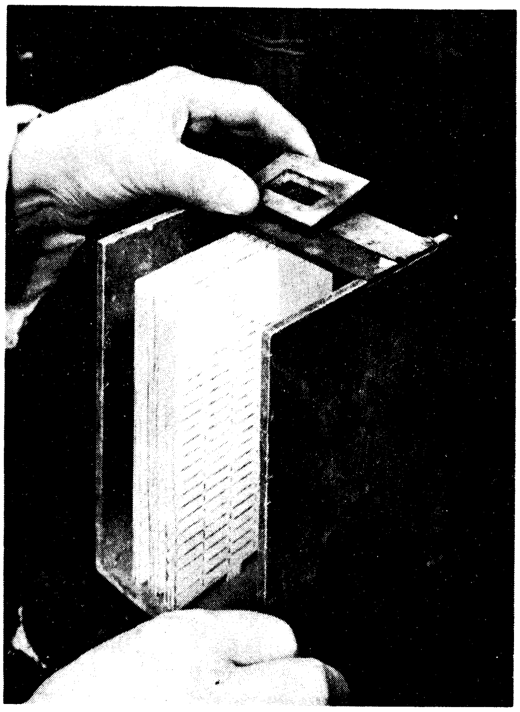
Burning techniques. Now that the plate lug extension above the burning comb has been fixed (Photograph 13) and the steel mold used to form the plate strap is in position (Photograph 15), use a reducing flame and puddle lead from a pure-lead burning stick into the mold (Photograph 15)



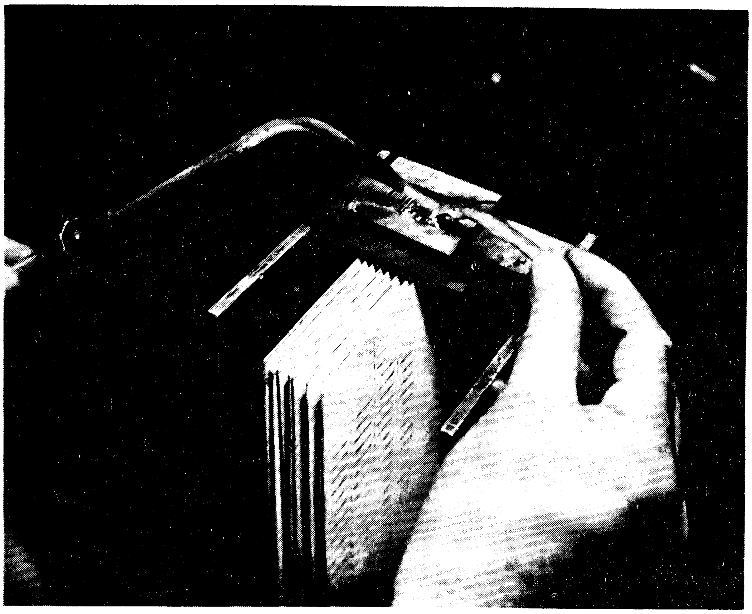
Photograph 12. Relation of Plate Lug and Burning Comb.



Photograph 13. Assembly of Plates in Burning Comb.



Photograph 14. Placing the Steel Mold Around the Plate Lugs Extending through the Burning Comb.



Photograph 15. Puddling the First Layer of Lead from a Burning Stick into the Mold in Building Up the Plate Strap to the Desired Thickness.

so that the thickness of the molten lead extends between 4/5 and 5/6 of the distance from the top of the burning comb to the top of the plate lug which extends above the burning comb. This is called the first layer of lead. Melt the top of the first layer of lead about the lugs and add additional lead from the burning stick to form a continuous lead strap to the top of the mold (Photograph 15). (Note: If desired, molten lead may be poured into the mold to a depth of 4/5 to 5/6 of the distance from the top of the burning comb to the top of the lug which extends above the burning comb. The top of this first layer of lead should then be melted and the thickness of the strap completed by running lead from a lead burning stick to the top of the mold, (Photograph 15).

The first layer of lead in the burning mold lends mechanical strength to the plate lugs and helps reduce running of the lead on the plate lugs when the balance of the strap is welded or sealed to the first layer of lead in the mold. An expert lead burner may produce the strap in one operation.

Set the cell post on the plate strap in a predetermined position and pass the reducing flame around the base of the cell post to weld it to the plate strap (Photograph 16). In some battery designs the attachment of the cell post and the production of the plate strap may be combined into one operation, as in the use of a combined aluminum cell post and plate strap which has been lead-plated.

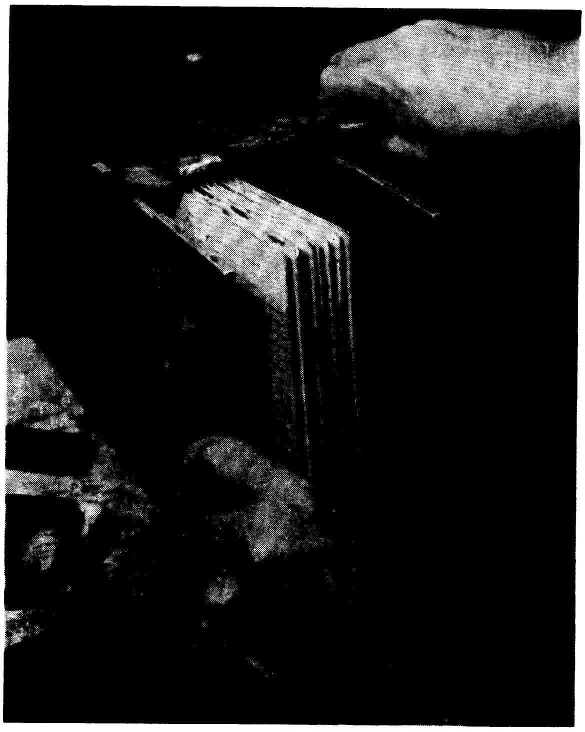
The hot, completed element may be removed from the comb as indicated (Photograph 17) or left to cool in the comb until it may be handled.

Inspection of Separators (Step 9)

Since the spacing between the assembled positive and negative plates is usually of the order of 0.030 to 0.040 inch, it is necessary to inspect the separators; we have found that as many as 10 or 15 percent of separators of these thicknesses will be imperfect, i.e., contain one or more small openings. These elements can be inspected by passing them over a 250-watt electric light enclosed so as to focus the light on the separator as it passes.

These openings, while small, would not be of such great importance if there were a larger separation between the positive and negative grids. However, with such a small clearance for acid circulation to remove sloughing positive oxides, it is necessary that the separators be free from small visible openings. This inspection step makes possible the running of 12-15 S.A.E. overcharge cycles on the batteries before failure occurs.

Photograph 16. Welding the Cell Post to the Cell Plate Strap.



Photograph 17. Removal of the Burned Positive or Negative Cell Element from the Burning Comb.

Formation of Lead-Plated Aluminum Cell Elements (Step 13)

The following method is being used to case-form the elements of 2HN 12-volt 45-A.H. batteries. The 6TN 12-volt 90-A.H. batteries are formed at double the rates indicated for 2HN 12-volt 45-A.H. batteries.

At the present time we are using 0.060-inch-thick positive plates and 0.030-inch-thick negative plates assembled with wrap-around pormax separators 0.030 inch in thickness. The temperature of formation is maintained between 80 and 90°F by setting the unsealed battery case with the elements connected with temporary pure-lead straps in water. The formation is done in 1.100-sp.gr. sulfuric acid. The formation cycle may be summed up as shown in Table 7.

TABLE 7

CASE-FORMATION CYCLE OF 0.060-INCH-THICK-POSITIVE PLATES ASSEMBLED WITH 0.030-INCH-THICK NEGATIVE PLATES

Specific Gravity of Acid, 1.100; Temperature, 80-90°F

Operation	Type of Battery	Current Density, Amp/sq in.	Current for Eight Positive Plates per Element, Amp	Time, hr	Condition
1. On charge	2HN 12-volt 45-A.H.	0.015	5	30	Sulfate cleared.
2. Discharge	2HN 12-volt 45-A.H.	0.009	3	3-3-1/2	To end voltage of 10.8 volts.
3. On charge	2HN 12-volt 45-A.H,	0.015	5	21	Positive a uniform chocolate-brown color at close of formation period.

Dump the 1.100-sp.gr. acid, add 1.300 sp.gr. acid, and charge at 3 amperes for 1-1/2 hours; measure the specific gravity of the acid and continue the charge until the acid does not gain in specific gravity during a 1-hour interval between specific-gravity readings. Now adjust the specific gravity of the acid while charging at the 3-ampere rate. The mixing of the acid is slow due to (1) the thinness of the separator ribs and (2) the wrap-around separators employed.

This formation is conducted in the case in which the battery is to be housed. The battery is completely assembled except for the covers and tarring and burning of the connectors and terminal posts, which is done after the battery has been formed.

Lead-Burning Cell Connectors and Terminal Posts (Step 18)

In step 18 the cell connectors and terminal posts are burned. The cell connectors are burned as in the production of ordinary lead-antimony batteries except that pure-lead connectors are employed. The terminal posts are built up of pure lead in a mold which has the dimensions required of the final terminal posts. The terminal post is built from the top of the cell cover to the exposed top of the terminal post, and the lead sleeve of the cover and post are sealed together with molten lead.

Charging of Lead-Plated Aluminum-Grid Storage Batteries

The charging procedure for type 2HN 12-volt 45-A.H. and 6TN 12-volt 90-A.H. lead-plated aluminum-grid batteries is given below:

1. After the 2HN 12-volt 45-A.H. battery has been discharged to an end voltage of either 10.8 or 6.0 volts, the specific gravity of the acid and the number of ampere-hours obtained from the battery during the discharge cycle are recorded. This number of ampere-hours obtained from the discharge cycle is then multiplied by 1.1 to give the approximate ampere-hours to be charged into the battery on the subsequent charging cycle.

2. The next battery is charged at 2.5 amperes until the number of ampere-hours returned to the battery equals the number of ampere-hours obtained during the discharge cycle. At this point the charging rate is reduced to 1.5 amperes and charging continued at this rate until the specific gravity of the acid is between 1.285 and 1.290 and the voltage of the battery measured across the terminal posts, while being charged at 1.5 amperes, lies between 16.20 and 16.50 volts. When the specific gravity of the acid and the battery potential reach these values, the battery is completely charged.

3. The completion of the charging cycle will frequently be reached when the ampere-hour input equals the product obtained by multiplying the ampere-hours of discharge by 1.05, providing the above recharging procedure has been followed.

4. Since the plate thickness is the same in both cases, the 6TN 12-volt 90-A.H. batteries are charged in the same manner except that the initial charging rate and the finishing charging rate indicated in Table 8 below are used for 16- and 17-positive-plate assemblies.

TABLE 8

CHARGING RATE FOR LEAD-PLATED-ALUMINUM-GRID BATTERIES

Charging Rate, Amp	Current Density, Amp/sq in.	Total Area, sq in.	Type of Lead-Plated-Aluminum-Grid Battery
2.5	0.00864	289	2HN with 7 positives
1.5	0.00501	289	2HN with 7 positives
2.85	0.00864	330	2HN with 8 positives
1.5	0.00454	330	2HN with 8 positives
5.5	0.00833	660	6TN with 16 positives
3.0	0.00454	660	6TN with 16 positives
5.85	0.00606	701	6TN with 17 positives
3.2	0.00454	701	6TN with 17 positives

5. The above charging procedure is based on a positive plate thickness of 0.060 inch. If the positive plates are 0.040 inch thick, and the plate area is the same, then the initial charging rate is 4/5 of that given in Table 8 and the finishing rates are the same as those given in the table.

In the charging of the lead-plated aluminum-grid batteries it is important to remember that the voltage of a 12-volt battery at the end of the charging cycle should be between 16.2 and 16.5 volts, while the voltage of a 12-volt battery made from lead-antimony grids is not as high. Thus a charging unit which is used to charge a lead-antimony grid battery is usually set to cut out at 14.7 volts, but such a cut out voltage will leave the ordinary lead-plated aluminum-grid battery only about two-thirds charged, or with a final specific gravity of 1.250 to 1.260 (the specific gravity, if the cell is charged to an end voltage of 16.2 and 16.5 volts, will be 1.285 to 1.290). This means that the line voltage near the end of the charge should be such that it will be between 16.2 and 16.5 volts if the battery is to reach full charge. The above charging rates are based on the voltage of 16.2 to 16.5 volts.

As an example, the charging of a lead-plated aluminum-grid 12-volt battery which contains 0.060 inch-thick positive plate and 0.030 inch-thick negative plates separated with pormax separators of 0.030 inch in thickness will be presented in the report to be issued June 30, 1954.

PILOT-PLANT EQUIPMENT USED FOR THE PRODUCTION OF LEAD-PLATED ALUMINUM GRIDS

In outlining the equipment required to lead-plate the aluminum battery grids, only that equipment actually needed for the plating is listed in Table 9 and no attempt is made to give actual size of tanks, rheostats, filters, d-c generators or rectifiers, or any other equipment pertinent to the production of lead-plated aluminum battery grids. The choice of this apparatus naturally is dependent on the production desired. However, it is important to set up the controls as outlined and to plan for adequate facilities to handle the job.

This equipment list is subject, of course, to change as improvements may be made which delete or add to the existing requirements.

TABLE 9

PILOT-PLANT EQUIPMENT USED FOR THE PRODUCTION OF LEAD-PLATED ALUMINUM BATTERY GRIDS

Description	Number Required
Vapor degreaser	One
Basket for holding grids during degreasing	One
Steel tank with drain, water, steam coil, temperature regulator, and overflow; for alkali cleaning	One
Steel tank treated inside to inhibit rust formation, with hot-water facility to operate at 160-180°F, inlet and overflow dam or water spray; for hot-water rinse	One
Stainless-steel tank or equivalent with drain; for 1.270-sp. gr. HNO_3	One

TABLE 19 (cont)

Description	Number Required
Steel tank treated inside to inhibit rust formation, water inlet, and overflow dam or spray; for cold-water rinse	One
Steel tank treated inside to inhibit rust formation, water inlet, and overflow drain or spray with heat regulator to operate at 160-180°F; for hot-water rinse	One
Korseal-lined steel tank or equivalent with heat regulator to operate at 110-115°F; for conditioning dip	Two
Steel tank treated inside to inhibit rust formation, water inlet, and overflow dam or spray with heat regulator to operate at 160-180°F; for hot-water rinse	One
Korseal-lined steel tank or equivalent with drain; for lead fluoborate plating solution	Depending on production desired
Steel tank treated inside to inhibit rust formation, water inlet, and overflow dam with heat regulator to operate at 160-180°F; for final rinsing	
D-c rectifier or d-c generator; size optional	Depending on production desired
Plating racks, constructed of cast No. 12 Al alloy; size optional	Depending on production desired
Drying oven, to operate at 220-250°F	One
Balance scales; for weighing plated grids and dry chemicals	Two; one for dry chemicals, one for plated grids
Plastic shields designed to block off path of lead ions and equalize deposit of lead plate on grid; design dependent on plating installation	Depends on plating installation

TABLE 9 (cont)

Description	Number Required
Rheostat with step controls, ammeter, shunt, and voltmeter; Capacity required dependent on time cycle and area of grids plated in each tank	One for each lead-plating tank
Cathode work rod, with plating-rack holders attached and with reciprocating motion or equivalent; design dependent on design of plating installation	Depends on plating installation
Anode rods	Three per tank when designed in tandum.
Filtering equipment, for filtering lead-plating solution: (1) Alsop Disc filter or equivalent, stainless-steel construction with motor, acid-resistant hose, stainless-steel nipple, and strainer (2) Cuno Filter or equivalent for rough filtering of solutions during carbon treatment	One of each
Cutoff machine, for cutting grid lug to length	Depending on production, usually one
Press with motor, plate and anvil; for pressing grids to thickness; size optional, but not less than 50-ton	One
Lead melting pot, oil- or gas-fired; for melting lead to cast anodes; size optional, but not less than 30-lb capacity	Two
Lead ladle; for pouring lead; size optional, but not less than 12-lb capacity	One
Anode molds; for making lead anodes; size dependent on plating installation	Two
Motorized cutoff saw or shears; for cutting lead anodes to length; size dependent on plating installation and size of lead anodes	One

TABLE 9 (cont)

Description	Number Required
Motorized drill and taps, for miscellaneous work	One
Exhaust hood and fan, for exhausting fumes from plating line	One
Work bench, with vice, hammer, pipe wrenches, assorted files, assorted crescent wrenches, screwdrivers, pliers, and like tools	One
Hydrometer, range 1.100 to 1.300	Two: one for HNO_3, one for lead fluoborate bath
Burette and stand	Two; one for titration of conditioning bath, one for titration of lead-plating bath
Pipettes, for obtaining sample of baths; 1- to 10-ml capacity	Two
pH paper, acid range 0-1.5, for lead baths	
Interval time clock; for timing cycles	Depends on plating installation
Plating-rack loading jig; for alignment of grids in rack	Depends on plating installation
Bench rack-holding fixture, for holding loaded plating racks	Depends on plating installation
Air line, equipped with filter and connected to all tanks except alkali cleaner and water rinse tanks	One

TABLE 9 (Conc)

Description	Number Required
Dolly or truck for handling lead pig	One
Oven to operate at 500-600°F; for heat-treating aluminum grids	One

CHARACTERISTICS OF LEAD-PLATED ALUMINUM-GRID BATTERIES

Self-discharge of Lead-Plated Aluminum Grid Batteries on Standby

In the January, 1953, report, pages 1 and 2, the standby discharge capacity of three batteries that stood 37 days is reported. This report indicates that these batteries lost of the order of 1 percent or less of their capacity, which confirms previous standby experiments we have conducted on other lead-plated aluminum-grid batteries using different thicknesses of grids. No special study was made of the specific gravity of the electrolyte during standby. Special work had been done by private battery companies and it was reported that the loss in gravity was, in general, less than that of the lead-antimony batteries for corresponding lengths of time.

In order to re-evaluate the above findings, six 2HN 12-volt 45-A.H. batteries were charged and set aside for various periods as indicated in Table 10.

The batteries employed in this standby experiment were batteries which were produced in our laboratory and shipped to the Detroit Tank Arsenal on February 6, 1953. These batteries remained in the possession of the Detroit Tank Arsenal until approximately April 1, 1953, when they were returned for us to charge and condition for other experiments. Of this lot, batteries 129, 132, 137, 139, 140, and 141 were selected at random for these experiments. The elements in these batteries contained 8 positive 0.060-inch-thick grids, and 9 negative 0.030-inch-thick grids assembled with 0.030-inch-thick pormax separators. The aluminum grids used in these elements had 3/8-inch-tall feet which rested on the bridges in the bottom of the cells.

In Table 10, column 2 lists the discharge capacities in minutes at the 25-ampere rate for each of these batteries just prior to their shipment to Detroit. Column 3 gives the capacities in minutes at the 25-ampere discharge rate which were obtained from these batteries on recharging

TABLE 10

STANDBY RECORD OF SIX 2HN 12-VOLT 45-A.H. BATTERIES; STANDBY ON OPEN CIRCUIT

Battery No.	25-amp Discharge Time Before Shipment to Detroit*, min	25-amp Discharge Time After Return from Detroit**, min	Start of Standby Period	End of Standby Period	Time of Standby Days	Number of Previous Discharge Cycles	Discharged at 25 amp Just Prior to Standby Period at 80°F			Specific Gravity of Acid at 82°F			25 amp Discharge at End of Standby Period		% Variation from Capacity before Standby period	Capacity loss Expected Due to Change in sp.gr. of Acid, amp-hr
							Cycle No.	Time, min	Amp-hr	Start of Standby Period	End of Standby Period	End of Discharge Cycle	Time, min	Amp-hr		
129	70	60	1 June 1953	15 July 1953	45	8	9	55	22.9	1.290	1.285	1.175	58	24.1	+ 5.25	- 9.65
132	72	60	1 June 1953	15 July 1953	45	8	9	60	25.0	1.290	1.290	1.175	60	25.0	0.0	0.0
137	75	75	1 June 1953	9 Sept 1953	101	11	12	70	29.1	1.285	1.260	1.125	70	29.1	0.0	-38.2
139	72	78	1 June 1953	9 Sept 1953	101	11	12	70	29.1	1.290	1.260	1.125	70	29.1	0.0	-45.8
140	72	75	1 June 1953	3 Dec 1953	186	9	10	75	31.2	1.280	1.225	1.150	40	16.6	-46.5	-78.5
141	74	75	1 June 1953	3 Dec 1953	186	9	10	75	31.2	1.285	1.225	1.125	50	20.8	-33.3	-85.5

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*Batteries sent to Detroit Tank Arsenal on February 6, 1953.

**Batteries returned to University of Michigan laboratory on April 10, 1953. These Batteries were reconditioned and the results of their discharge cycles are given in column 7 with capacity in minutes shown in column 9.

and discharging following their return. All six of the batteries were reconditioned just prior to June 1, when each was placed on standby. In this experiment, six batteries were fully charged by our usual charging technique (see page 56), caps were screwed in tightly, and the units were set on a bench in the laboratory. No special precaution was taken to secure them against contamination or accidental contact with any outside sources. No addition of acid or water was made during the standby period. The temperature of the laboratory was approximately 75-85°F.

On July 15, after a standby period of 45 days, batteries 129 and 132 were discharged at the 25-ampere-hour rate and the number of minutes required to reduce the voltage to 10.8 volts was recorded for each battery. It will be noted that the discharge time in the case of No. 129 increased by 3 minutes, while that for No. 132 remained constant at 60 minutes of discharge time.

Batteries 137 and 139 were allowed to stand until September 9, 1953, a total of 101 days. Neither of these batteries decreased in capacity during this standby period. The discharge times for these batteries were identical to those before standby.

Batteries 140 and 141 were allowed to stand on open circuit until December 3, 1953, a total of 186 days. These batteries gave a discharge of 40 and 50 minutes respectively at the 25-ampere discharge rate. This would indicate a loss in capacity of 46.5 and 33.33 percent respectively.

The information obtained on batteries 129, 132, 137, and 139 duplicate previous experiments, but the loss in capacity indicated by batteries 140 and 141 is greater than we had experienced in previous experiments.

We have been of the opinion that a loss in specific gravity of the acid in the batteries during the standby period is not an accurate criterion of the discharge capacities of the batteries. The data on batteries 129, 132, 137, and 139 show no reduction in their discharge capacities as compared with the discharge capacities just prior to the standby period, but all these batteries, except No. 132, showed a reduction in the specific gravity of the acid. The amount of reduction in capacity as based on the specific gravity of the acid for these batteries is given in column 17. We have had similar experience with batteries of this type in previous standby periods in excess of 100 days. If we are to credit the figures given in Table 10 for batteries 129, 132, 137, and 139, there seems to be no direct correlation, between reduction in capacity of the batteries on standby and the reduction in specific gravity of the acid. A similar analysis of the data on batteries 140 and 141 also shows no direct correlation, since the decrease in specific gravity in the acid indicated at least a 75 percent loss, while the actual loss of discharge capacity was less than 50 percent.

In general, a loss in specific gravity after 101 days does indicate some loss in capacity, but there seems to be no direct relation between the two quantities.

In Table 11 the specific gravity of each of these batteries is reported week by week during the first 45 days.

The specific gravity was measured by the usual battery hydrometer. It is understood that more exact measurements could have been made, but these are more nearly in accord with the values any layman or industrial user of the batteries would obtain. These measurements indicate little or no loss in capacity due to a change of specific gravity, which is borne out by the capacity at the 25-ampere-hour rate indicated in Table 10.

In the January, 1953, report, a study was presented on the effect of possible puncturing of the lead coating on one of the lead-plated grids. On page 9 this study is summarized as follows:

> "At the end of the standby of 37 to 41 days each battery was discharged at the same rate as it had been discharged 37 to 41 days earlier. The data tabulated in the tables referred to in this report indicate that exposed aluminum on the lead-plated aluminum grids immersed in the battery acid does not affect the time capacity of these batteries at high discharge rates. The percentage of aluminum in the battery acid increased, but the extent of solution of the aluminum under the lead electroplate is retarded by the formation of aluminum sulfate and aluminum oxide, which help to retard further action of the battery acid on the aluminum grid."

The aluminum ion has only one valence; hence, it does not assist standby discharge. If any aluminum were to be deposited on the battery plate, it would soon be converted to the sulfate and to the oxide, which would become practically inactive. The main possible objection to aluminum in the electrolyte would be the ultimate collection of aluminum oxide on the surface of the plates, reducing their active surface areas and thus tending to reduce the capacity of the battery in proportion to the area of the plates inactivated by the shielding of the aluminum deposit.

Resistance of Lead-Plated Aluminum Grids

The resistance per unit length at 20°C of the grid stem composed of Pb-Sb alloy and lead-plated aluminum grids has been calculated and is given in Table 12. The resistance per unit area at 20°C to the center of the grids at right angles to the plane of the grid is given in Table 13.

TABLE 11

CHANGE IN SPECIFIC GRAVITY OF ACID IN 2HN 12-VOLT 45-A.H. BATTERIES ON STANDBY FOR A PERIOD OF 45 DAYS

Date	Cell No.1	Cell No.2	Cell No.3	Cell No.4	Cell No.5	Cell No.6	Average	Days on Standby
				Battery 129				
Started June 1, 1953	1.290	1.290	1.290	1.290	1.290	1.290	1.290	0
June 8	1.290	1.290	1.290	1.290	1.290	1.290	1.290	8
June 16	1.290	1.290	1.290	1.290	1.290	1.285	1.289	16
June 23	1.285	1.285	1.285	1.285	1.285	1.285	1.285	23
June 29	1.285	1.285	1.285	1.285	1.285	1.285	1.285	29
July 15	1.285	1.285	1.285	1.285	1.285	1.285	1.285	45
				Battery 132				
June 1	1.290	1.290	1.290	1.290	1.290	1.290	1.290	0
June 8	1.290	1.290	1.290	1.290	1.290	1.290	1.290	8
June 16	1.290	1.290	1.290	1.290	1.290	1.290	1.290	16
June 23	1.290	1.290	1.290	1.290	1.290	1.290	1.290	23
June 29	1.290	1.290	1.290	1.290	1.290	1.290	1.290	29
July 15	1.290	1.290	1.290	1.290	1.290	1.290	1.290	45
				Battery 137				
June 1	1.285	1.285	1.285	1.285	1.285	1.285	1.285	0
June 8	1.285	1.285	1.285	1.285	1.285	1.285	1.285	8
June 16	1.280	1.285	1.285	1.285	1.285	1.285	1.2841	16
June 23	1.285	1.285	1.285	1.285	1.285	1.285	1.285	23
June 29	1.280	1.285	1.285	1.285	1.285	1.285	1.2841	29
July 5	1.285	1.285	1.285	1.285	1.285	1.285	1.285	35
July 15	1.280	1.285	1.285	1.285	1.285	1.280	1.2833	45

TABLE 11 (Cont.)

Date	Cell No.1	Cell No.2	Cell No.3	Cell No.4	Cell No.5	Cell No.6	Average	Days on Standby
				Battery 139				
June 1	1.290	1.290	1.290	1.290	1.290	1.290	1.290	0
June 8	1.290	1.290	1.290	1.290	1.290	1.290	1.290	8
June 16	1.285	1.285	1.285	1.285	1.285	1.285	1.285	16
June 23	1.285	1.285	1.285	1.285	1.285	1.285	1.285	23
June 29	1.285	1.285	1.285	1.285	1.285	1.285	1.285	29
July 5	1.280	1.280	1.280	1.280	1.280	1.280	1.280	35
July 15	1.280	1.280	1.280	1.280	1.280	1.280	1.280	45
				Battery 140				
June 1	1.285	1.285	1.285	1.285	1.280	1.280	1.283	0
June 8	1.285	1.285	1.285	1.285	1.280	1.280	1.2833	8
June 16	1.290	1.285	1.290	1.290	1.285	1.285	1.288	16
June 23	1.290	1.285	1.290	1.290	1.285	1.285	1.288	23
June 29	1.290	1.285	1.285	1.285	1.285	1.285	1.2841	29
July 5	1.285	1.285	1.285	1.285	1.285	1.285	1.285	35
July 15	1.280	1.285	1.285	1.285	1.280	1.280	1.2833	45
				Battery 141				
June 1	1.285	1.285	1.285	1.285	1.285	1.285	1.285	0
June 8	1.285	1.285	1.285	1.285	1.285	1.285	1.285	8
June 16	1.285	1.285	1.285	1.285	1.285	1.285	1.285	16
June 23	1.285	1.285	1.285	1.285	1.285	1.285	1.285	23
June 29	1.285	1.285	1.285	1.285	1.285	1.285	1.285	29
July 5	1.280	1.280	1.280	1.280	1.280	1.280	1.280	35
July 15	1.280	1.280	1.280	1.280	1.280	1.280	1.280	45

TABLE 12

COMPARISON OF THE LINEAR RESISTANCE OF LEAD-PLATED ALUMINUM GRIDS WITH SOLID LEAD-ANTIMONY ALLOY GRIDS

Description of material	Width, inches	Thickness, inches	Length, cm	Resistance per Unit Length, ohm/cm
0.030-inch Al	0.5	0.030	1	30.3×10^{-6}
0.030-inch Al coated with 0.015-inch of Pb (total, 0.060-inch)	0.5	0.060	1	26.1×10^{-6}
0.015-inch Al	0.5	0.015	1	60.5×10^{-6}
0.015-inch Al Coated with 0.0075-inch of Pb (total 0.030 inch)	0.5	0.030	1	52.7×10^{-6}
91% Pb - 9% Sb	0.5	0.060	1	132×10^{-6}
91% Pb - 9% Sb	0.5	0.030	1	264×10^{-6}

TABLE 13

COMPARISON OF UNIT AREA RESISTANCE OF LEAD-PLATED ALUMINUM GRIDS WITH SOLID LEAD-ANTIMONY (8%) ALLOY GRIDS

Description of Material	Total Thickness, inches	Traversed Thickness, inches	Area, cm^2	Resistance per Unit Area, $ohms/cm^2$
0.030-inch Al coated with 0.015-inch of Pb	0.060	0.030	1	0.899×10^{-6}
0.015-inch Al coated with 0.0075-inch of Pb	0.030	0.015	1	0.450×10^{-6}
91% Pb - 9% Sb	0.060	0.030	1	2.06×10^{-6}
91% Pb - 9% Sb	0.030	0.015	1	1.03×10^{-6}

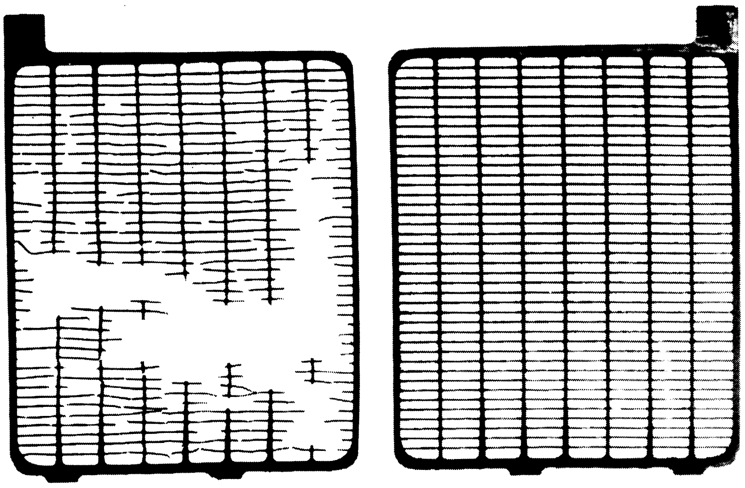
Comparison of the Surface Corrosion of Lead-Antimony and Lead-Plated Aluminum Grids

To compare the rate of surface corrosion of cast lead-antimony battery grids and lead-plated aluminum grids, a cell consisting of one positive and two negative lead-antimony unpasted grids was connected in series with a like cell containing lead-plated aluminum grids. Each grid was accurately weighed before starting the surface-corrosion test. The weights of the lead-antimony grids were recorded as one group and the weights of the lead-plated aluminum grids recorded as a second group. Between the positive and negative grids of each group were inserted microporous rubber separators having a thickness of 0.042 inch. Rubber bands were put around the outside of the grid assembly to keep the grids in place. They were then placed in 1.283-sp.gr. H_2SO_4 and charged at 0.022 amp/sq in. of positive grid surface area. The grids were charged continuously for 168 hours, after which time they were removed from the acid, carefully dipped in three washings of distilled water, dried for 4 hours at 110°C, and then accurately weighed; the process of charging was then repeated for subsequent cycles of 168 hours at 0.022 amp/sq in.

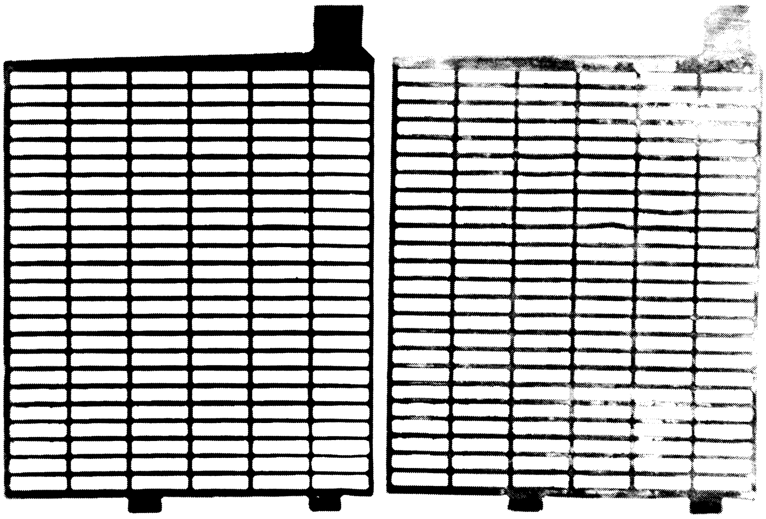
Graph 3 shows the percentage loss in weight of the positive elements of the two types of grids. The lead-antimony grid, as shown in Graph 3, had less surface corrosion during the first three weeks of the test, but after the three-week period the surface corrosion rate of the lead-antimony grid increased rapidly with the overcharge and at the end of the fourth week it was more than 1.5 times as fast as the surface corrosion of the lead-plated aluminum grid. At the end of the fifth week of surface corrosion, the positive lead-antimony grid had corroded 1.7 times as fast as the positive lead-plated aluminum grid, while at the end of the sixth week or 660 ampere-hours of charge, the lead-antimony grid had corroded 2 times as rapidly as the lead-plated aluminum grid under the same conditions of acid concentration, current density, and temperature. At the end of the sixth week the lead-antimony positive grid had lost 42.24 percent of its original weight, while the lead-plated aluminum positive grid had lost only 20.75 percent of its original weight. Photograph 18 shows the condition of the positive and negative lead-antimony grids after 660 ampere-hours of charge. Photograph 19 shows the positive and negative lead-plated aluminum grid after 820 ampere-hours of charge. This surface-corrosion test was conducted at a current density during the charging cycle equivalent to the regular overcharge rate specified for 2HN-type batteries.

Weight Change During Cycling of Lead-Plated Aluminum Grids

The purpose of this cycling test was twofold; (1) to determine the number of charge and discharge cycles the lead-plated aluminum grids

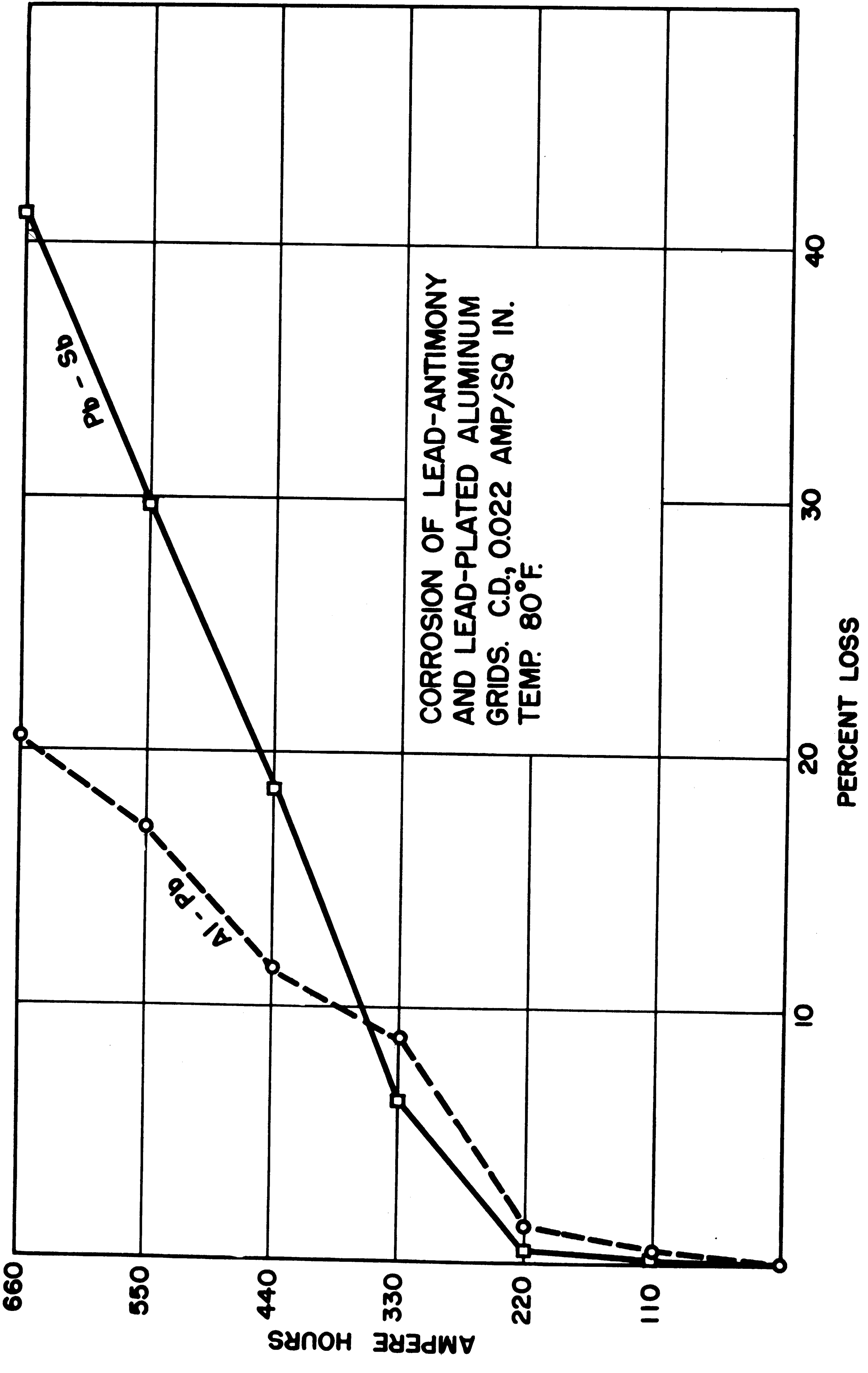


Photograph 18. Lead-Antimony Grids after 660-A.H. continuous Charge at 0.022 amp/sq in.



Photograph 19. Lead-Plated Aluminum-Grids after 880-A.H. Continuous Charge at 0.022 amp/sq in.

GRAPH 3



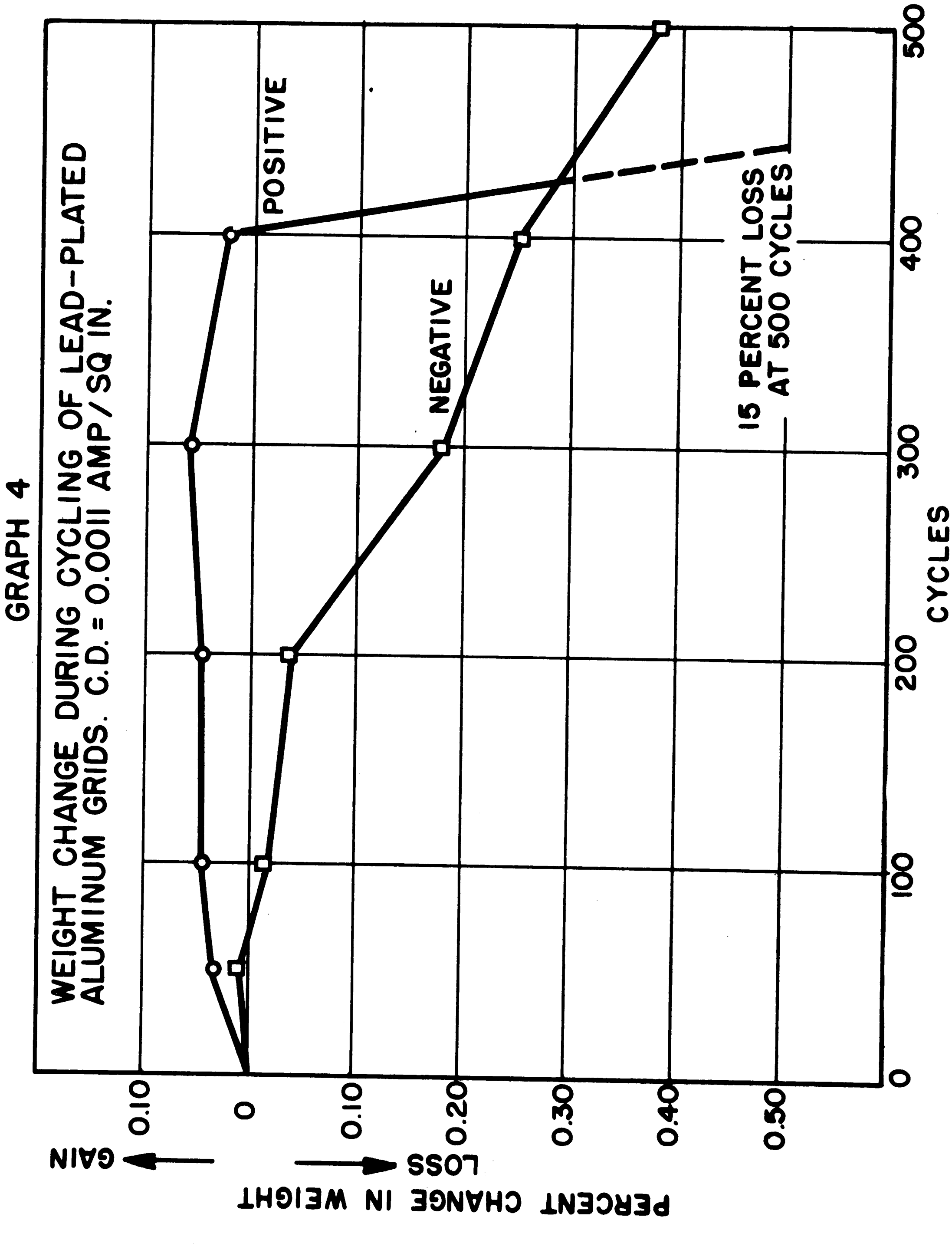
CORROSION OF LEAD-ANTIMONY AND LEAD-PLATED ALUMINUM GRIDS. C.D., 0.022 AMP/SQ IN. TEMP. 80°F.

would stand and (2) to determine the change in weights of both positive and negative grids during the cycling. A description of the cycling is given below.

Graph 4 shows the change in weight of both the positive and negative lead-plated aluminum grids at the end of 50, 100, 200, 300, and 400 cycles, respectively. In this test the grids were accurately weighed before cycling. They were then assembled unpasted into a cell consisting of one positive and two negative elements with microporous rubber separators 0.042 inch thick and were placed in 1.283-sp.gr. H_2SO_4 and given a 15-minute charge at 80°F and a current density equivalent to 0.011 amp/sq in. of positive surface area. The charging rate selected is approximately equivalent to the regular charging rate used for 2HN-type batteries. At the end of a 15-minute charging cycle the cell was discharged at the same rate as the charging rate. When the cell voltage during discharge dropped to 0 volts, the time was recorded and another 15-minute cycle was started. Graph 4 shows the completion of 500 cycles. The test was continued to breakdown of the lead electroplate at 520 cycles.

During the first 200 cycles the time ratio of charge to discharge averaged approximately 60 to 1. Since the charging time was held at a constant of 15 minutes, the discharge time gradually increased, changing the time ratio of charge to discharge to approximately 30 to 1 at the end of 300 cycles, approximately 3.3 to 1 at the end of 400 cycles, and approximately 1.25 to 1 at the end of the 500th cycle.

Graph 4 clearly indicates that during a series of cycling under normal charging and discharging conditions, the positive grids show an increase in weight which does not change materially during the first 300 cycles. The negative grids during the cycling show a loss in weight after the first 50 cycles. The opposite condition is revealed in Graph 6, where cycling does not take place and the current is always in one direction. During cycling the increase in weight of the positive grid is due to the formation of PbO_2, which is probably held intact by the presence of small amounts of $PbSO_4$ in the positive grid. The negative grid forms $PbSO_4$ during discharge, which is quite insoluble in the H_2SO_4. This $PbSO_4$ then sloughs off, resulting in a decrease in weight during cycling of the negative grids. This clearly indicates that a 0.015-inch lead deposit is adequate for more than 300 cycles.



GRAPH 4

WEIGHT CHANGE DURING CYCLING OF LEAD-PLATED ALUMINUM GRIDS. C.D. = 0.0011 AMP/SQ IN.

PERFORMANCE OF LEAD-PLATED ALUMINUM—GRID BATTERIES

Comparison 5-Second Voltage, Battery Voltage, and Percent Discharged

Study of battery voltage versus percent discharged at various discharge rates has shown that the lead-plated aluminum-grid 2HN 12-volt 45-A.H. battery maintains a very high average voltage. This is essential for a high discharge power factor, whether it is figured on the weight of the battery or per pound of active material.

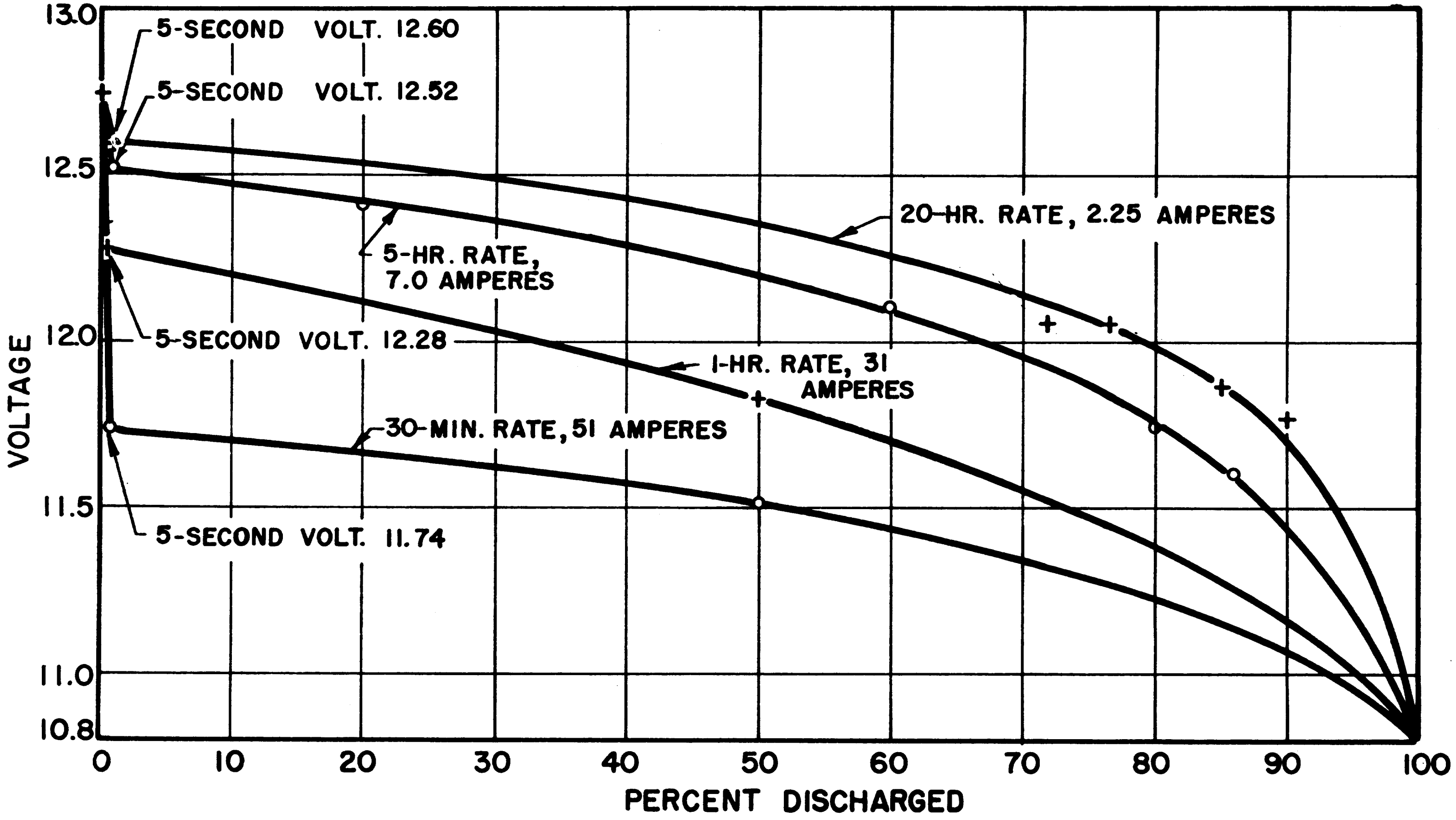
Graph 5 shows the 5-second voltages at the 20-, 5-, 1-, and 1/2-hour discharge rates for a type 2HN 12-volt 45-A.H. battery made of lead-plated aluminum grids, plotting the voltages as ordinate against the percent discharged condition of the battery as abscissa for the various rates. A high 5-second voltage is indicated for all rates. There is also a tendency for a high voltage to be maintained until near the end of the discharge period, when the voltage drops rapidly. This type of discharge insures a high power factor.

Graph 6 shows the same information on the same type of battery as Graph 5, except that measurements were taken at 10-, 8.5-, 3.5-, 2- and 1-minute discharge rates. The 1-minute rate curve is dotted because since there was no equipment available to observe the battery being discharged at the 1-minute rate accurately the 1-minute rate was calculated by the Peukert equation based on the observed data for the 3.5- and 2-minute rates. The curves on Graph 6 show that a high voltage is maintained until the battery has delivered about 75 percent of its total energy at the 10-, 8.5-, 3.5-, or 2-minute discharge rate. The power factor is high and the battery will serve as an almost constant source of power.

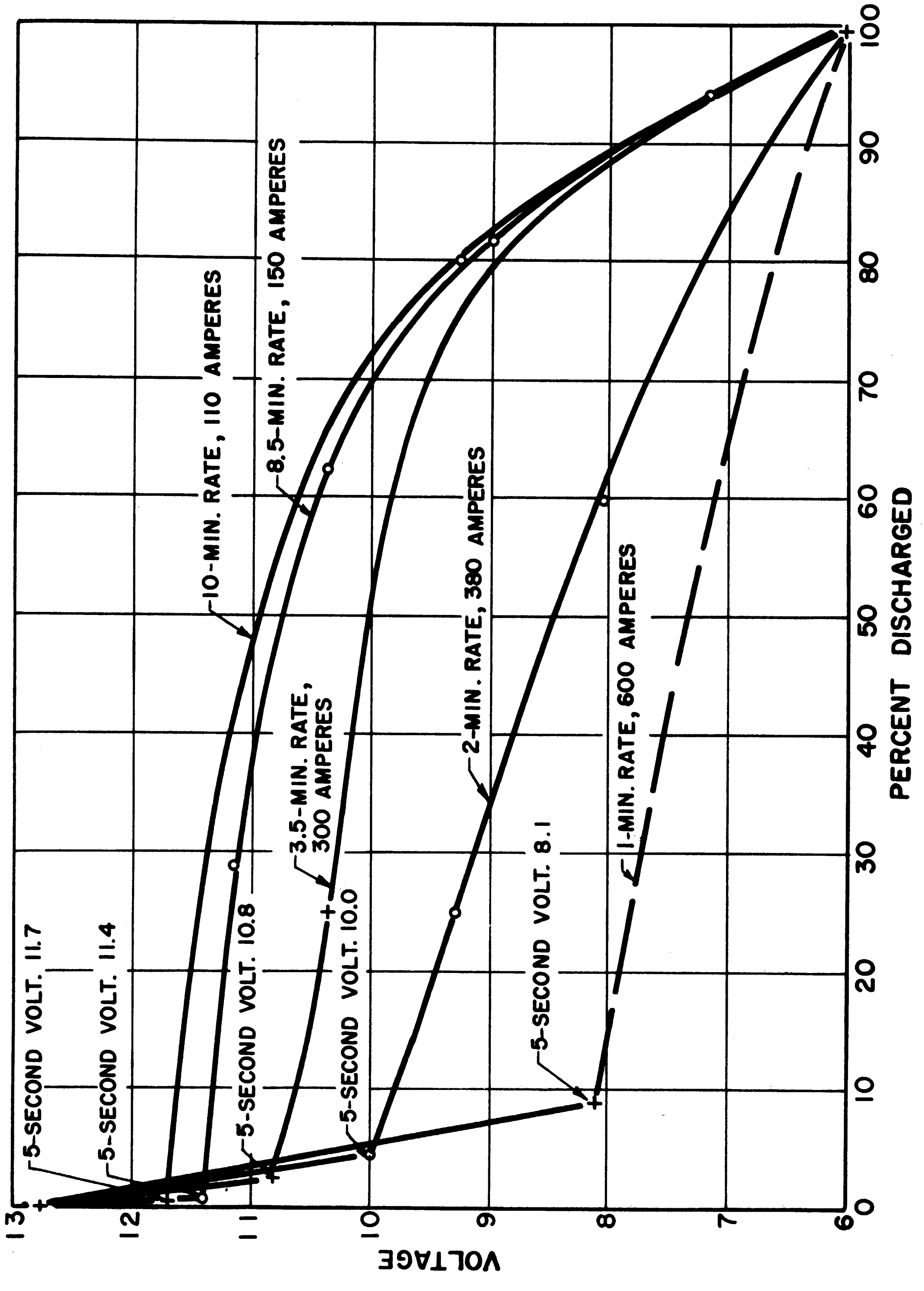
Recovery of Lead-Plated Aluminum-Grid Batteries on Open Circuit After Discharge

Since the lead-plated aluminum-grid 2HN batteries are designed for low-temperature discharges and at the same time to deliver the proper rating at the 20-hour rate, it has been thought advisable to determine the recovery of capacity at various temperatures, such as -65°F and -40°F, and compare these with the recovery of the same type of batteries discharged at similar rates at room temperature. The results of these tests are shown in Graphs 7, 8, 9, and 10.

Graph 7 is a study of the recovery rate (Battery No. 110) of the type 2HN 12-volt 45-A.H. lead-plated aluminum-grid battery discharged

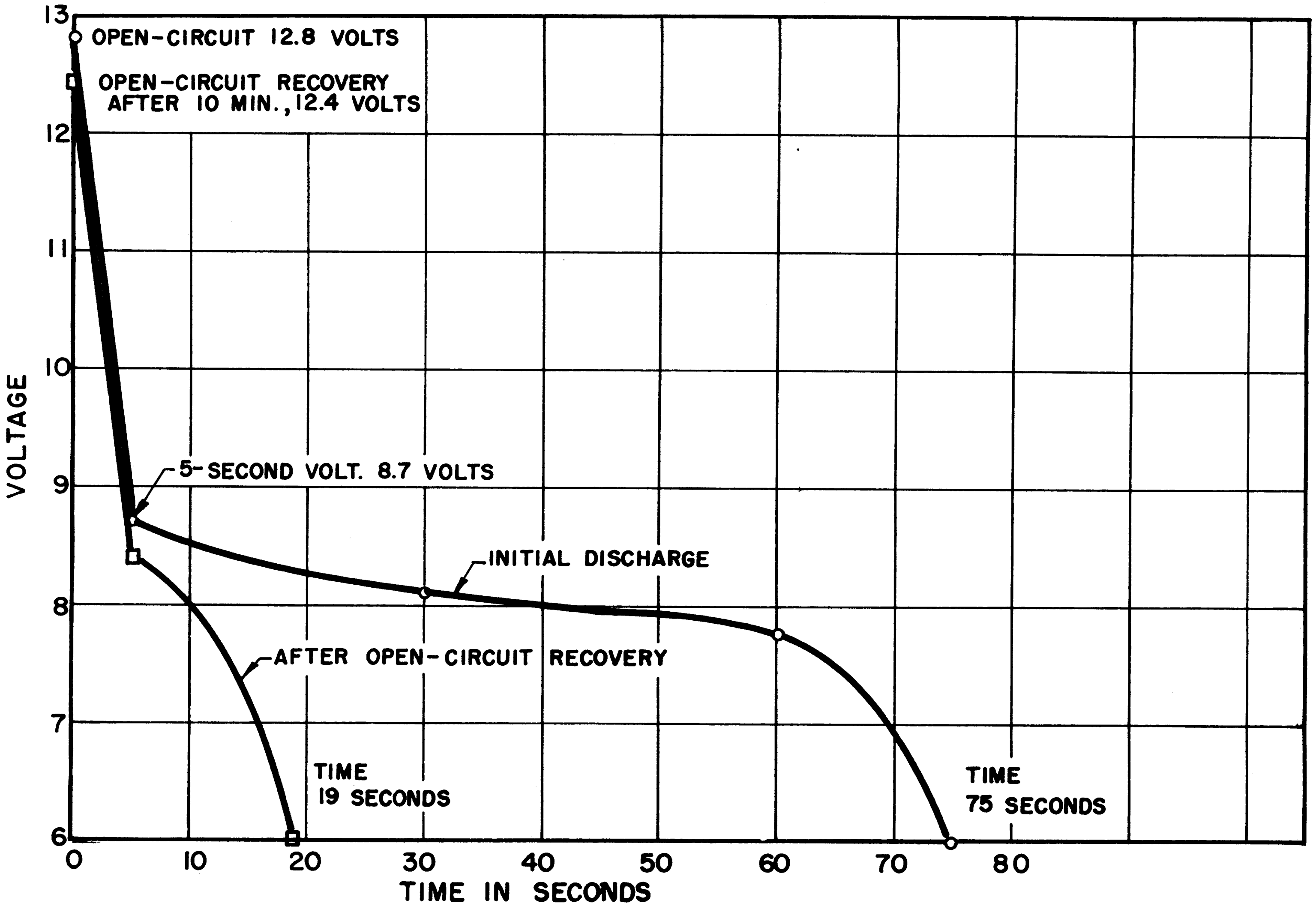


GRAPH 5
COMPARISON OF VOLTAGE VERSUS PERCENT DISCHARGED, TYPE 2 HN 12-VOLT 45-A.H. BATTERY, AT VARIOUS DISCHARGE RATES, TEMPERATURE 80°F.

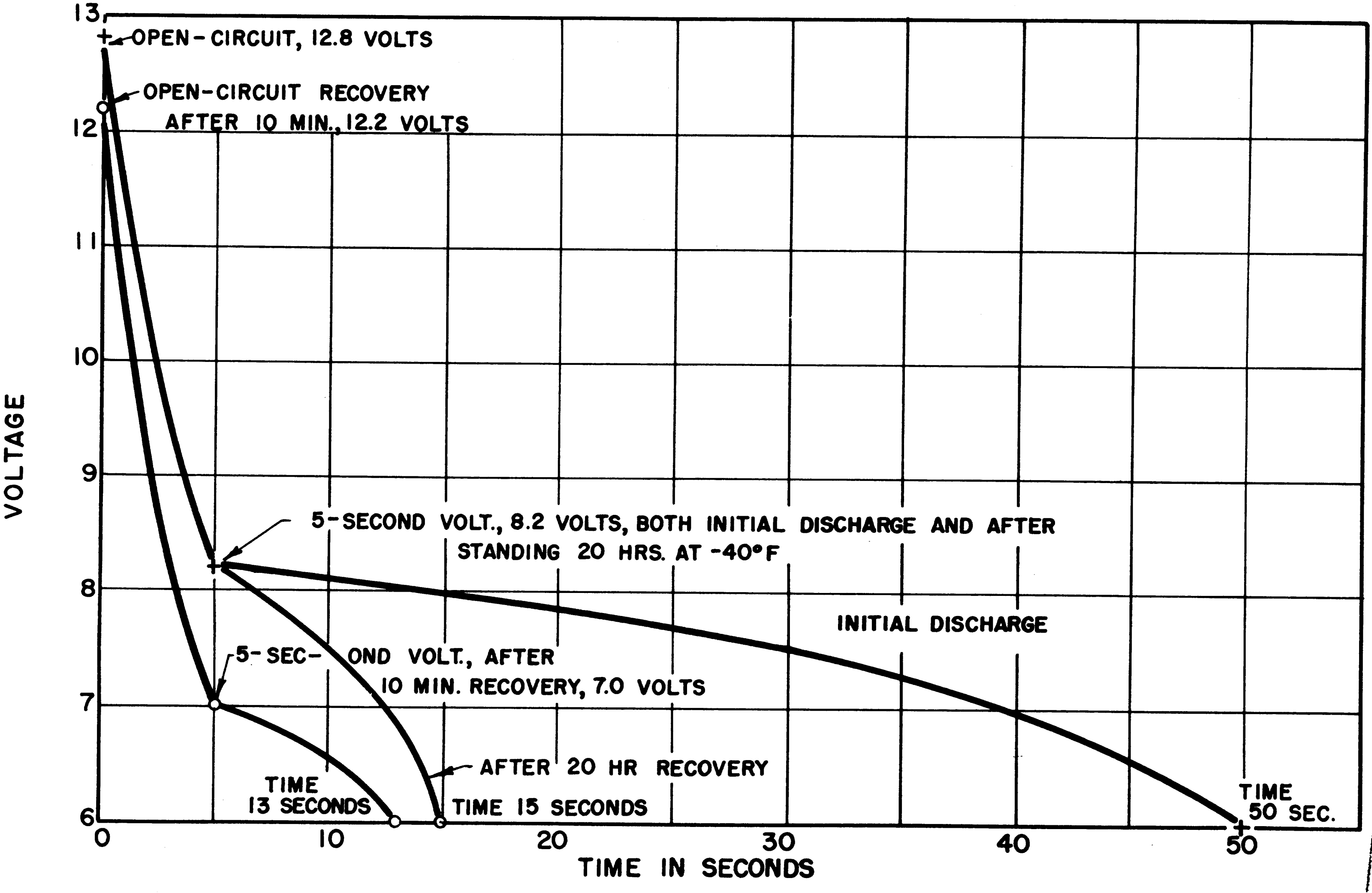


GRAPH NO. 2. VOLTAGE vs. PERCENT DISCHARGED TYPE 2HN
12-VOLT 45-A.H. UNIVERSITY OF MICHIGAN
BATTERY ALL DISCHARGES AT 80° F

GRAPH 6

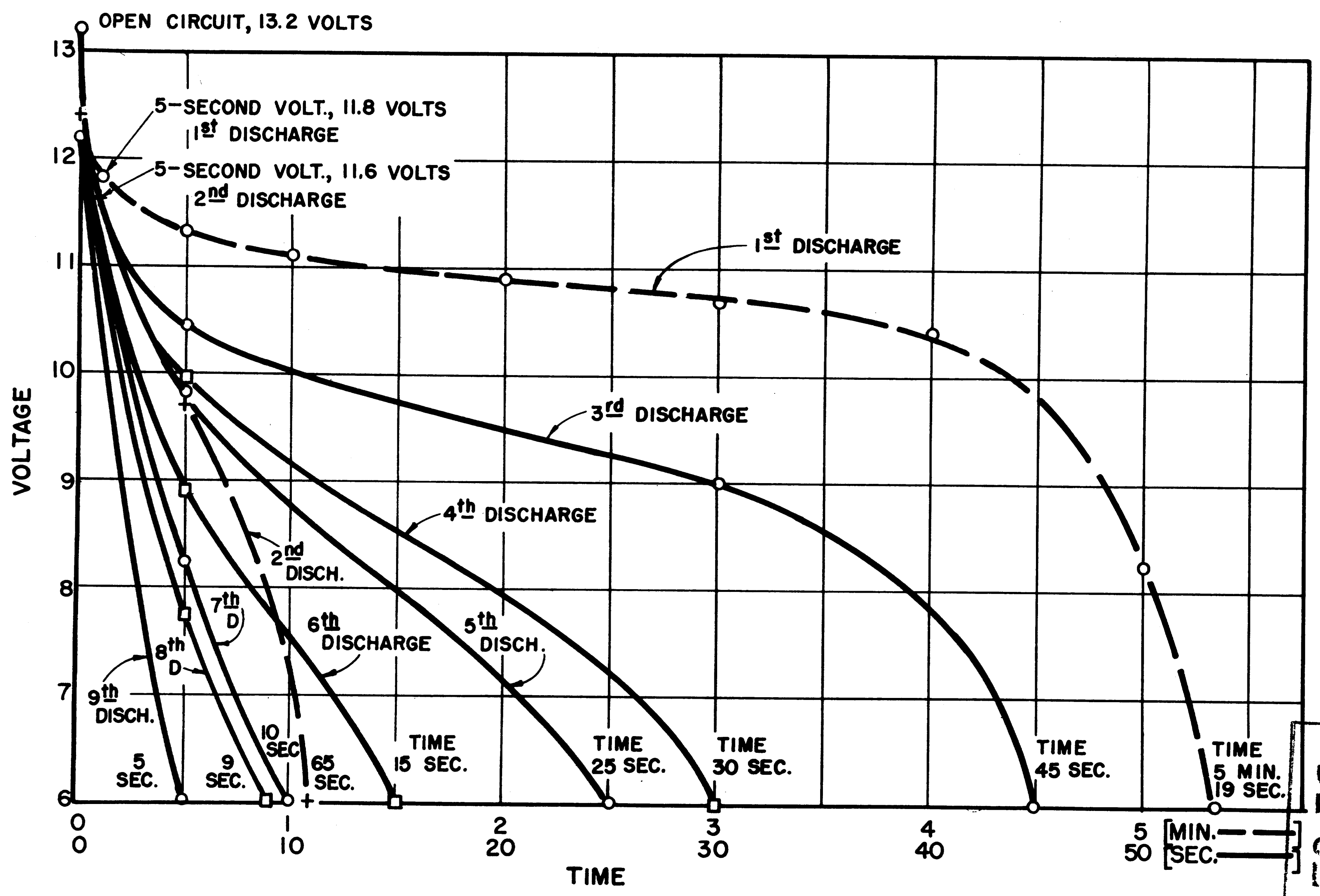


GRAPH 7
OPEN-CIRCUIT RECOVERY AFTER TEN MINUTES FOR TYPE 2HN 12-VOLT 45-A.H. BATTERY DISCHARGED AT THE 150-AMPERE RATE, TEMPERATURE -65°F. BATTERY NO. 110, CYCLE NO. 5.



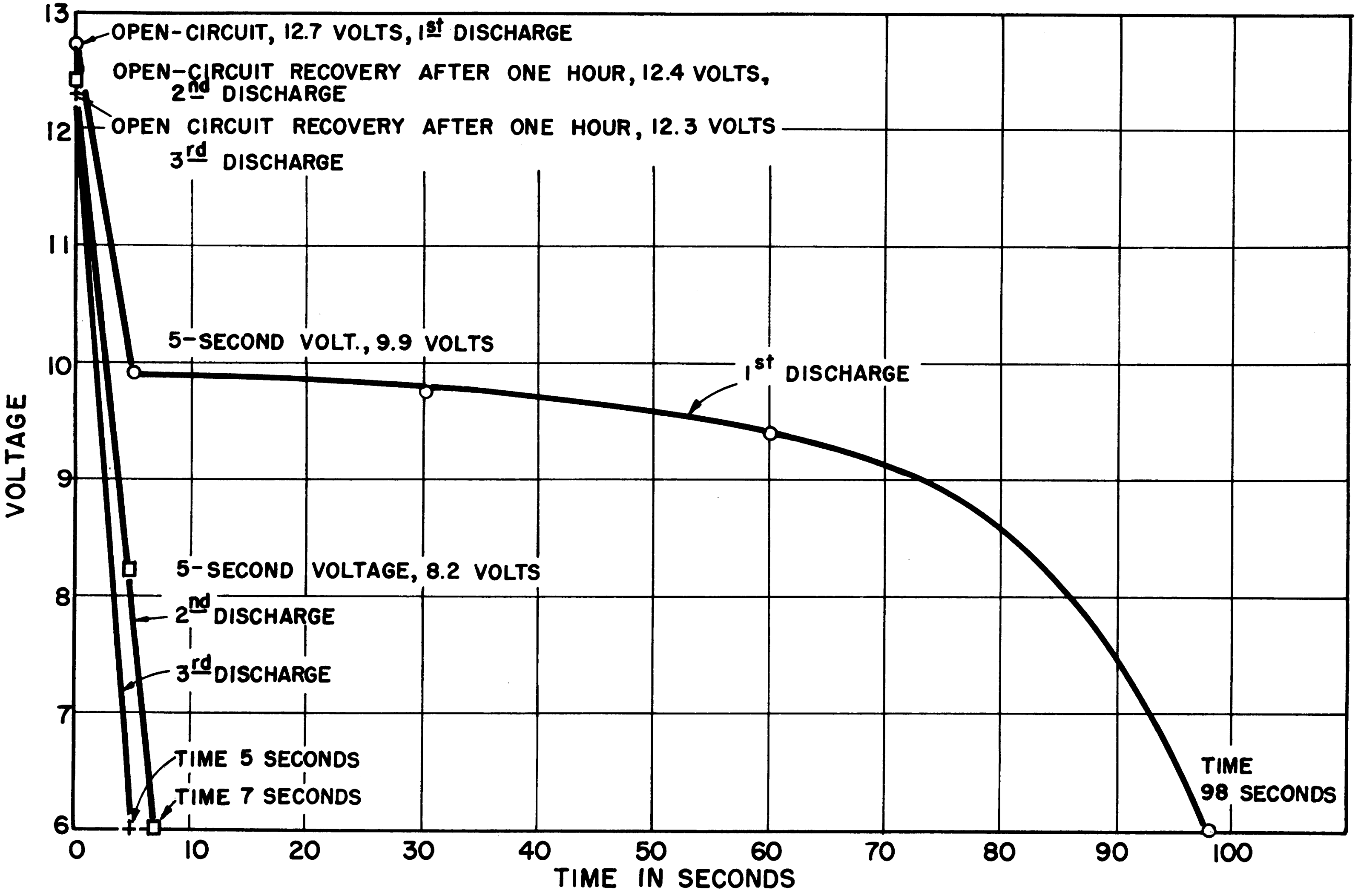
GRAPH 8

OPEN-CIRCUIT RECOVERY AFTER TEN MINUTES FOR TYPE 2 HN 12-VOLT 45-A.H. BATTERY DISCHARGED AT THE 300-AMPERE RATE, TEMPERATURE -40°F. BATTERY NO. 110, CYCLE NO. 7.



GRAPH 9

OPEN-CIRCUIT RECOVERY AFTER ONE HOUR FOR TYPE 2HN 12-VOLT 45 A.H. BATTERY DISCHARGED AT THE 150-AMPERE RATE, TEMPERATURE 80°F. BATTERY NO. 110.



GRAPH 10

OPEN-CIRCUIT RECOVERY AFTER ONE HOUR FOR TYPE 2 HN 12-VOLT 45-A.H. BATTERY DISCHARGED AT THE 150-AMPERE RATE, TEMPERATURE -40°F. BATTERY NO. 108.

at the 150-ampere rate and at a temperature of -65°F. The battery was allowed to stand for 10 minutes after it had been discharged at 150 amperes at -65°F to an end voltage of 6 volts and then discharged again at the same rate. As shown in Graph 7, the initial discharge was for 1 minute and 15 seconds at -65°F at the 150-ampere rate to an end voltage of 6 volts, and the battery recovered in 10 minutes to an open-circuit voltage of 12.4 volts as compared to an original open-circuit value of 12.8 volts. The second 150-ampere drain at -65°F gave a 5-second voltage of 8.4 volts and a discharge period of 18 seconds to an end voltage of 6 volts.

Data in Graph 8 are for a study of the recovery capacity of the same battery as that shown in Graph 7 at -40°F but discharged at the 300-ampere rate to an end voltage of 6 volts. At -40°F the battery had a time capacity of 50 seconds at the initial 300-ampere discharge rate and a 5-second voltage of 8.2. When allowed to stand for 10 minutes at -40°F and then discharged under the same conditions, its 5-second voltage was 7.0 and the time required to drop the voltage to 6 volts was 13 seconds. It was then held at -40°F for 20 hours without recharging and again discharged at the 300-ampere rate. On this discharge, the 5-second voltage was the same as during the first discharge, but the capacity dropped from 50 seconds to 13 seconds.

This reveals that the lead-plated aluminum battery plate construction will function at low temperature and high rates of discharge and that it has a recovery characteristic which is very desirable in subzero weather. At a temperature of -65°F, there may be temporary ice formation in the pores or on the surface of the plate, resulting from the first discharge at -65 or -40°F, but the ice is readily converted into water and diffuses through the battery, leaving the oxide exposed. The failure to function after two or three strikes at -40 or -65°F is probably due to surface discharge effects involving the lead oxide. One such effect is surface sulfation.

Graph 9 is a study of the recovery capacity of a type 2HN 12-volt 45-A.H. battery (Battery 110) discharged at the 150-ampere rate at 80°F to an end voltage of 6 volts. It was allowed to stand without charging at a temperature of 80°F for a 1-hour interval and then discharged again at 150-ampere rate to 6 volts. This procedure was repeated until the 5-second voltage dropped to 6 volts at the 150-ampere rate, which required nine such discharge cycles. The recovery capacity and the discharge time are shown in Graph 9. Since the oxide in the plates had yielded less than half the ampere-hour capacity it does at the 20-hour rate, the failure to function after the ninth strike is considered to be due, in large measure, to the exhaustion of the surface oxides or their conversion to lead sulfate, which insulated or sealed in the remainder of the active oxide from contact with the electrolyte.

Graph 10 shows the effect of discharging a 2HN 12-volt 45-A.H. battery (Battery 108) constructed of pasted lead-plated aluminum grids which was discharged at 150 amperes and a temperature of -40°F to an end voltage of 6 volts at 1-hour recovery intervals while being held at -40°F. The results of Graph 10, as compared with the data of Graph 8, on first glance might seem to conflict; but on analysis the difference is quite understandable. In Graph 8, the ampere discharge rate is double that in Graph 10; hence, the acid on the surface and in the surface pores is exhausted readily, with an early drop in voltage due to surface discharge effects (ice formation, sulfation, exhaustion of acid, etc.). In this case ice is readily dissipated due to solvation and diffusion, while the sulfation constitutes only a thin layer which is still porous enough to permit acid diffusion. In the case of Graph 10, the initial discharge lasted about twice as long, thus permitting a deeper penetration of the sulfate and of ice formation. While the ice was undoubtedly removed during the 1-hour standby period, the initial sulfation covered the surface of the active material more effectively, thus reducing its contact with the acid electrolyte. Here a state of exhaustion was soon reached on the second strike at -40°F. As a consequence, the ampere-hour efficiency at -40°F favors discharging at the 300-ampere rate rather than the 150-ampere rate by a ratio of almost 3 to 2.

Life History of Three 2HN 12-Volt 45-A.H. Batteries

Batteries No. 108, 109 and 110 were assembled with 8 positive 0.060-inch-thick plates, 9 negative 0.030-inch-thick plates and 0.030-inch-thick pormax separators 5-1/2 inches long by 4-1/2 inches wide. Each grid had two lugs on the bottom 3/16 inch high.

The elements were assembled in the cell volumes of a 2HN case and case-formed in 1.100-sp.gr. H_2SO_4 at 7 amperes per element or a current density of 0.02 amp/in.^{2}. At the close of the formation period the 1.100-sp.gr. acid was dumped and new 1.285-sp.gr. acid added. The specific gravity while charging was adjusted to 1.285.

The cycling of these batteries is shown in Table 14. At the close of the overcharge cycle the batteries were dismantled and the apparent cause of failure noted.

Battery No. 108. Battery No. 108 did not pass the 8th overcharge cycle on February 20, 1953. It was dismantled and it was observed that:
(1) the positive grids were sloughing freely;
(2) the negative plates were shorting across to the positive plates at the bottom and also through the separators; and
(3) one cell was shorted across at the top between the plate straps which was the only observable puncture of the lead electroplate.

TABLE 14

HISTORY OF THREE 2HN 12-VOLT 45-A.H. BATTERIES

Cycle No.	Dis-charge Rate, amp	End Voltage per Battery	Temperature, °F		Battery 108		Battery 109		Battery 110		5-Second Voltage		
			Initial	Final	Time	Amp-hrs	Time	Amp-hrs	Time	Amp-hrs	Bat. 108	Bat. 109	Bat. 110
1	25	10.8	78	--	1.16 hr	29.0	1.16 hr	29.0	0.91 hr	22.8	--	--	--
2	25	10.8	78	--	1.28 hr	32.0	1.33 hr	33.2	0.91 hr	22.8	--	--	--
3	25	10.8	78	--	1.3 hr	32.5	1.35 hr	33.6	0.91 hr	22.8	--	--	--
4	2.25	10.8	78	--	21.33 hr	48.0	21.45 hr	48.35	Lost	--	--	--	--
5	150	6.0	-65	--	1.2 min	3.0	1.1 min	2.75	* 1.9 min 0.3 min	--	8.2	8.8	8.9 8.4
6	25	10.8	80	--	1.25 hr	31.2	1.38 hr	34.5	0.91 hr	22.8	--	--	--
7	150	6.0	-40	--	** 2.16 min 1.03 min	5.4 2.5	1.33 min	3.33	--	--	9.6	--	--
7	300	6.0	-40	--	--	--	--	--	0.83 min ***0.21 min 0.08 min 0.25 min	--	--	--	8.2 7.0 6.0 8.2
8	2.25	10.8	74	71	22.75 hr	51.18	21.08 hr	46.8	19.5 hr	43.9	--	--	--
9	150	6.0	0	8	4.1 min	10.25	2.49 min	6.96	5.0 min	12.5	10.5	11.2	10.5

---

* After an initial discharge of 1.9 minutes at 150 amperes at a temperature of -65°F, Battery 110 was allowed to stand 10 minutes at -65°F and again discharged under the same conditions, to an end voltage of 6.0 after 0.3 minute.

** After an initial discharge of 2.16 minutes at 150 amperes at a temperature of -40°F, Battery 108 was allowed to stand for 20 hours at -40°F and then discharged at 150 amperes to an end voltage of 6.0 after 1.03 minutes.

*** This battery was subjected to a series of discharges at -40°F. The first discharge was to an end voltage of 6.0; the battery was allowed to stand 10 minutes between successive discharges to an end voltage of 6.0. After the 5-second voltage reached 6 volts, the battery stood 24 hours at -40°F and then gave a 0.25-minute discharge at 150 amperes.

TABLE 14, continued

Cycle No.	Dis-charge Rate, amp	End Voltage per Battery	Temperature, °F		Battery 108		Battery 109		Battery 110		5-Second Voltage		
			Initial	Final	Time	Amp-hrs	Time	Amp-hrs	Time	Amp-hrs	Bat. 108	Bat. 109	Bat. 110
10	150	6.0	78	105	6.07 min	15.20	6.0 min	15.0	7.28 min	18.0	10.8	11.4	11.4
11	8	10.8	78	--	4.5 hr	36.0	4.8 hr	38.4	4.75 hr	38.0	--	--	--
12	75	6.0	72	80	19.3 min	24.12	19.7 min	24.6	17.28 min	21.5	11.8	11.7	11.9
13	7.5	10.8	78	--	4.08 hr	30.6	4.66 hr	34.85	4.75 hr	--	--	--	--
14	75	6.0	0	12.5	10.66 min	13.3	6.11 min	7.63	1.1 min	--	11.4	11.4	11.3
15	7.5	10.8	80	--	4.0 hr	30.0	3.45 hr	25.87	4.45 hr	--	--	--	--
16	75	6.0	-42	-40	3.48 min	4.3	2.23 min	2.80	4.43 min	--	10.5	10.6	11.4
17	7.5	10.8	78	--	2.18 hr	16.3	2.92 hr	21.9	4.5 hr	--	--	--	--
18	150	6.0	-40	-40	1.63 min 0.11 min 0.08 min	4.07 0.27 0.20	0.8 min 0.8 min	2.0 0.20			9.9 8.2 6.0	9.8 6.0	-- --
18	150	6.0	80	80					5.3 min 1.1 min 0.75 min 0.5 min * 0.41 min 0.25 min 0.16 min 0.15 min 0.08 min	-- -- -- -- -- -- -- -- --			11.8 11.6 10.4 9.9 9.8 8.9 8.2 7.7 6.0
19-1**	150	6.0	74	82	4.0 min	10.0	2.05 min	5.03	4.58 min	--	11.2	11.3	11.9

---

*After an initial discharge of 5.3 minutes at 150 amperes and 80°F, Battery 110 was allowed to stand at 80°F and then discharged at 1-hour intervals at 150 amperes to an end voltage of 6.0 until the 5-second voltage and the terminal voltage reached 6 volts.

**At the close of the 18 cycles, these batteries were placed on overcharge cycling.

TABLE 14, concluded

Cycle No.	Dis-charge Rate, amp	End Voltage per Battery	Temperature, °F		Battery 108		Battery 109		Battery 110		5-Second Voltage		
			Initial	Final	Time	Amp-hrs	Time	Amp-hrs	Time	Amp-hrs	Bat. 108	Bat. 109	Bat. 110
19-2	150	6.0	75	80	3.13 min	7.8	3.13 min	7.82	4.28 min	--	11.1	10.5	11.4
19-3	150	6.0	74	80	1.73 min	4.3	3.25 min	8.15	3.91 min	--	10.6	11.3	11.2
19-4	150	6.0	62	78	1.41 min	3.51	2.75 min	6.87	3.65 min	--	8.4	11.06	11.05
19-5	150	6.0	76	78	0.65 min	1.63	2.83 min	7.08	3.05 min	--	8.10	11.05	11.1
19-6	150	6.0	76	82	0.85 min	--	1.2 min	--	2.28 min	--	8.4	10.85	10.9
19-7	150	6.0	72	76	0.50 min	--	0.88 min	--	1.98 min	--	8.0	10.7	11.6
19-8	150	6.0	75	--	0.30 min	Failed	2.0 min	5.0	2.85 min	--	8.0	11.2	11.0
19-9	150	6.0	78	--	--	--	1.43 min	--	1.98 min	--	--	11.8	11.8
19-10	150	6.0	72	--	--	--	1.75 min	--	2.41 min	--	--	12.0	11.5
19-11	150	6.0	72	--	--	--	0.88 min	--	Run not recorded		--	11.0	--
19-12	150	6.0	72	--	--	--	1.33 min	--	3.5 min	--	--	10.5	11.5
19-13	150	6.0	73	--	--	--	0.80 min	--	2.5 min	--	--	11.0	11.5
19-14	150	6.0	74	--	--	--	1.33 min	--	2.9 min	--	--	11.0	11.2
19-15	150	6.0	76	--	--	--	0.55 min	--	Run not recorded		--	10.0	--
19-16	150	6.0	83	--	--	--	0.88	--	2.6 min	--	--	11.4	11.4
19-17	150	6.0	82	--	--	--	0.33 min	Failed	1.5 min	--	--	8.3	11.3
19-18	150	6.0	82	--	--	--	--	--	0.91 min	--	--	--	11.0
19-19	150	6.0	80	--	--	--	--	--	0.3 min	--	--	--	5.0

Battery No. 109. Battery No. 109 failed to pass the 17th overcharge cycle on June 15, 1953. This battery was assembled in the normal fashion with 0.030-inch-thick pormax separators. The lugs of the plates which rested on the bridges in the bottom of the cell were separated by only 0.030 inch. It is not surprising that the lugs shorted when the grids began to slough. No punctures of lead electroplate were observed.

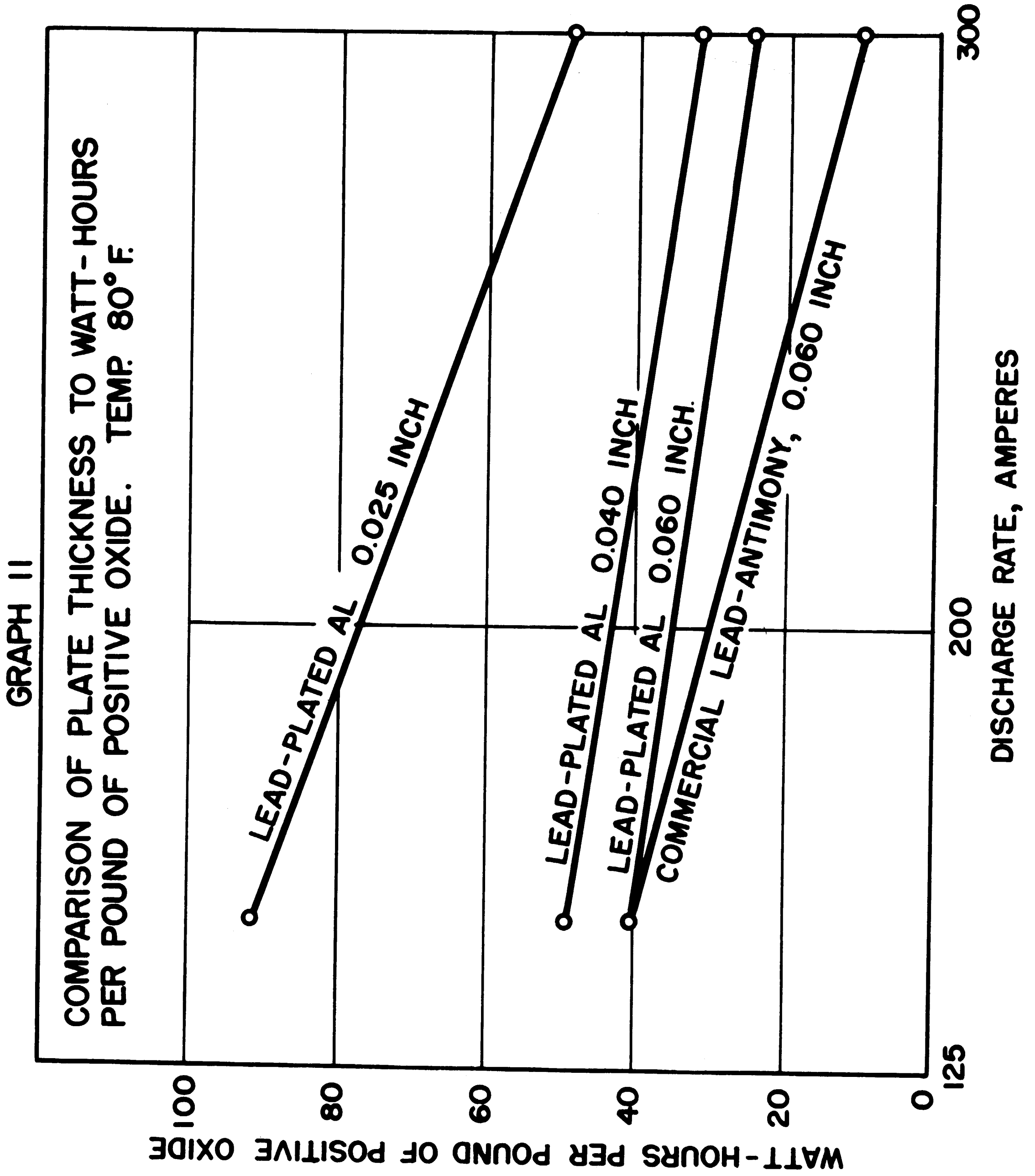
Battery No. 110. Battery No. 110 passed the 18th overcharge cycle, on June 19, 1953, but failed on the 19th overcharge cycle due to excessive sloughing of the negative and positive plates, which caused bridging of the 0.030-inch-thick gap between the separators on the bridges at the bottom of the cell. There was some shorting on the edges of the grids where the separators were improperly assembled. No other causes of failure were observed.

The rise in temperature, excessive gassing, and nonacceptance of charge may be controlled by observing the charging voltage. Another method of controlling these factors, which may reduce the ampere-hour capacity of the battery, is to increase the thickness of the ribs on the separators with a corresponding decrease in positive-plate area. A better method is to eliminate the feet on the bottom of the plates and use a separator which is wrapped around the negative plate so that the negative plate is completely shielded from positive-plate sloughing.

Plate Thickness vs. Watt-Hours per Pound of Positive Oxide

The watt-hour efficiency per pound of positive oxide shown in Graph 11 for various thicknesses of grids was obtained from the discharge curves at 150- and 300-ampere rates of 2HN 12-volt batteries. Each of the different thicknesses of grids shown in the graph was assembled into the same cell volume, and consequently each assembly differed in its weight of positive oxide. A plainometer was used on the discharge curves of the 2HN 12-volt batteries, using 9.3 volts as the end voltage. The total watt-hours obtained for each of the respective assemblies were then calculated to a one-cell equivalent. This gave the watt-hours from a known weight per cell of positive oxide material, which was converted to the watt-hours per pound and recorded in Graph 11.

At the 150-ampere discharge rate the 0.040-inch-thick grid gave 20 percent more watt-hours per pound than the 0.060-inch-thick grid, while the 0.025-inch-thick grid gave 125 percent more watt-hours. At the 300-ampere discharge rate the 0.040-inch-thick grid gave 300 percent more watt-hours per pound that the 0.060-inch-thick grid, as compared to 490 percent more watt-hours for the 0.025-inch-thick grid.



GRAPH 11

COMPARISON OF PLATE THICKNESS TO WATT-HOURS PER POUND OF POSITIVE OXIDE. TEMP. 80° F.

The weight of the finished batteries with the three types of grid construction is recorded as approximately 35 pounds each. The watt-hours per pound of battery are higher for the 0.040-inch- and 0.025-inch-thick lead-plated aluminum grids than for the 0.060-inch-thick lead-antimony grids at discharge rates of 150 and 300 amperes. The data from which Graph 11 was constructed are shown in Graphs 12, 13, 14, 15, 16, 17, 18, and 19.

Failure of Batteries No. 117, 119, and 120 to Charge

University of Michigan Batteries No. 117, 119, and 120 are shown on the Detroit Tank Arsenal records as Batteries XXI, XX3, and XX4 respectively.

These batteries and elements are assembled in 6TN 12-volt 90-A.H. cases. The plates are produced from the lead-plated aluminum type of grids, pasted with lead oxides. Each element of batteries No. 117 and 119 consisted of 18 positive 0.060-inch-thick plates and 19 negative 0.030-inch-thick plates assembled with 4-1/2-inch-wide by 5-inch-tall 0.030-inch-thick pormax separators. Battery No. 120 has the same assembly except it has 17 positive and 18 negative plates.

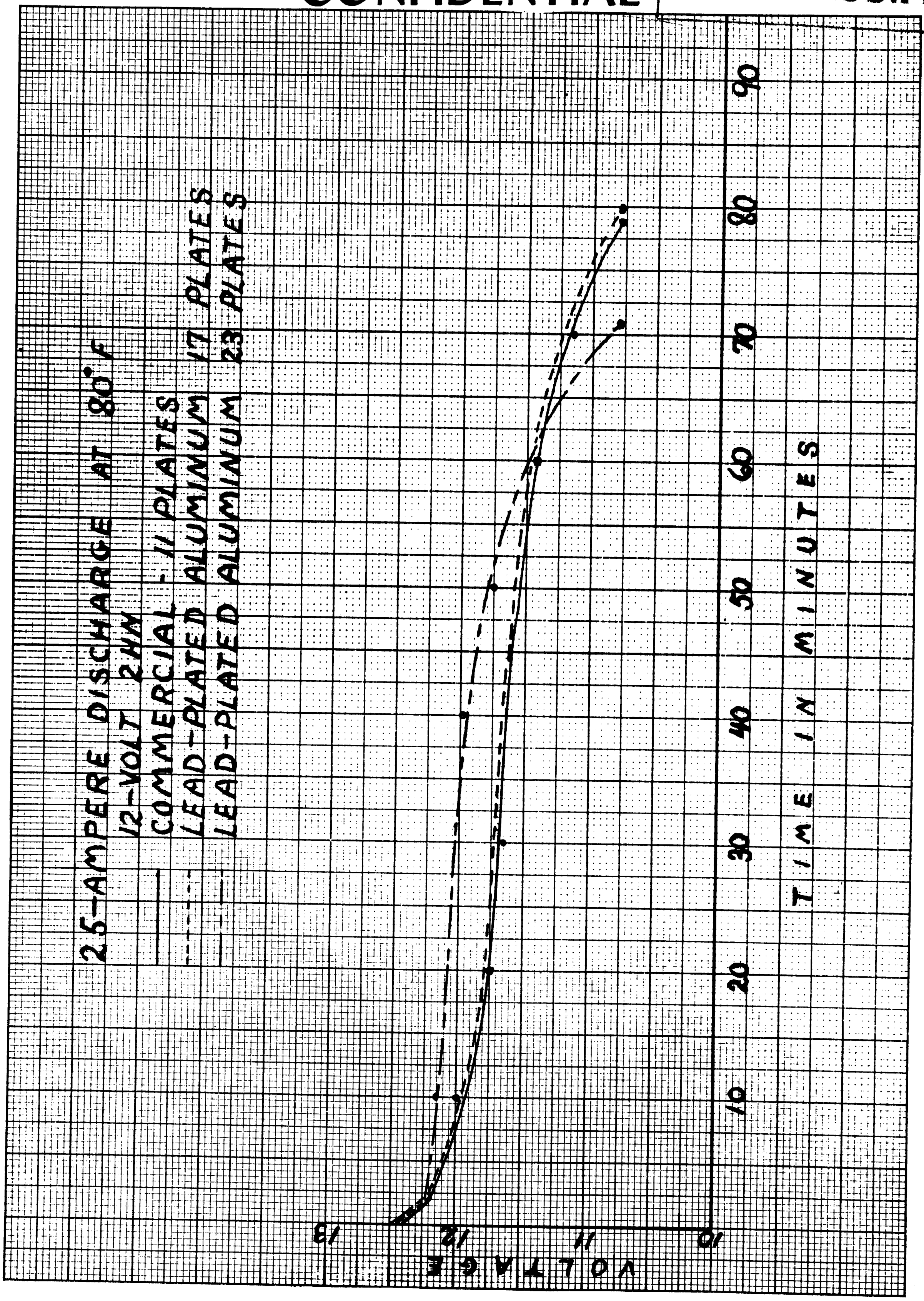
These batteries were sent to the Detroit Tank Arsenal on December 19, 1952. They were returned to the University of Michigan on May 30, 1953.

The Arsenal reports (1) that these batteries did not accept charge, (2) that the specific gravity of the acid does not return to its origianl value even after 200 hours of continuous charging at constant voltage, (3) that the batteries also gassed excessively, (4) that the acid showed above the top of the grids during charging, then dropped on standby to a level which could not be seen, and (5) that the ampere-hour capacity did not approach that shown in the graphs which accompanied the batteries at the time they were delivered.

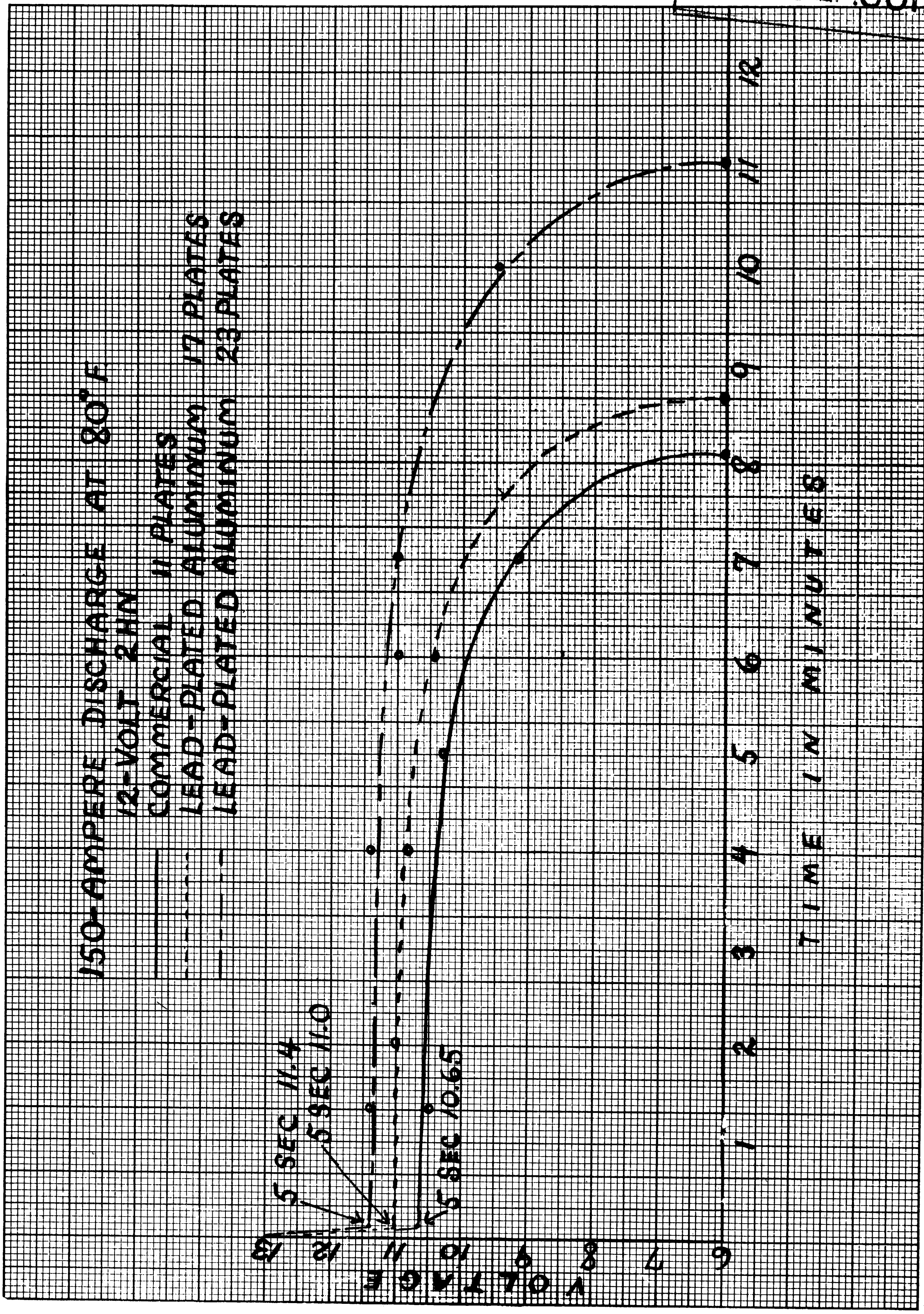
The batteries were therefore dismantled and the following observations made:

(1) The batteries do not accept charge because the upper voltage limit of the charging equipment employed was set to finish a lead-antimony acid battery (14.7 volts). A lead-antimony acid battery is usually completely charged when the cell voltage reached 2.55 volts, or 15.3 volts for a 12-volt lead-antimony acid battery.

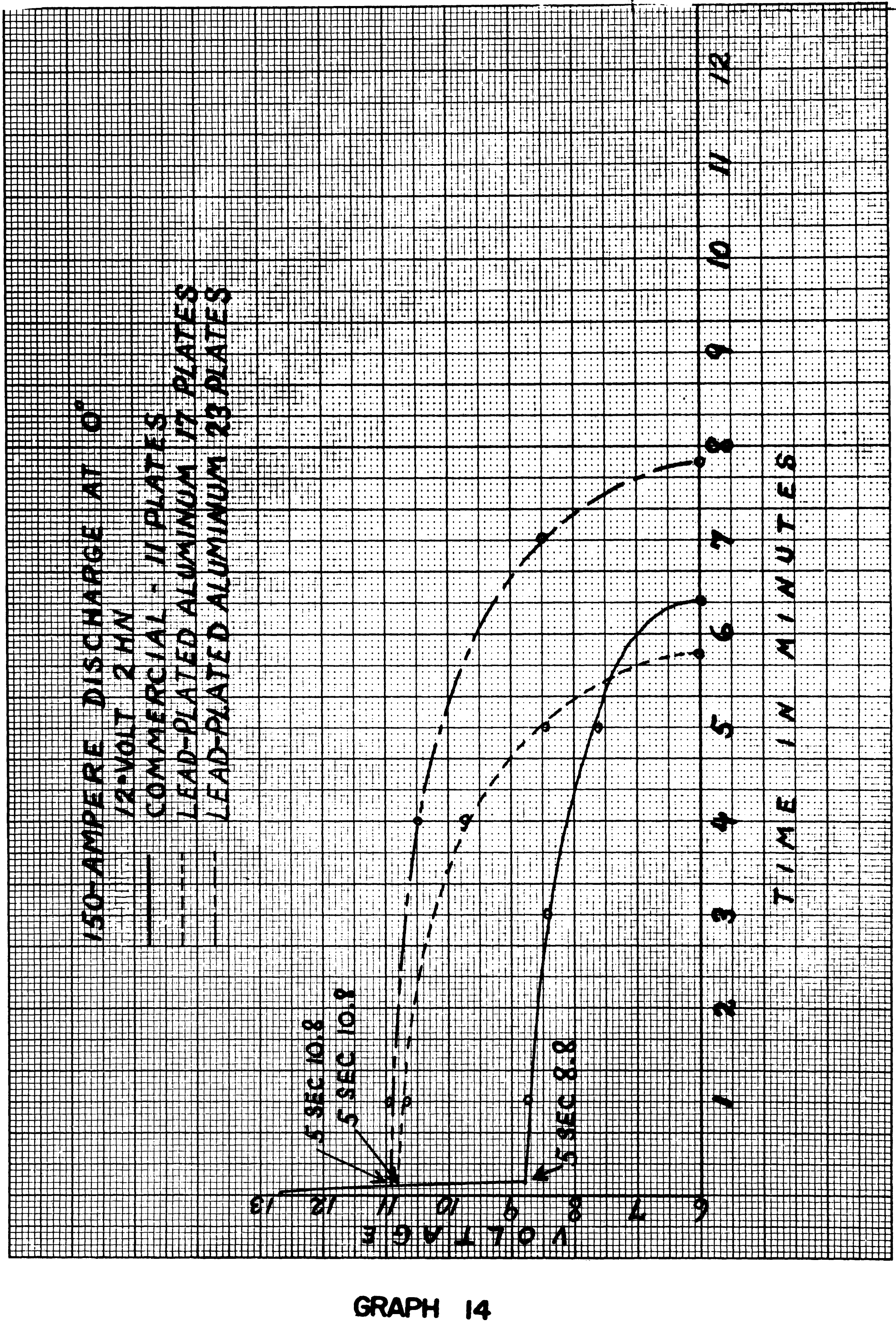
The lead-plated aluminum-grid batteries, however, require a voltage of 16.5 volts to complete the charge. Since the lead-antimony acid battery charging voltage is usually set at 14.7 to 15 volts so as not to


25-AMPERE DISCHARGE AT 80°F
12-VOLT 2HN
COMMERCIAL - 11 PLATES
LEAD-PLATED ALUMINUM 17 PLATES
LEAD-PLATED ALUMINUM 23 PLATES
TIME IN MINUTES
10
20
30
40
50
60
70
80
90
VOLTAGE
13
12
11
10

GRAPH 12

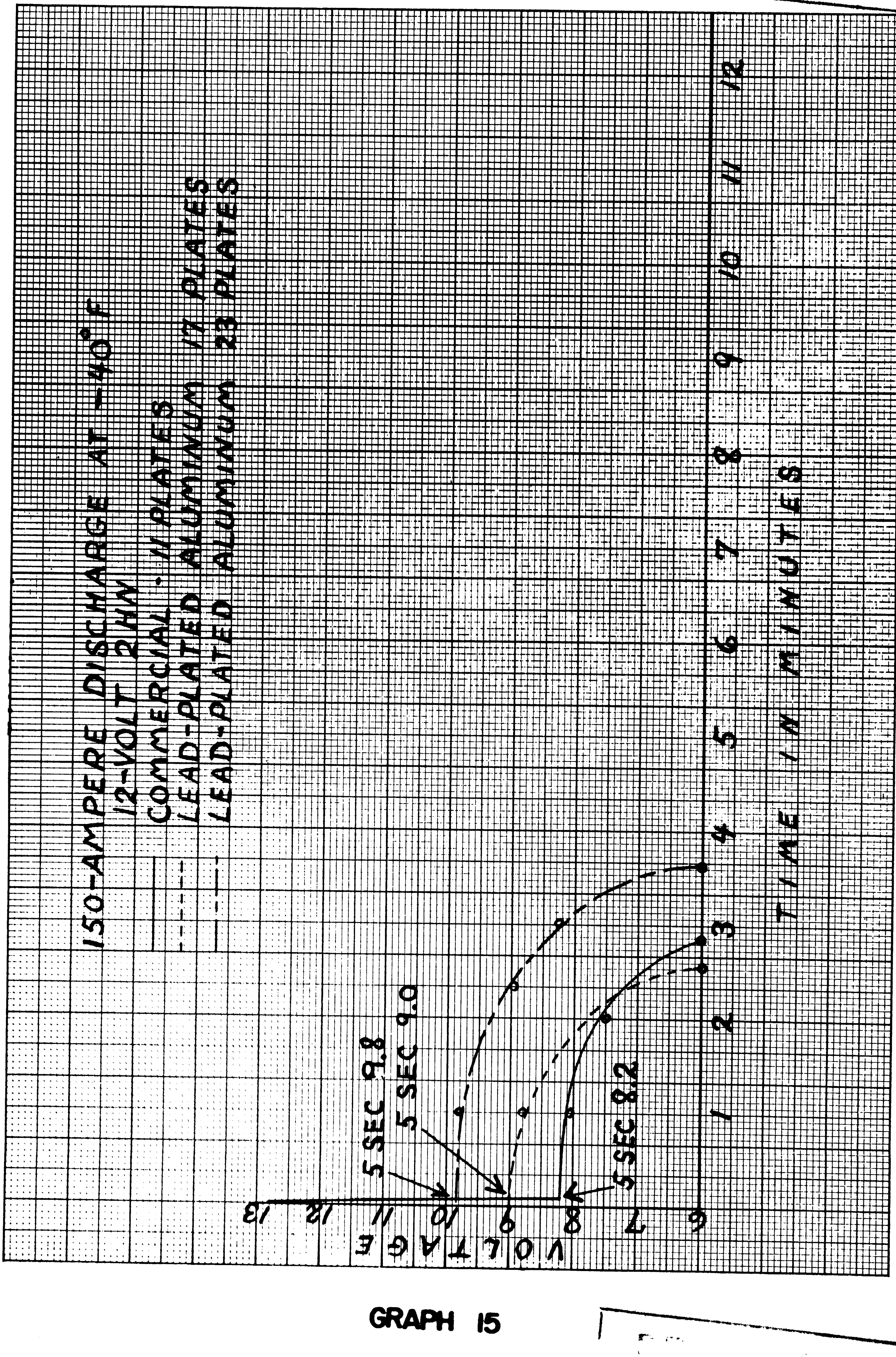

150-AMPERE DISCHARGE AT 80°F
12-VOLT 2HN
COMMERCIAL 11 PLATES
LEAD-PLATED ALUMINUM 17 PLATES
LEAD-PLATED ALUMINUM 23 PLATES
5 SEC 11.4
5 SEC 11.0
5 SEC 10.65
VOLTAGE
13
12
11
10
9
8
7
6
TIME IN MINUTES
1
2
3
4
5
6
7
8
9
10
11
12

GRAPH 13


150-AMPERE DISCHARGE AT 0°
12-VOLT 2 HN
COMMERCIAL - 11 PLATES
LEAD-PLATED ALUMINUM 17 PLATES
LEAD-PLATED ALUMINUM 23 PLATES
5 SEC 10.8
5 SEC 10.8
5 SEC 8.8
VOLTAGE
6
7
8
9
10
11
12
13
TIME IN MINUTES
1
2
3
4
5
6
7
8
9
10
11
12

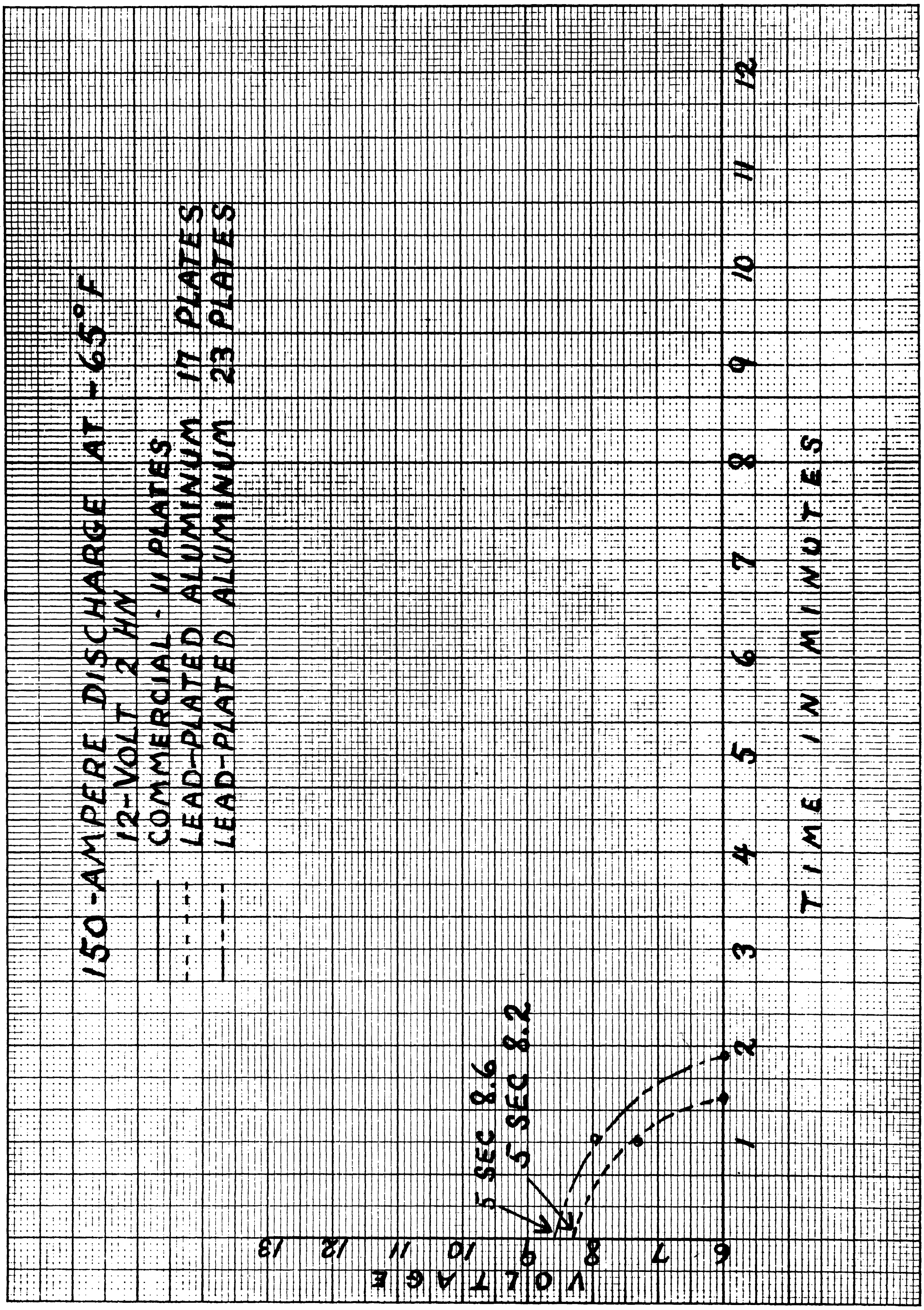
GRAPH 14

DE-CLASSIFIED

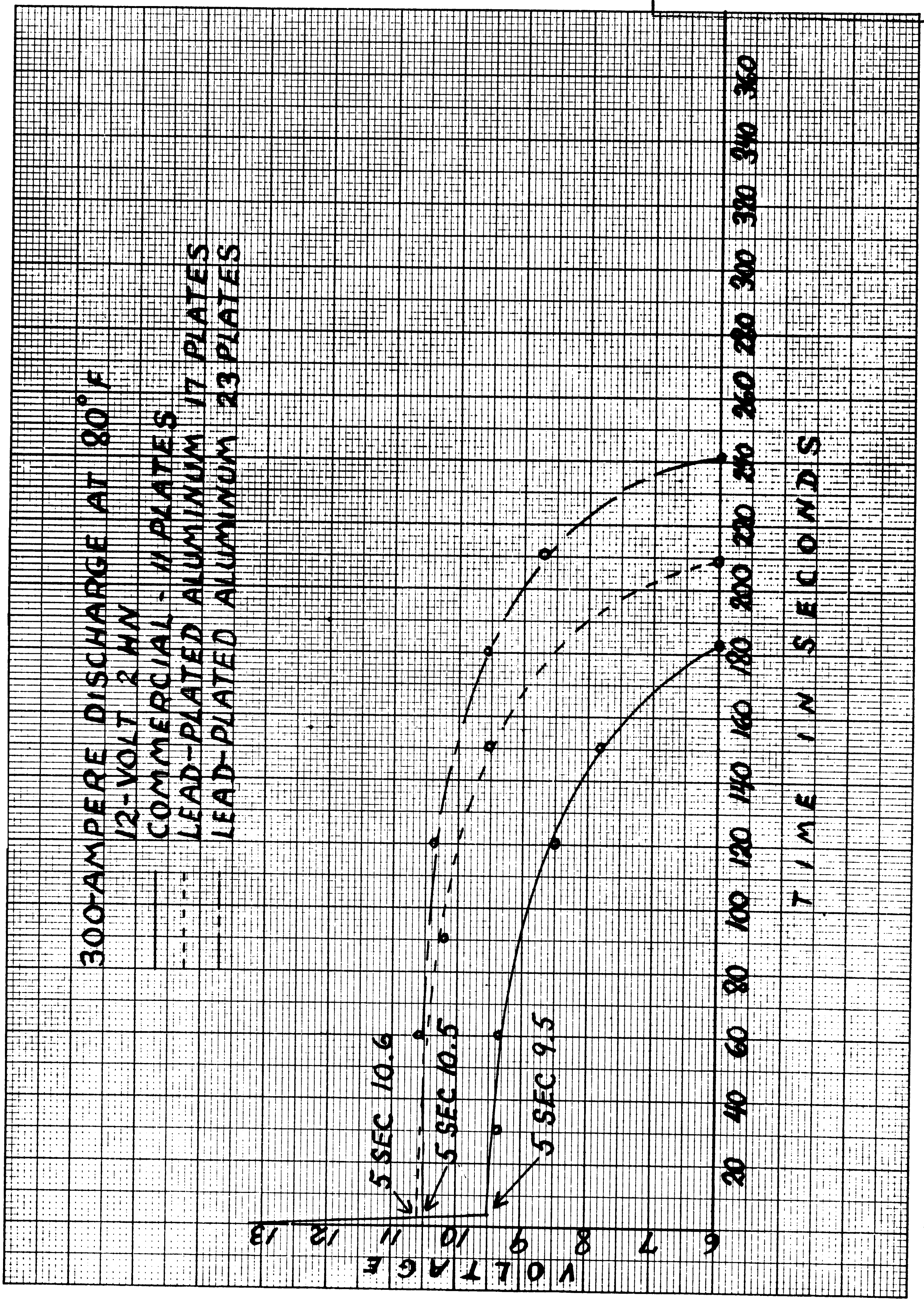


GRAPH 15

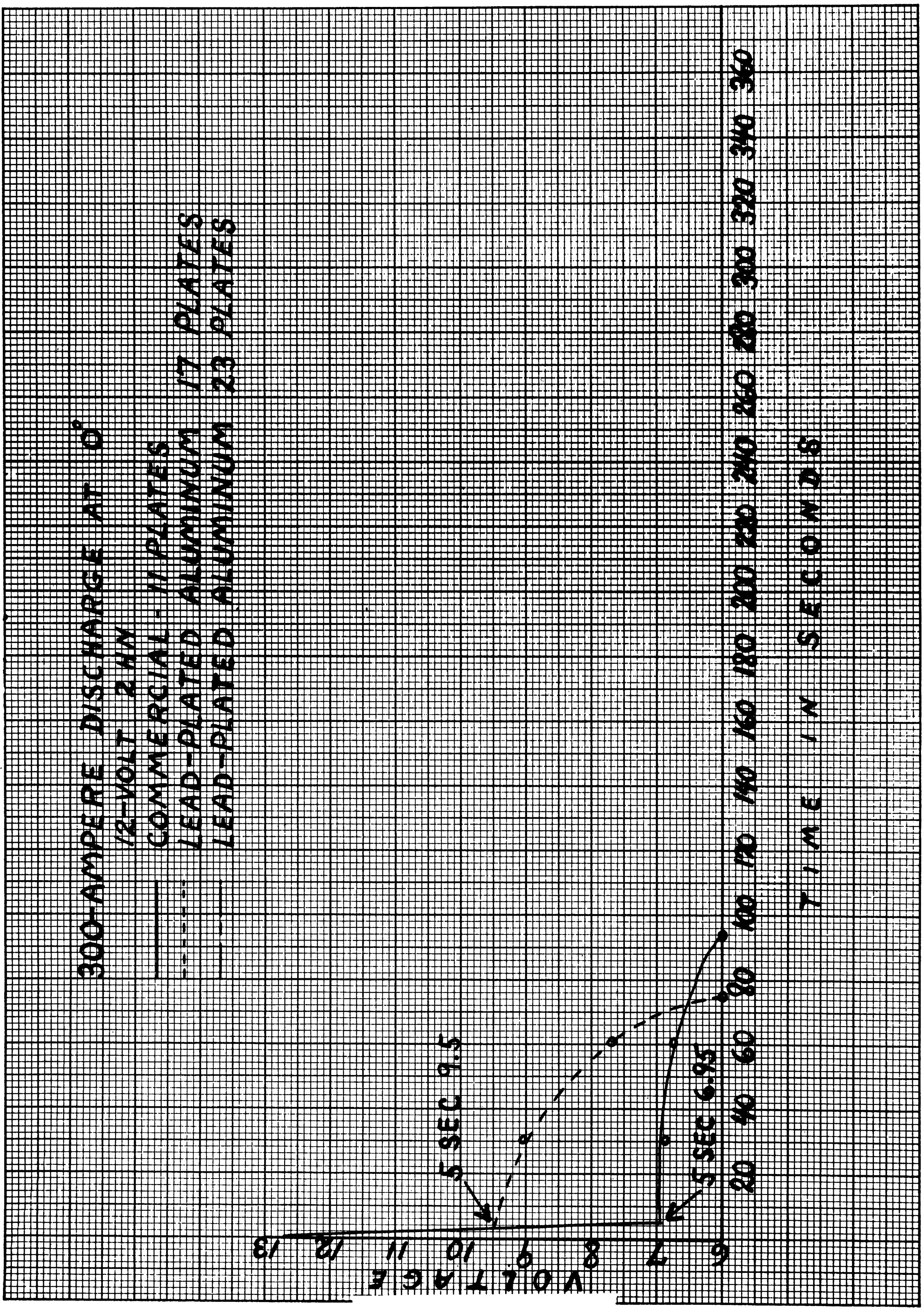
DE-CLASSIFIED


150-AMPERE DISCHARGE AT -65° F
12-VOLT 2 HN
—— COMMERCIAL - 11 PLATES
- - - - LEAD-PLATED ALUMINUM 17 PLATES
—·— LEAD-PLATED ALUMINUM 23 PLATES
5 SEC 8.6
5 SEC 8.2
VOLTAGE
6
7
8
9
10
11
12
13
TIME IN MINUTES
1
2
3
4
5
6
7
8
9
10
11
12

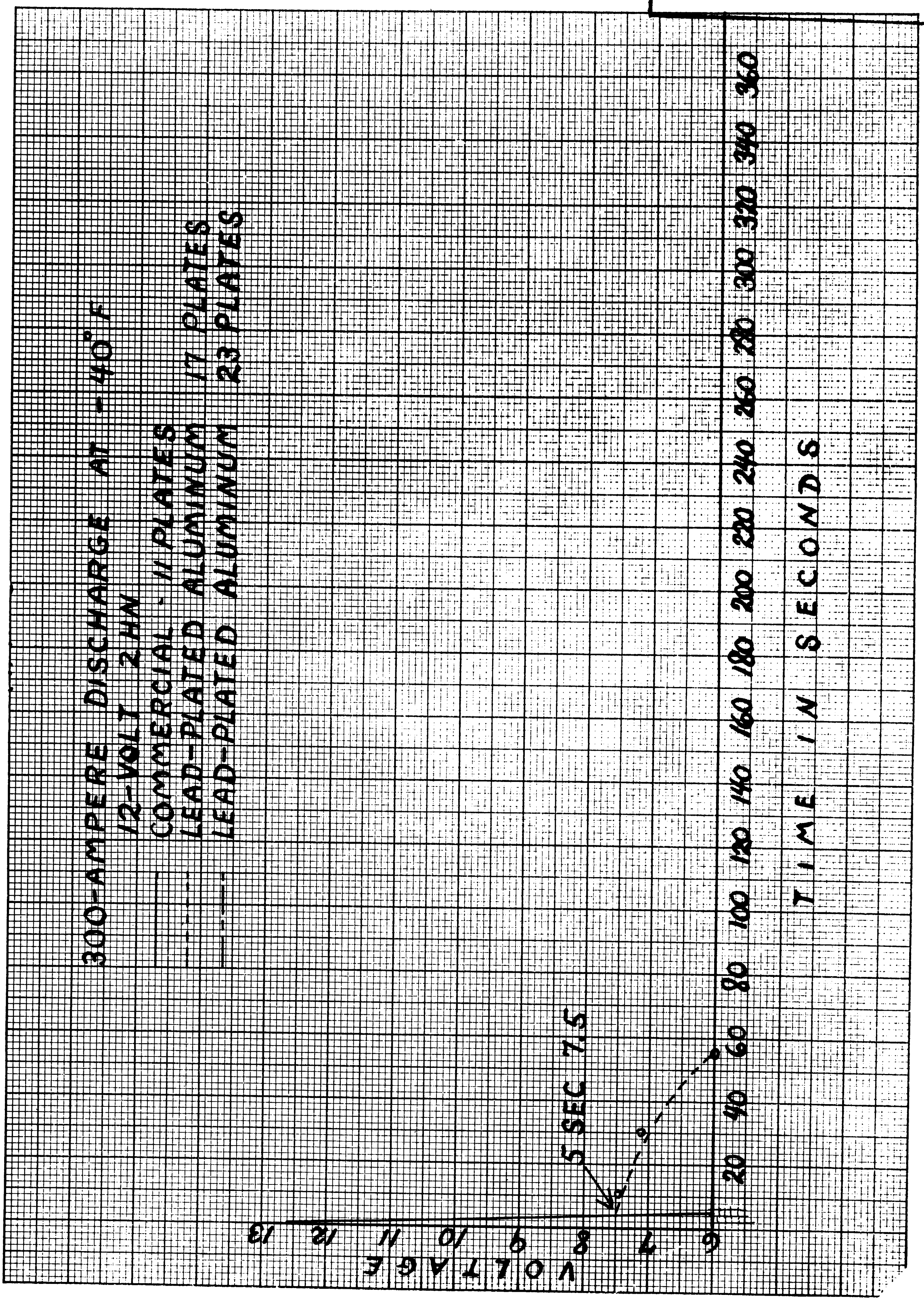
GRAPH 16


300-AMPERE DISCHARGE AT 80°F
12-VOLT 2 HN
COMMERCIAL - 11 PLATES
LEAD-PLATED ALUMINUM 17 PLATES
LEAD-PLATED ALUMINUM 23 PLATES
5 SEC 10.6
5 SEC 10.5
5 SEC 9.5
TIME IN SECONDS
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
VOLTAGE
6
7
8
9
10
11
12
13

GRAPH 17


300-AMPERE DISCHARGE AT 0°
12-VOLT 2 HN
COMMERCIAL - 11 PLATES
LEAD-PLATED ALUMINUM 17 PLATES
LEAD-PLATED ALUMINUM 23 PLATES
5 SEC 9.5
5 SEC 6.95
TIME IN SECONDS
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
VOLTAGE
6
7
8
9
10
11
12
13

GRAPH 18


300-AMPERE DISCHARGE AT -40°F
12-VOLT 2HN
COMMERCIAL - 11 PLATES
LEAD-PLATED ALUMINUM 17 PLATES
LEAD-PLATED ALUMINUM 23 PLATES
5 SEC 7.5
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
TIME IN SECONDS
6
7
8
9
10
11
12
13
VOLTAGE

GRAPH 19

overcharge the battery seriously, it is apparent that a lead-plated aluminum-grid battery will reach a specific gravity of only about 1.250-1.260 at the voltage of 14.7-15.0, and will begin to function like a battery in an automobile where the generator cuts out at 14.7. The specific gravity of the acid will not increase because the back emf of the battery balances the emf impressed on the terminals by the charging unit. If the current flowing through the battery is too greatly reduced, the battery will sulfate on the charging line if the back emf is as great as the impressed emf.

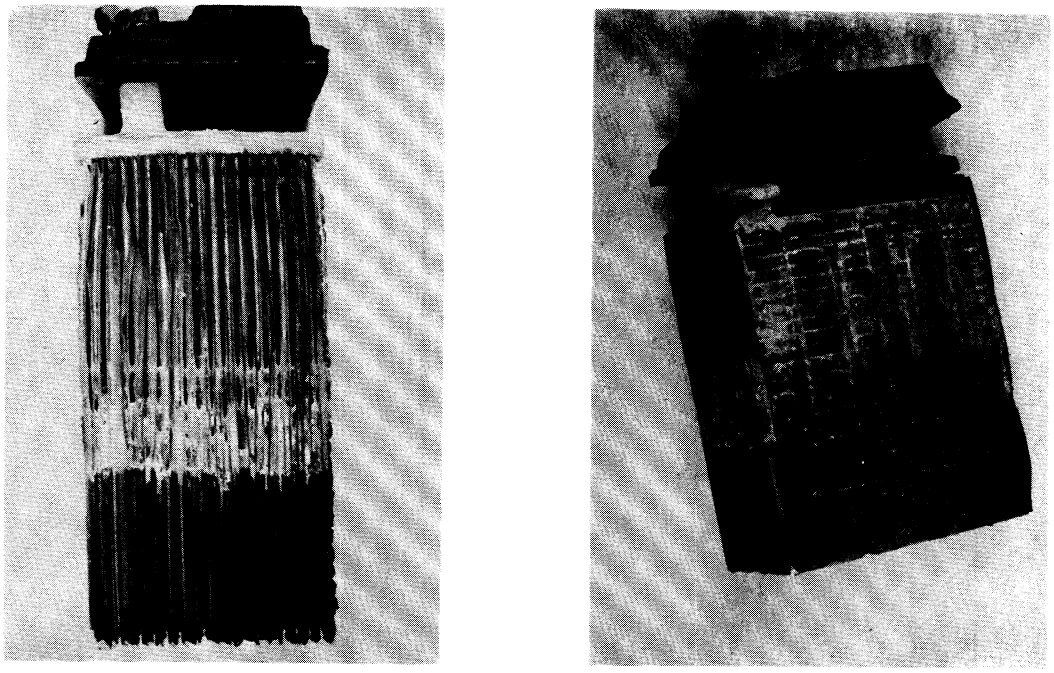
To charge the lead-plated aluminum-grid batteries the impressed emf must be greater than the back emf of the battery, namely 17 volts.

It has been observed that when the impressed emf has reached 14.7 volts the battery begins to float on the line as the back emf reaches 14.7 volts. It is obvious the battery cannot charge, as the emf is too low to cause the removal of sulfate from the surface and convert it into lead dioxide on the positive grids or sponge lead on the negative grids. To charge the pure-lead surface of the lead-plated aluminum-grid plate and to convert the desired amount of lead sulfate to active positive PbO_2 and active negative sponge lead requires an emf of 16.7 volts. The specific gravity of the electrolyte did not increase above 1.250-1.260, as the emf was too low to change the remaining $PbSO_4$ to H_2SO_4 and PbO_2 and/or Pb.

(2) The acid did not circulate in battery No. 117, 119, and 120 because (a) the channels between the ribs on the separators became imbedded in the active material of the positive plate due to expansion of the active material of the negative plate, and (b) the cells were not filled with electrolyte to a line above that indicated in Photographs 20a and 20b. The lower edge of the white line across each element in the lower portion of each photograph indicates the level of the acid in the cells. The lack of electrolyte caused sulfation of the top two-thirds of the plates (Photographs 20a and 20b). Since the electrolyte wet only the lower one-third of each plate, the normal charging current density for the battery was virtually tripled as only the lower half of the plates were being charged. This high charging current density accelerated gassing for a normal charging rate. There was also a loss of electrolyte and a rise in temperature, which caused the separators to become welded to the upper two-thirds of the plate and caused an overcharging of the lower one-third of the plates (see Photograph 21). There was excessive sloughing of the positive active material on the lower one-third of the plates.

In spite of this abuse the lead electroplate was intact, and there were no shortings.

These cells were removed, equipped with new separators, and reassembled; on cycling they were found to have over half of their rated

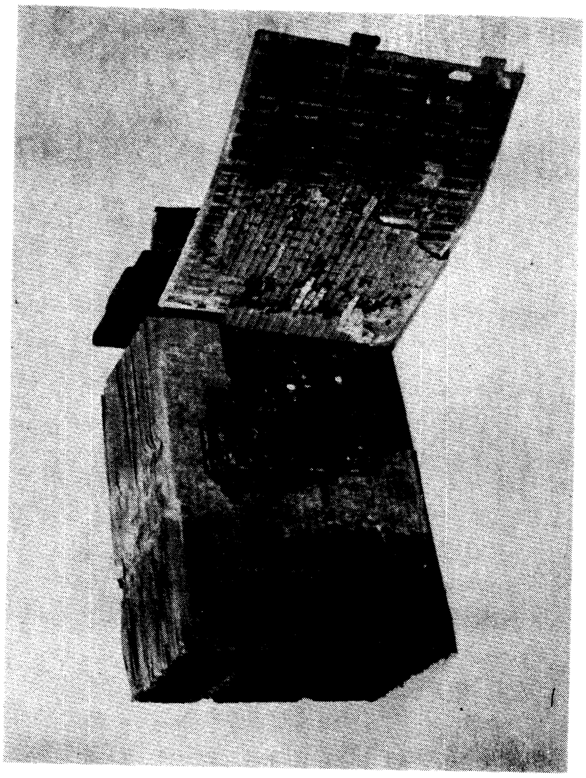


(a) (b)

Photograph 20. Photograph Showing Effect of Improper Charging of Batteries:

(a) Edge view of element charged over 200 hours at a maximum impressed emf of 14.7 volts.

(b) Side view of same element shown in (a).



Photograph 21. Photograph of the Effect of Improper Charging of Lead-Plated Aluminum-Grid Batteries.

capacity on the first discharge following the reassembly. If the cells are worked sufficiently, the sulfate may be partially removed and almost normal ampere-hour capacity restored. Should the plates in the heavily sulfated condition be overcharged, however, they may slough excessively before the original balance between $PbSO_4$ and PbO_2 or Pb is restored.

(3) The gassing was due to (a) excessive current density on the bottom third of the plates as a result of overcharging, (b) the closing of part of the channels between the separator and the positive plates, and (c) a lack of general circulation of the electrolyte.

(4) On charge the gas pumped what little electrolyte there was to the surface of the cell element. When charging was discontinued the electrolyte settled to a level two-thirds the height of the element below the top of the element.

(5) The ampere-hour capacity could not be expected to equal that of a normal battery, as only one-third of the plates were active, i.e., covered with electrolyte.

Battery Inspection and Study of Batteries Returned from Wright Field.

The following lead-plated aluminum-grid batteries were returned for our inspection and study on January 8, 1953, after a series of tests conducted at Wright Field, Dayton, Ohio.

M7-B-46, a 12-volt 6TN 90-A.H. battery
M7-B-45, a 12-volt 2HN 45-A.H. battery
M7-B-69C, a 12-volt 2HN 45-A.H. battery
M7-B-71C, a 12-volt 2HN 45-A.H. battery

Construction of the batteries is shown in Table 15.

Batteries M7-B-46 and M7-B-45 had an electroplate system composed of zinc, copper, nickel, and lead, while batteries M7-B-69C and M7-B-71C had an electroplate system composed of zinc, chromium, nickel, and lead.

When these batteries were dismantled and an inspection of the elements made, the following deficiencies were noted:

Battery M7-B-46:

1. Four of the six cells were dry. Either the electrolyte had been poured out or boiled out, or no water had been added during tests on the battery.
2. Most of the lugs were eaten through and shorted.
3. The principal cause of failure was the diffusion of copper through the lead electroplate of the positive plate and its subsequent deposition on the negative plate.

TABLE 15

CONSTRUCTION DETAILS OF BATTERIES SENT TO WRIGHT FIELD

Battery No.	Type	Positive Plates		Negative Plates		Thickness of Microporous Rubber Separator, inches	Date Manufactured	Notes on Electroplate System
		Number Per Cell	Thickness, inches	Number Per Cell	Thickness, inches			
M7-B-46	6TN	15	0.040	16	0.030	0.042	5/11/51	usual
M7-B-45	2HN	8	0.040	9	0.030	0.042	5/11/51	partly Cu
M7-B-69C	2HN	8	0.040	9	0.030	0.042	11/2/51	partly Cr
M7-B-71C	2HN	8	0.040	9	0.030	0.042	11/2/51	partly Cr

Battery M7-B-45:

1. Five of the six cells were dry. No acid remained in the cell due to lack of addition of water, spillage, excessive gassing, or boiling on charge.
2. All the plates were sulfated, possibly due to lack of sufficient electrolyte or a low charging voltage.
3. Most of the positive plates were shorted due to solution of the lead.
4. Copper diffused through the lead electroplate and deposited on the negative plates, leaving a very porous lead deposit on the positive plates.

Battery M7-B-69C:

1. Four of the six cells were dry. The other two were damp, but the acid was low.
2. The lugs on the positives were all corroded to the aluminum and had shorted.
3. The plates were badly sulfated.

Battery M7-B-71C:

1. The cells which were covered with acid were in good condition.
2. The top lugs of the plates were blistered.
3. The top lugs of one or two positive plates of each cell were eaten through and the plates had dropped from the plate strap. The plating job must have been imperfect.
4. The plates were sulfated, possibly due to a low charging voltage.

These four batteries were not of the best design nor the best type of construction:

1. No copper should be used under a lead electroplate, as it will diffuse through the lead electroplate and be deposited on the negative plate. Nickel electroplate of 0.001 to 0.002 inch is not sufficient to prevent copper diffusion.

2. The chromium substituted for the copper in the electroplate system did not seem to improve the life cycle of the electroplate system materially. This may have been due to the interelectroplate coat pealing at the chromium-electroplate interface.

3. Copper which diffused through the lead electroplate seems to have left it sufficiently porous to accelerate the sulfation of the lead electroplate and also produce passages through the lead electroplate which admitted acid to the aluminum. Until the passages were greatly enlarged, they were sealed by Al_2O_3 or/and $Al_2(SO_4)_3 \times H_2O$. This seems to account for the excessive lug corrosion and shorting.

Design of a 12-Volt 65-A.H. Battery (Battery No. 152)

The purpose of this battery design was to determine if a lead-plated aluminum-grid battery could be produced with a 65-A.H. capacity based on the knowledge obtained in the production of 2HN 12-volt 45-A.H. and 6TN 12-volt 90-A.H. batteries.

Specifications for the 12-Volt 65-A.H. Chrysler Battery. A 12-volt battery case such as is used in the design of lead-antimony batteries was secured; it occupies 718 cubic inches and has the following dimensions:

Dimension	Width, inches	Height, inches	Length, inches
Outside	7	8-3/8	12-1/4
Inside	6-1/4	6-1/4	11-5/8
Inside of Cell	6-1/4	6-1/4	1-5/8

Each elements is composed of 13 plates:

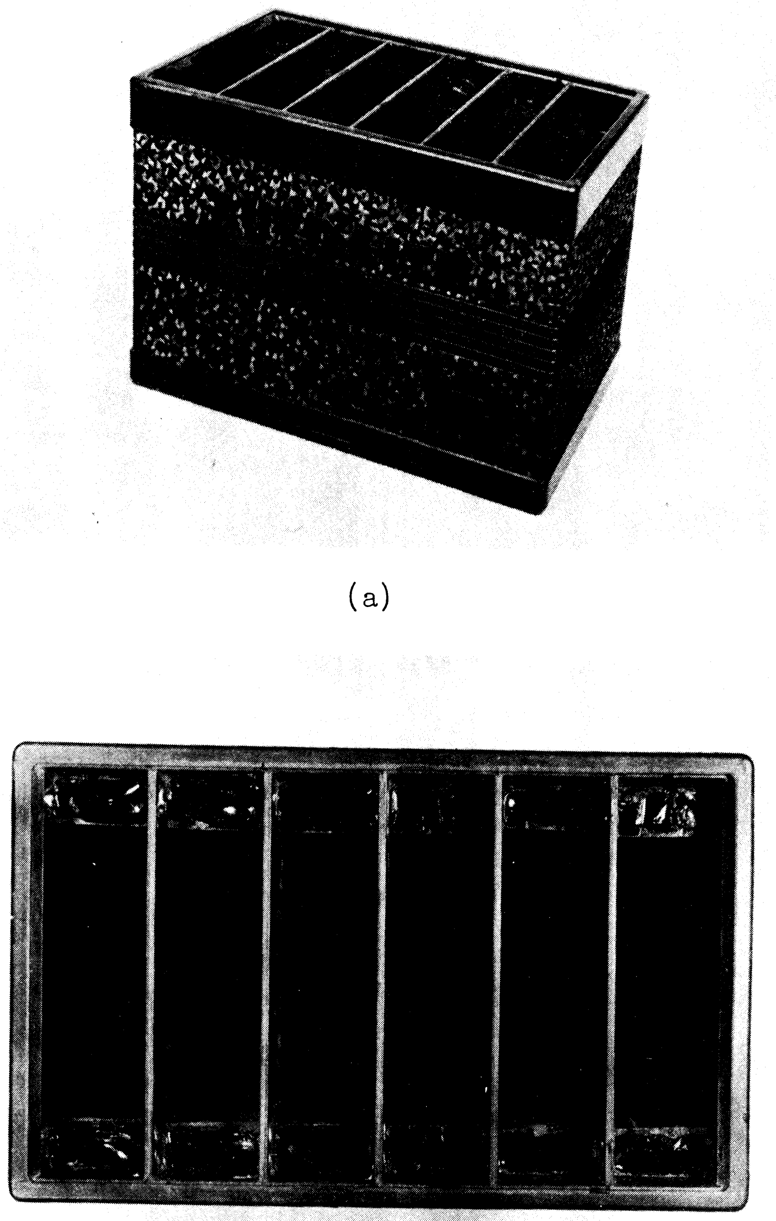
Number and Type of Plates	Thickness, inches	Height, inches	Width, inches	Total Plate Area per Element, in.^{2}
6 Positive	0.063	5.25	5.667	356
7 Negative	0.063	5.25	5.667	514

Specific gravity of the acid is 1.285, and the separators are the conventional type, approximately 0.060 inch thick.

This battery is required to produce 3.25 amperes (at the 20-hour rate) at 80°F to an end voltage of 10.8 volts and 150 amperes for 3.71 minutes at -20°F to an end voltage of 6 volts.

Specifications for Lead-Plated Aluminum-Grid Battery. The 12-volt Chrysler case was blocked off so as to accommodate the smaller 2HN grids. Side and top views of the case may be seen in Photographs 22a and 22b. The volume of the battery case was reduced 117 cubic inches to a final volume of 601 cubic inches, with the following dimensions:

Dimension	Width, inches	Height, inches	Length, inches
Outside (Proposed)	5-1/4	8-3/8	12-1/4
Inside	4-1/2	6-1/4	11-1/8
Inside of Cell	4-1/2	6-1/4	1-5/8



(a)

(b)

Photograph 22. View of Chrysler Battery Case as Modified: (a) Side view; (b) Top view showing reduction in volume of cell capacity.

Each element is composed of 21 plates:

Number and Type of Plates	Thickness, inches	Height, inches	Width, inches	Total Plate Area per Element, in.^{2}
10 Positive	0.060	5-1/16	4-1/8	420
11 Negative	0.030	5-1/16	4-1/8	462

The separators are 0.030-inch-thick pormax (plastic) wrapped around the negative plate. The specific gravity of the acid is 1.285. A total of 579.5 grams of positive oxide and 414.5 grams of negative oxide was used in each element. The total weight of the element (10 positive plates, 11 negative plates, 22 separators, acid, and lead plate strap) was 6.19 pounds.

Performance requirements are the same as for the lead-antimony Chrysler 12-volt 65-A.H. battery. The performance data of the lead-plated aluminum-grid battery is given in Table 16.

By reference to the table giving the discharge data of a Chrysler 12-volt 65-A.H. battery, it may be observed that this battery is nearly living up to specifications. Sometimes it exceeds specifications while other times it is just under specifications, apparently because of variation in discharge techniques and the personnel used in conducting the discharges.

It should be noted that this battery can be built with a reduction of 117 cubic inches in overall volume as compared to the existing 12-volt 65-A.H. battery.

If we were to use the present case with lead-plated aluminum-grids of the height and width of those used in lead-antimony 12-volt 65-A.H. batteries, the capacity would exceed those of the proposed lead-plated aluminum-grid batteries and the existing lead-antimony batteries as follows: the 3.25-ampere rate (20-hour rate) could be raised to 4.5 amperes, and the specified 150-ampere-hour rate of 3.71 minutes at -20°F could be raised to 5.1 minutes at the same temperature, -20°F.

Inspection Report on 6TN and 2HN Batteries Sent to Yuma Test Station

The batteries included in this test were four 6TN 12-volt 90-A.H. batteries, Nos. 126, 128, 157, and 158 and eight 2HN 12-volt 45-A.H. batteries Nos. 135, 136, 142, 143, 147, 148, 149, and 151. Their construction is detailed in Table 17.

The batteries were sent to the Detroit Tank Arsenal Laboratory on February 2, 1953, and remained there until April 20, 1953, when they were

TABLE 16

DISCHARGE DATA AND LIFE-CYCLE DATA, TO DECEMBER, 1953

Cycle No.	Discharge Rate, amp	End Voltage	5-Second Voltage	Time of Discharge	Ampere-hrs	Temp., °F	Remarks
1	25	10.8	--	1 hr, 50 min	45.7	72	First discharge is generally low.
2	3.25	10.8	--	21 hr, 30 min	69.8	74	Met low-rate requirement.
3	150	6.0	11.6	12 min, 4 sec	30.2	76	No specification.
4	3.25	10.8	--	22 hr, 5 min	71.7	80	Met low-rate requirement.
5	150	6.0	11.0	8 min, 20 sec	20.8	0	No specification.
6	3.25	10.8	--	25 hr, 30 min	82.8	80	Met specification.
7	150	6.0	10.2	2 min, 48 sec	7.0	-41	No specification.
8	3.25	10.8	--	19 hr, 30 min	64.2	83	Not fully charged.
9	150	6.0	7.0	18 sec	0.75	-65	No specification.
10	150	6.0	7.0	18 sec	0.75	-65	No specification.
11	150	6.0	10.2	2 min, 21 sec	5.9	-40	No specification.
12	3.25	10.8	--	20 hr	65	76	Met specification.
13	150	6.0	10.6	3 min, 55 sec	9.8	-20	5-sec voltage under specification.
14	3.25	10.8	--	20 hr	65	78	Met specification.
15	150	6.0	10.85	3 min, 22 sec	--	-20	
16	150	6.0	10.85	3 min, 30 sec	--	-20	
17	3.25	10.8	--	25 hr, 45 min	83.69	81	
18	150	6.0	10.65	3 min, 54 sec	--	-20	
19	3.75	10.8	--	17 hr, 30 min	67.5	83	Met specification at 3.75 amperes.
20	150	6.0	9.5	1 min, 17 sec	--	-40	
21	3.25	10.8	--	19 hr, 30 min	63.4	82	Not fully charged.
22	150	6.0	6.95	18 sec	--	-65	
23	3.0	10.8	--	20 hr, 30 min	61.8	78	Not fully charged.
24	25	10.8	--	1 hr, 20 min	--	80	
25	Not recorded						
26-1*	150	6.0	12.10	11.7 sec	--	80	
26-2	150	6.0	11.60	5 min, 43 sec	--	82	
26-3	150	6.0	11.90	10 min	--	80	
26-4	150	6.0	11.50	4 min	--	80	Stood 21 days before discharging.
26-5	150	6.0	11.50	3 min, 50 sec	--	80	
26-6	150	6.0	10.8	1 min, 40 sec	--	80	Stood 21 days before discharging.
26-7	150	6.0	11.1	3 min	--	80	Regular ASTM cycle.

*Number after dash indicates number of overcharge cycle.

TABLE 17

CONSTRUCTION OF THE BATTERIES RETURNED FROM THE DETROIT TANK ARSENAL, CENTER LINE, MICHIGAN WHICH HAD BEEN TESTED IN YUMA, ARIZONA

Battery		Date Manu-factured	Number of 0.060-inch Positive Grids	Number of 0.030-inch Negative Grids	Separator	Number of Discharges Prior to Being Sent to Yuma
No.	Type					
126	6TN	12-29-52	17	18	0.030-inch-thick pormax feet on the grids	7
128	6TN	12-29-52	17	18	0.030-inch-thick pormax feet on the grids	7
157	6TN	3-23-53	17	18	0.030-inch-thick pormax wrapped around negative	1
158	6TN	3-23-53	17	18	0.030-inch-thick pormax wrapped around negative	1
135	2HN	1-12-53	8	9	0.030-inch-thick pormax feet on the grids	6
136	2HN	1-12-53	8	9	0.030-inch-thick pormax feet on the grids	7
142	2HN	1-26-53	8	9	0.030-inch-thick pormax feet on the grids	6
143	2HN	1-29-53	8	9	0.030-inch-thick pormax feet on the grids	6
147	2HN	1-26-53	8	9	0.030-inch-thick pormax feet on the grids	6
148	2HN	1-26-53	8	9	0.030-inch-thick pormax feet on the grids	6
149	2HN	1-26-53	8	9	0.030-inch-thick pormax feet on the grids	6
151	2HN	1-26-53	8	9	0.030-inch-thick pormax feet on the grids	6

returned to the laboratory at the University of Michigan. The record of their treatment at the Arsenal is not available. Each battery was given one or two cycles (cycle No. 6 or 6 and 7 of Table 22) before they were returned to the Detroit Tank Arsenal about June 8, 1953, to be sent to the Yuma Test Station.

After the completion of their tests at Yuma Test Station about September 29, 1953, the batteries were returned to the laboratory of the University of Michigan for inspection and study. The results of the inspection of the batteries as-received are given in Table 18.

At the Yuma Test Station, the vehicular operation characteristics and the standby characteristics were tested. A comparison of the specific gravity of the acid in each cell as-received with the specific gravity listed in the September 29, 1953, report from the Yuma Test Station is given in Table 19, while the specific gravity after recharging is given in Table 20. In most instances the batteries regained their original specific gravity, and the values are generally higher than those reported at the Yuma Test Station and recorded in Table 19.

Further data on the condition of the batteries at the close of the Yuma tests are presented in Table 21, and the available cycling data in shown in Table 22.

Discussion of Conclusions of Yuma Test Station Report of September 29, 1953

It should be recalled that the 6TN batteries contained 17 positive plates 0.060 inch thick and 18 negative plates 0.030 inch thick, assembled with 0.030-inch-thick pormax plastic separators, while the 2HN batteries contained 8 positive plates 0.060 inch thick and 9 negative plates 0.030 inch thick, assembled with 0.030-inch-thick pormax plastic separators.

The elements fit rather tightly in the cell. This means that the active material was crowded between part of the ribs on the separators and there was not very much space for acid circulation. These plates had feet which rested on the bridge at the bottom of the cell. The clearance between the edges of two positive plates was of the order of 0.090 inch. This crowding of the elements left little opportunity for (1) circulation of acid (2) sloughing of positive material, and (3) the washing away of any positive material from the surface of the bridge which might cause shorting between the positive and negative plates.

Comments on Conclusion A. It is stated in this section of the report that the water consumption of the experimental aluminum-grid batteries is considerably greater than that of standard lead-antimony batteries under high ambient temperatures as experienced in the desert. This conclusion seems quite valid for the batteries tested.

TABLE 18

INSPECTION DATA ON BATTERIES RETURNED FROM THE DETROIT TANK ARSENAL, CENTER LINE, MICHIGAN, WHICH HAD BEEN TESTED IN YUMA, ARIZONA

Battery		Accepted Charge	Retained Charge	Corroded Lugs (Positive or Negative)	Positive and Negative Oxide Intact	Holes in the Separators	Dead Cells	Battery Voltage on Return
No.	Type							
126*	6TN	No	No	Both	Yes	Yes*	1	2.0
128	6TN	Yes	--	No	Yes	No	2	2.0
157*	6TN	No	No	Both	Yes	Yes*	2	2.0
158**	6TN	No	No	Both	Yes	No	2	2.0
135	2HN	Yes	Yes	No	Yes	No	0	2.0
136	2HN	Yes	Yes	No	Yes	No	0	2.0
142	2HN	Yes	Yes	No	Yes	No	0	2.0
143	2HN	Yes	Yes	No	Yes	No	0	2.06
147	2HN	Yes	Yes	No	Yes	No	0	2.04
148	2HN	Yes	Yes	No	Yes	No	0	2.0
149	2HN	Yes	Yes	No	Yes	No	0	2.06
151	2HN	Yes	Yes	No	Yes	No	0	2.0

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*Leaky case: the battery had apparently been dropped.

**Complete battery was dismantled.

TABLE 19

COMPARISON BETWEEN YUMA TEST STATION DATA AND UNIVERSITY OF MICHIGAN DATA ON THE SPECIFIC GRAVITY OF THE ACID IN EACH CELL OF EACH BATTERY

Battery No.	Data Source	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Average	Dead Cells on Discharge
126[1]	Yuma	1.240	1.292	1.252	1.232	1.292	1.166	1.245	Nos. 5 and 6
(6TN)	UM	1.275	1.150	1.135	1.190	1.150*	Dry*	1.180	
128[2]	Yuma	1.292	1.280	1.286	1.242	1.232	1.242	1.260	Nos. 3 and 4
(6TN)	UM	1.235	1.175	1.160	1.185	1.235	1.185	1.195	
157[3]	Yuma	1.280	1.252	1.262	1.242	1.262	1.262	1.260	Nos. 2 and 3
(6TN)	UM	1.150	Dry*	**	**	1.150	**	1.150	
158[4]	Yuma	1.282	Dead	Dead	1.236	1.266	1.246	1.205	Nos. 1 and 4
(6TN)	UM	1.050	1.100	1.050	1.050	1.200	1.200	1.108	
135	Yuma	1.266	1.232	1.292	1.312	1.343	1.272	1.285	All good
(2HN)	UM	1.215	1.270	1.230	1.215	1.120	1.200	1.208	
136	Yuma	1.252	1.246	1.292	1.312	1.286	1.272	1.280	All good
(2HN)	UM	1.210	1.225	1.240	1.225	1.175	1.185	1.210	
143	Yuma	1.252	1.276	1.312	1.322	1.312	1.282	1.295	All good
(2HN)	UM	1.235	1.260	1.250	1.245	1.240	1.220	1.242	
151	Yuma	1.272	1.272	1.292	1.292	1.272	1.272	1.280	All good
(2HN)	UM	1.235	1.235	1.260	1.260	1.235	1.235	1.243	
Stored Batteries									
142	Yuma	1.282	1.292	1.292	1.302	1.292	1.302	1.294	All good
(2HN)	UM	1.260	1.260	1.260	1.260	1.260	1.260	1.260	
147	Yuma	1.262	1.282	1.312	1.302	1.292	1.302	1.292	All good
(2HN)	UM	1.235	1.235	1.235	1.235	1.250	1.235	1.238	
148	Yuma	1.300	1.297	1.290	1.300	1.300	1.272	1.293	All good
(2HN)	UM	1.265	1.240	1.260	1.260	1.235	1.210	1.245	
149	Yuma	1.300	1.300	1.300	1.312	1.300	1.300	1.302	All good
(2HN)	UM	1.250	1.250	1.250	1.250	1.225	1.250	1.246	

*Case was broken.

**Too low to read.

Notes:
1. Case had been dropped and broken, plates bent and shorted; acid leak.
2. Cells 3 and 4 shorted because they were too tight in the case.
3. Cells 2 and 3 blistered on top of positive lugs; too tight in the case.
4. Cells 1 and 4 shorted on sides of grids; separators too narrow; shorted on negative lugs; separators too short.

TABLE 20

SPECIFIC GRAVITY AND CELL VOLTAGE DATA OF THE BATTERIES BY CELLS ON CHARGING, FOLLOWING THEIR INSPECTION AS RECORDED IN TABLES 18 AND 19

	Specific Gravity of the Acid in Each Cell of Each Battery When Fully Charged							Recharge Voltage of Each Cell and the Corresponding Positive and Negative Voltage against Cadmium as Observed							
Battery No.	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Aver-age	Voltage of:	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Terminal Voltage
126*	--	--	--	--	Broken	Broken	--	Cell	2.64	2.58	2.58	2.60	Broken case	Broken case	10.40 for 4 cells
								Pos.cad.	2.40	2.40	2.40	2.36			
								Neg.cad.	-0.22	-0.22	-0.22	-0.22			
128*	1.265	1.235	1.235	1.235	1.260	1.235	1.244	Cell	2.68	2.58	2.58	2.62	2.66	2.62	15.74
								Pos.cad.	2.44	2.42	2.32	2.44	2.42	2.40	
								Neg.cad.	-0.24	-0.20	-0.20	-0.22	-0.22	-0.20	
157*	1.265	Broken	Shorted	1.265	1.275	1.275	1.270	Cell	2.60	Broken	Shorted	2.62	2.64	2.64	10.50 for 4 cells
								Pos.cad.	2.40			2.38	2.42	2.40	
								Neg.cad.	-0.20			-0.24	-0.22	-0.24	
158*	1.185	1.260	1.270	1.170	1.270	1.260	1.236	Cell	2.08	2.64	2.66	2.14	2.66	2.68	14.86
								Pos.cad.	2.16	2.44	2.46	2.22	2.44	2.44	
								Neg.cad.	+0.10	-0.20	-0.20	+0.08	-0.20	-0.24	
135	1.285	1.300	1.300	1.285	1.285	1.275	1.288	Cell	2.62	2.68	2.68	2.64	2.60	2.68	15.90
								Pos.cad.	2.40	2.50	2.50	2.50	2.40	2.40	
								Neg.cad.	-0.20	-0.16	-0.18	-0.16	-0.18	-0.24	
136	1.285	1.285	1.300	1.300	1.265	1.265	1.283	Cell							
								Pos.cad.							
								Neg.cad.							
143	1.275	1.300	1.300	1.300	1.275	1.260	1.285	Cell	2.46	2.48	2.46	2.46	2.46	2.40	14.72
								Pos.cad.	2.34	2.34	2.34	2.34	2.34	2.34	
								Neg.cad.	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	
151	1.270	1.285	1.285	1.285	1.275	1.275	1.279	Cell	2.66	2.64	2.62	2.66	2.58	2.60	15.76
								Pos.cad.	2.50	2.48	2.50	2.52	2.46	2.42	
								Neg.cad.	-0.18	-0.16	-0.16	-0.16	-0.20	-0.18	
142	1.235	1.285	1.285	1.285	1.285	1.285	1.276	Cell	2.70	2.64	2.70	2.70	2.70	2.70	16.14
								Pos.cad.	2.50	2.50	2.50	2.50	2.50	2.50	
								Neg.cad.	-0.20	-0.18	-0.20	-0.20	-0.20	-0.20	
147	1.300	1.300	1.285	1.300	1.285	1.300	1.295	Cell	2.62	2.60	2.64	2.64	2.72	2.64	15.86
								Pos.cad.	2.44	2.42	2.46	2.46	2.48	2.48	
								Neg.cad.	-0.20	-0.20	-0.24	-0.24	-0.24	-0.18	
148	1.260	1.290	1.290	1.260	1.280	1.300	1.280	Cell	2.60	2.64	2.64	2.64	2.60	2.64	15.76
								Pos.cad.	2.30	2.46	2.46	2.40	2.40	2.46	
								Neg.cad.	-0.20	-0.20	-0.20	-0.20	-0.20	-0.14	
149	1.280	1.280	1.285	1.280	1.280	1.280	1.281	Cell	2.42	2.66	2.66	2.64	2.66	2.66	15.70
								Pos.cad.	2.46	2.46	2.46	2.46	2.46	2.46	
								Neg.cad.	+0.02	-0.20	-0.20	-0.18	-0.10	-0.20	

*Type 6TN batteries; all others were type 2HN.

TABLE 22

LIFE HISTORY IN CYCLES INSOFAR AS IS KNOWN OF THE BATTERIES SENT TO THE YUMA TEST STATION

Battery No.	Cycles at the University of Michigan							Cycles at Yuma Test Station	Cycles at the University of Michigan
	Cycle History of Battery from Records of the University of Michigan Laboratory								Discharge to 10.8 volts at the 25-ampere rate, following a conditioning charge (Table 20) after their inspection (Tables 18 and 19)
	Cycle No. 1	Cycle No. 2	Cycle No. 3	Cycle No. 4	Cycle No. 5	Cycle No. 6	Cycle No. 7		
126*	180 min	158 min	154 min	Run not recorded	22.6 hr	170 min	24.5 hr	The only record we have is given in Table 21.	180 min for 5 good cells
128*	186 min	165 min	160 min	Run not recorded	22.6 hr	175 min	25.3 hr		180 min for 4 good cells
157*	195 min								195 min for 4 good cells
158*	195 min								180 min for 4 good cells
135	78 min	25.6 hr	77 min	70 min	21 hr	80 min			75 min
136	60 min	21 hr	55 min	22 hr	45 min	45 min	75 min		80 min
142	73 min	24.7 hr	77 min	80 min	26.0 hr	80 min			80 min
143	73 min	24.6 hr	77 min	80 min	26.2 hr	85 min			75 min
147	74 min	25.0 hr	76 min	73 min	22.0 hr	80 min			85 min
148	74 min	24.3 hr	76 min	70 min	22.0 hr	80 min			80 min
149	71 min	25.0 hr	80 min	70 min	26.0 hr	85 min			75 min
151	70 min	25.2 hr	80 min	80 min	26.0 hr	85 min			85 min

*Type 6TN batteries; all others were Type 2HN.

The spacing between the grids in the lead-antimony batteries is greater than that between aluminum-grid batteries. This means not only that there is less electrolyte present, but also that there should be greater gassing of the electrolyte as its specific gravity is decreased through sulfation of the plates in the aluminum-grid battery. The boiling point of low-specific-gravity acid more nearly approaches that of water than does that of high-specific-gravity acid. Considering the high temperatures involved, then, it is not surprising that the water consumption was greater than in the standard batteries.

The comments on Conclusion B are also pertinent to this problem.

Comments on Conclusion B. In Conclusion B the experimental aluminum-grid batteries are said to be inferior to the standard lead batteries in maintaining charge during vehicular operation under desert conditions.

It is not known what voltage was delivered by the generator on the experimental vehicles. If this voltage was in the neighborhood of 14 or 14.7 volts, the batteries could not be expected to maintain a specific gravity above 1225 to 1250. The aluminum-grid batteries require a minimum of 16.5 volts for complete charging.

A voltage below this value on the vehicle would mean that these batteries were floating on the line at partial charge and never could attain full charge, nor could they utilize fully the charge delivered to them at the low voltage. At the low voltage and the low specific gravity of the acid resulting from the low voltage, the plates would sulfate. Once sulfation started the low voltage would not be sufficient, in connection with the current delivered, to break down this sulfation layer. Hence, the battery would not maintain its full charge during vehicle operation.

If the voltage delivered by the generator of the vehicle was 17 volts, then the batteries should accept charge during vehicle operation.

Comments on Conclusion C. It is not surprising that the 6TN batteries experience permanent loss of capacity as the result of normal vehicle operation. This would be a natural consequence of several factors such as (1) low generator voltage, (2) sulfation resulting from low generator voltage, and/or (3) possible loss of some electrolyte through excessive packing of the plates in the cell, which would tend to reduce circulation of the electrolyte and retard loss of heat.

The difficulty with the packing of the cell is being eliminated by removing one positive and one negative plate. This will afford better circulation, greater utilization of the active material, and reduction of heat evolved during operation. It should at the same time reduce water consumption. The first two factors listed are at present, however, beyond control of the manufacturer.

Comments on Conclusion D. The conclusion that the experimental batteries appeared to have a normal self-discharge rate as compared to the lead-antimony batteries is surprising.

We have had 2HN batteries from the same group as those tested at Yuma on standby for 90 days with only a 12 percent loss in capacity. It would be interesting to know if the electrolyte had evaporated from these batteries and also if water was added just prior to the determination of their capacity after standby. It would also be interesting to know the condition of the separators below the vent, i.e., if they have been indented by the hydrometer and thermometer used to measure the gravity and temperature respectively. We have not in the past been placing a gauze under the vent opening, but are now doing so to prevent undue deformation of the separators and shorting of the plates through rough handling of hydrometers and thermometers.

Comments on Conclusion E. We concur with conclusion E that the terminal posts lack the necessary construction to withstand rough handling. This is a matter that was beyond our control. We have known for a long time that these terminals should be larger in view of the softness of lead as compared to antimony-lead.

The determination of what constitutes a dead cell seems to be part of the discrepancy between the Yuma Test Station data and our findings. If a cell will no longer give its rated capacity, it is looked upon with suspicion, and is expected to affect the terminal voltage of the battery profoundly. If a cell goes out before its fellows but the terminal voltage is above or equal to 1.8 volts at the end of the 20-hour rate or 1 volt at the 150-ampere rate for a 2HN-type battery, the cell is considered satisfactory. Generally a dead cell is one that cannot function even though it has sufficient acid to cover the plates. It is a weak cell if it gives only a fraction of its rated capacity.

The batteries that are being constructed today are of a different design from those tested at Yuma. The new 6TN batteries contain 16 positive and 17 negative grids, while the new 2HN batteries contain 7 positive and 8 negative grids instead of 8 positive and 9 negative grids. We have found that this decrease in plate area is more than offset by the greater efficiency of active material in the remaining plates.

We have also modified the construction of the newer batteries by using vinylite separators (not the exact type we desire, but the only kind we can obtain from the producers), which we wrap around the negative plates to prevent shorting on the bridge at the bottom of the cell at all times.