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THE SILVER OXIDE-ZINC ALKALINE PRIMARY CELL

PART 2

EFFECTS OF VARIOUS TYPES OF NEGATIVE ELECTRODES ON CELL CHARACTERISTICS

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PART 2

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C. M. Shepherd

December 20, 1951

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THE SILVER OXIDE-ZINC ALKALINE PRIMARY CELL

Part 2

Effects of Various Types of Negative Electrodes on Cell Characteristics

BACKGROUND

The silver oxide-zinc alkaline primary cell consists of a negative electrode of zinc, a positive electrode of silver peroxide, and an alkaline electrolyte (generally a potassium hydroxide solution). During discharge, the silver peroxide in the positive electrode is reduced to metallic silver and the metallic zinc in the negative electrode is oxidized either to zinc oxide or to a complex zincate ion. The reactions involved have not been fully determined and may prove to be fairly complex.

Because of its many desirable characteristics, an appreciable demand has arisen for this cell. It is a constant voltage, primary cell of low weight and volume, capable of operating at high current densities over a wide range of temperatures. Wherever the demand for the cell is based on minimization of weight or volume, a separate design generally will be needed for each set of conditions. Such a design will require more detailed information than is necessary for the construction of ordinary types of batteries. Considerable information concerning the properties and characteristics of this cell have been published previously (1, 2, 3, 4, 5, 6).

Measurements made with a mercury-mercurous oxide-potassium hydroxide reference electrode showed that cell failure always occurs at the negative electrode as long as sufficient silver oxide is present. Consequently, the cell capacity for a given electrolyte volume and a given set of operating conditions was found to be dependent upon the physical nature of the zinc(1). The capacity of a cell using high-purity sheet-zinc negative electrodes was determined for a wide range of electrolyte volumes, electrolyte concentrations, current densities, and temperatures. Although sheet zinc is not the most effective electrode material, it was chosen for study not only because it is eminently satisfactory in cells used under a wide range of conditions, but also because the data obtained can be used in developing theory and in promoting further electrode and cell design.

At a given set of conditions the capacity in minutes of a cell having sheet-zinc negative electrodes was found to be directly proportional to the electrolyte volume for electrode spacings between 0.015 inch and approximately 0.1 inch (1). Since other types of electrodes generally are more effective than sheet zinc at spacings below 0.015 inch, measurements were not made in this region. If porous electrodes are used, the amount of electrolyte absorbed in the electrodes increases and the amount between the electrode faces decreases as the distance between the electrodes is decreased. Since the portion of the electrolyte absorbed in the electrodes can not diffuse as readily, particularly at high current densities, the cell capacity would probably no longer be proportional to the electrolyte volume, but instead would be a complex function of the electrolyte distribution between the various portions of the cell. Moreover, if the cell is closely packed, there would be no convection currents such as are present when there is free space between the electrodes.

The fact that cell capacity is directly proportional to electrolyte volume under the limitations mentioned indicates that cell failure occurs for a given set of conditions when the electrolyte reaches a certain concentration which is a specific function of the zinc and potassium hydroxide content (1). At low current densities, however, a precipitate, probably zinc oxide, separates out from the electrolyte during discharge. Thus it is possible for an alkaline solution saturated with zinc (a condition reached part way through discharge at low current densities) to operate satisfactorily as the electrolyte by acting as the medium for converting zinc to zinc oxide and silver oxide to silver.

The capacity in minutes of a cell with sheet-zinc negative electrodes was found to be directly proportional to the electrolyte concentration between the approximate limits of 200 g/l and 500 g/l potassium hydroxide (1). The higher limit of electrolyte concentration varies slightly with change in temperature and current density. Above this limit the cell capacity drops off rapidly. This upper limit is the most effective electrolyte concentration that can be used in designing a cell to operate under a given set of conditions. Since the capacity of a cell using sheet-zinc negative electrodes is directly proportional to both the electrolyte volume and the electrolyte concentration, the two relationships may be combined. As a result, the capacity is directly proportional to the grams of potassium hydroxide present per unit electrode area at a given temperature and current density, within the limits of electrolyte volume and concentration previously mentioned (1). The equation for cell capacity becomes

$$C = KW \qquad (1)$$

where C is cell capacity in minutes, W is the weight of potassium hydroxide in the electrolyte expressed as grams per square inch of electrode area, and K is a function of current density and temperature.

In Figure 1, K is plotted against current density for five different temperatures (1). The variation of cell capacity and cell voltage with temperature, current density, volume of electrolyte and electrolyte concentration can be determined easily by use of this graph. The curve for 60^0 C at the extreme left of the chart shows a value of K equal to 240 minutes for a current density of 0.1 ampere per square inch.

At intervals along each curve in Figure 1 is recorded the average voltage which can be obtained at that particular point and the maximum electrolyte concentration at which the linear relationship holds true. These values of emf and electrolyte concentration are easy to interpolate since they do not change rapidly. The current density of 0.1 ampere per square inch for the above cell falls on the curve near a recorded emf of 1.52 volts and an electrolyte concentration of 520 grams per liter, the optimum concentration that can be used.

In Figure 1, the 40^0 C curve, which is found immediately to the right of the 60^0 C curve, is plotted against K in the same manner as the 60^0 C curve, with the single exception that the current density coordinates have been shifted to the right. The point on the abscissa which corresponds to 0.5 ampere per square inch for the 60^0 C curve corresponds to 0.05 ampere per square inch for the 40^0 C curve. A similar and equal shift of the current density coordinates is made on each of the successive temperature curves across the chart. The temperature difference between each successive temperature curve is constant, and the distance between any particular current density (such as 0.1 ampere per square inch) is constant for each successive curve.

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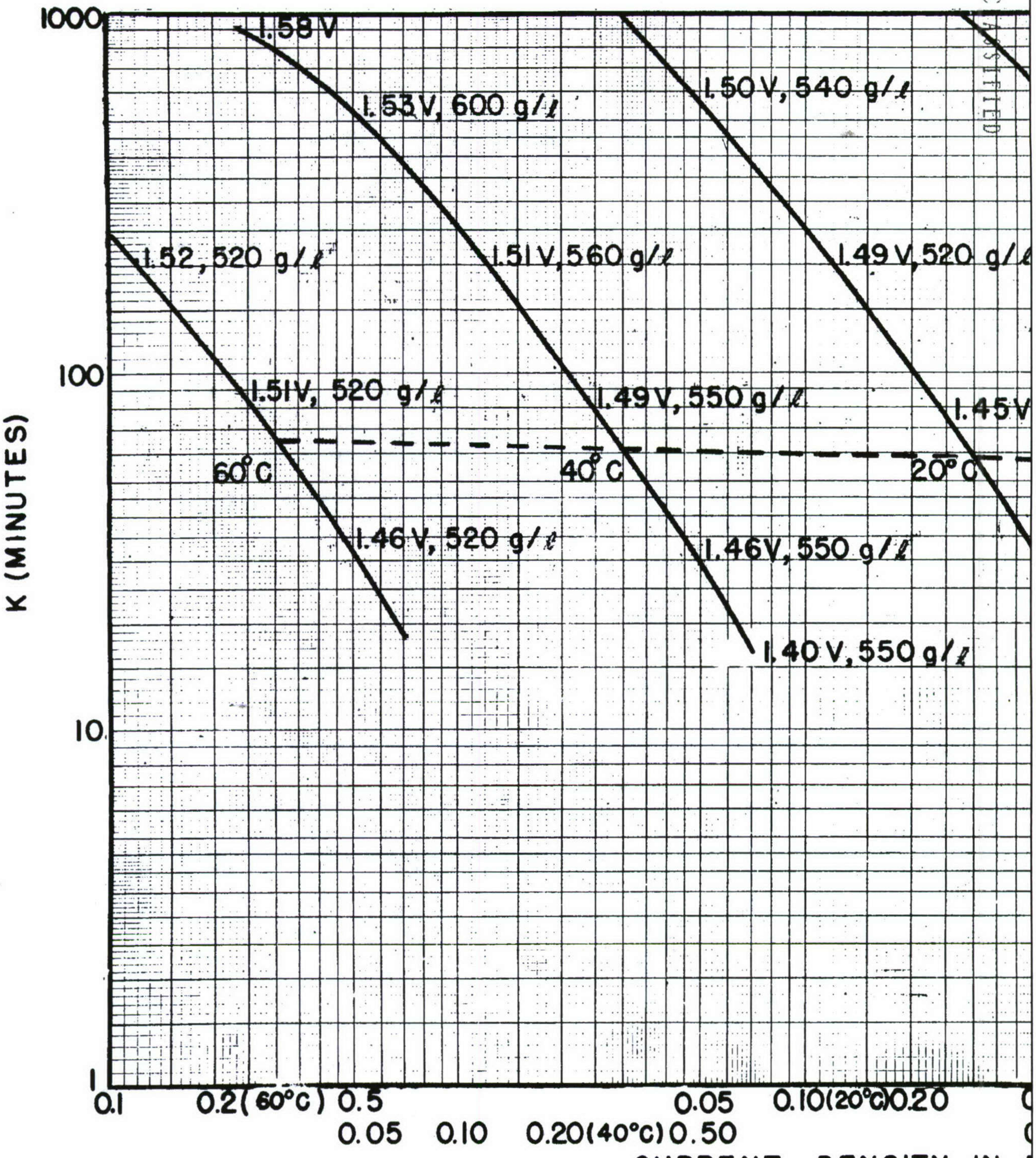

Figure 1 - Effect of variation in current density and temperature on cell capac
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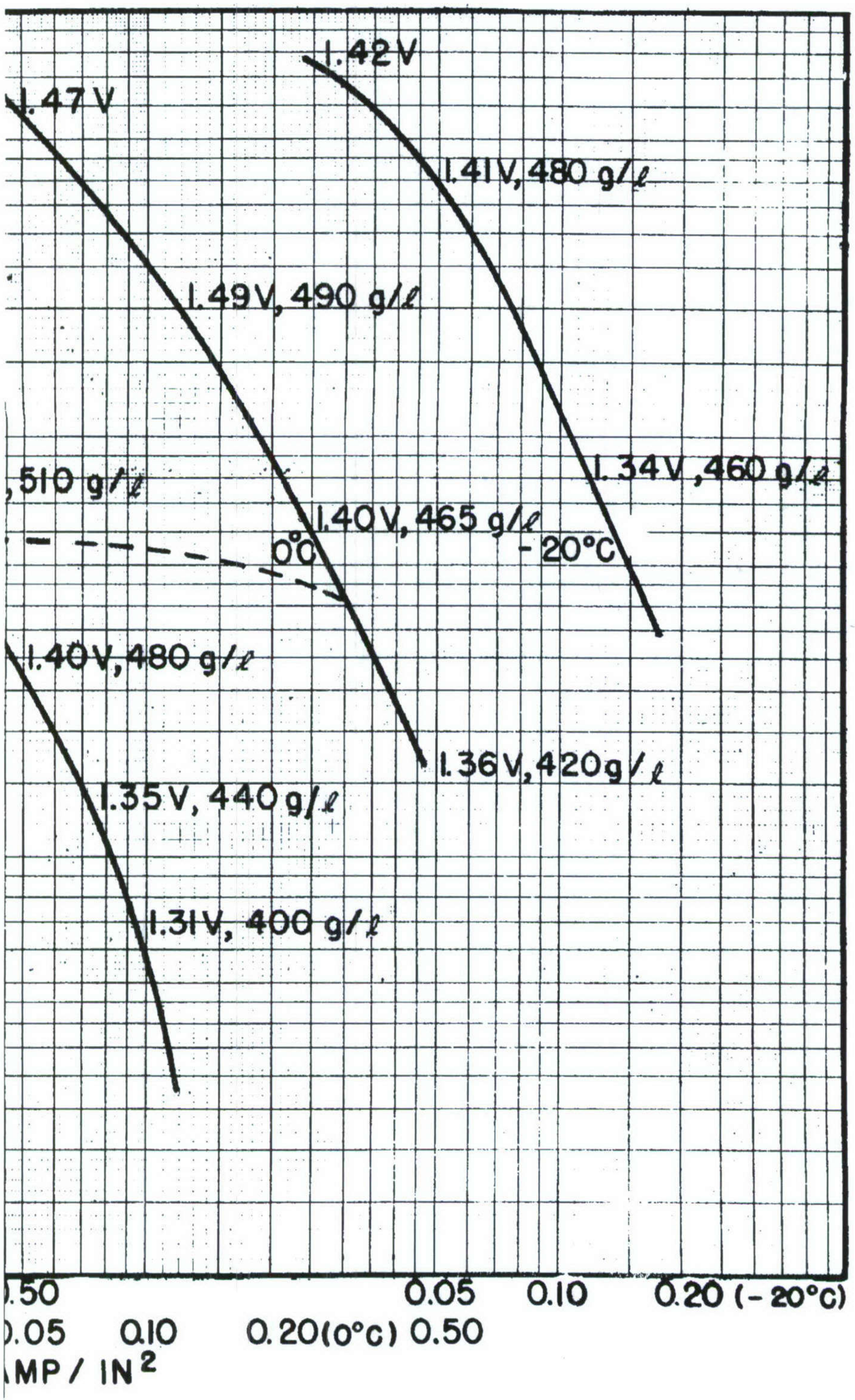

ity per gram of KOH per square inch of negative
lectrolyte concentrations)

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Thus, it is possible to draw a new curve that shows the variation of K with temperature at any particular current density. For example, curve A gives values of K at different temperatures for a current density of 0.3 ampere per square inch. The abscissa of A, which is graduated linearly, is temperature. The 60° C point on the abscissa of A is located at the point corresponding to 0.3 ampere per square inch on the 60° C curve, and the 0° C location is at the point corresponding to 0.3 ampere per square inch on the 0° C curve. By interpolation, the values of K at any temperature can readily be obtained. For instance, the value of K for 10° C lies halfway between the 0° C curve and the 20°C curve and is equal to 52.5 minutes.

Many of the demands for this cell are based on minimization of cell weight or volume for a given electrical output; or maximization of electrical output for a given cell weight or volume. Although the weight of a cell is simply the sum of the component weights, the minimum weight for a given set of operating conditions is a complex function of a large number of variables such as volume, concentration, and density of electrolyte; temperature; weight of grids, separators, and spacers; current density; area of electrodes—and many others.*

Since the zinc electrode is the first to fail during cell discharge, it should prove the most profitable to study when searching for improvement in cell capacity. An examination of Figure 1 shows that a decrease in current density is accompanied by a proportionately larger increase in cell capacity as expressed in units of time. For example, the curves in Figure 1 show that a cell operating at 40° C, having one square inch of negative electrode area and containing one gram of potassium hydroxide in solution would function for 35 minutes at a current density of 0.45 ampere per square inch. If the current density were decreased to 0.15 ampere per square inch, the cell capacity would then increase to 150 minutes. This increase in area could be obtained by a tripling of the number of electrodes in the cell. Unfortunately, such action would decrease the available electrolyte volume per unit area by two thirds. The resultant capacity would therefore be approximately one-third of 150 or 50 minutes. Although this is a considerable gain over the original capacity of 35 minutes, it is accompanied by an increase in grid weight caused by the tripling of the grid area.

If, however, it were possible to prepare a special zinc electrode having a larger surface area than a sheet-zinc electrode of the same dimensions, the resultant decrease in current density would give an increased cell capacity which would not be offset by an increase in grid weight. For these reasons, it is highly desirable to study various physical constructions of zinc electrodes in an attempt to determine which would be most suitable for use in the primary cell. The preliminary results of this work are embodied in this report, which is the second in a new series presenting NRL's participation in the study of the silver oxide-zinc alkaline cell.

EXPERIMENTAL METHODS

A test cell assembly was similar to that adopted by previous workers (1). One negative and two positive electrodes each 1-1/2 inches square were assembled with either polystyrene spacers 0.060 inch wide and 1.5 inches long or 0.003 inch, 40-mesh Saran screen separators between the electrodes. For the positive plate, a grid of 40 x 33-mesh silver screen was pasted with a mixture prepared from 5 grams of silver chloride and a few drops of 25% potassium hydroxide and then allowed to dry in air. Subsequently, the plates were oxidized anodically in a solution of 15% potassium hydroxide at 0.25 ampere for 24 hours, soaked in water for one day, and air dried.

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* This problem will be discussed in a future NRL report.

Cell cases, stamped from sheet polystyrene were 2-5/8 inches high, 1-5/8 inches wide, and of varying thickness. The electrolyte, normally 10cc potassium hydroxide at a given concentration, was added until its level was slightly above the top of the electrodes. The cell was discharged immediately after the addition of the electrolyte. All discharges were made at constant temperature and at a constant current, the voltage being recorded automatically. The cell discharge was considered complete when the emf had dropped to 1.0 volt. Since the cell voltage is nearly constant throughout a discharge, the emf at the time the cell is two-thirds discharged has been found to be essentially equivalent to the average discharge voltage, and was considered to be the representative voltage of the cell.

NEGATIVE ELECTRODES

Perforated Sheet Zinc

A metal cylinder of diameter D and length t is obtained when a circular hole of diameter D is punched in a sheet of thickness t. The surface area of the sheet will be changed by an amount equal to the total area of the cylinder minus two times the area of the ends of the cylinder. The area after punching equals the original area plus πDt minus $1/2\, \pi D^2$. If $t = nD$, then the increase in area equals $\pi nD^2 - 1/2 \pi D^2 = \pi D^2 (n - 1/2)$ and will always be positive whenever n, the ratio of the sheet thickness to the hole diameter, is more than one-half.

If a large number of holes of sufficiently small diameter are punched in a sheet of zinc, there will be an appreciable increase in the total surface area. Such a perforated sheet should give an increased cell capacity when used as an electrode, as long as the diameter of the holes is not small enough to limit diffusion and cause excessive polarization inside the hole. As the negative electrode dissolves during discharge, the total surface area decreases. If comparatively thick negatives are used, this decrease will be small. In actual cell construction, the thinnest possible electrodes would be used, in which case, the decrease in surface area during discharge would be large enough to affect the capacity appreciably. If, however, the thickness of the perforated sheet is decreased, the initial surface area is also decreased. Whenever an attempt is made to minimize cell weight, these two factors probably will limit the cell capacity to such an extent that the results obtained using perforated sheet negatives will be little better than the results obtained with solid sheet negative electrodes.

Discharge Data - A considerable amount of unpublished data was available for cells using 10cc of electrolyte and four different types of perforated sheet electrodes. Information concerning these electrodes is given in Table I.

TABLE I

Approximate Mesh	Hole Diameter (inches)	No. of Holes per square inch	Thickness of Sheet (inches)	Increase in Area (%)	Area of Unit Cell Electrode (sq. in.)
35	0.020	952	0.020	30	5.54
24	.024	517	.020	15.6	4.92
18	.033	331	.020	6.0	4.51
6	3/32	33	.020	-13.15	3.70

The figure in the last column gives the approximate total surface area of the unit 1-1/2-inch square electrode after deducting for the area covered up by the cemented polystyrene spacers. These figures can be compared to a similar area of 4.26 square inches for an electrode made of solid sheet zinc. Obviously, the increase in area that can be obtained by this method is limited.

Unfortunately the data for cells using these electrodes was not taken under proper statistically controlled conditions and as a consequence there was considerable variation in the results obtained. Since the results are nearly the same both practically and theoretically for 18, 24, and 35 mesh electrodes, the data for these three were combined and the average results are plotted in Figure 2. The data for 6-mesh electrodes are plotted in Figure 3.

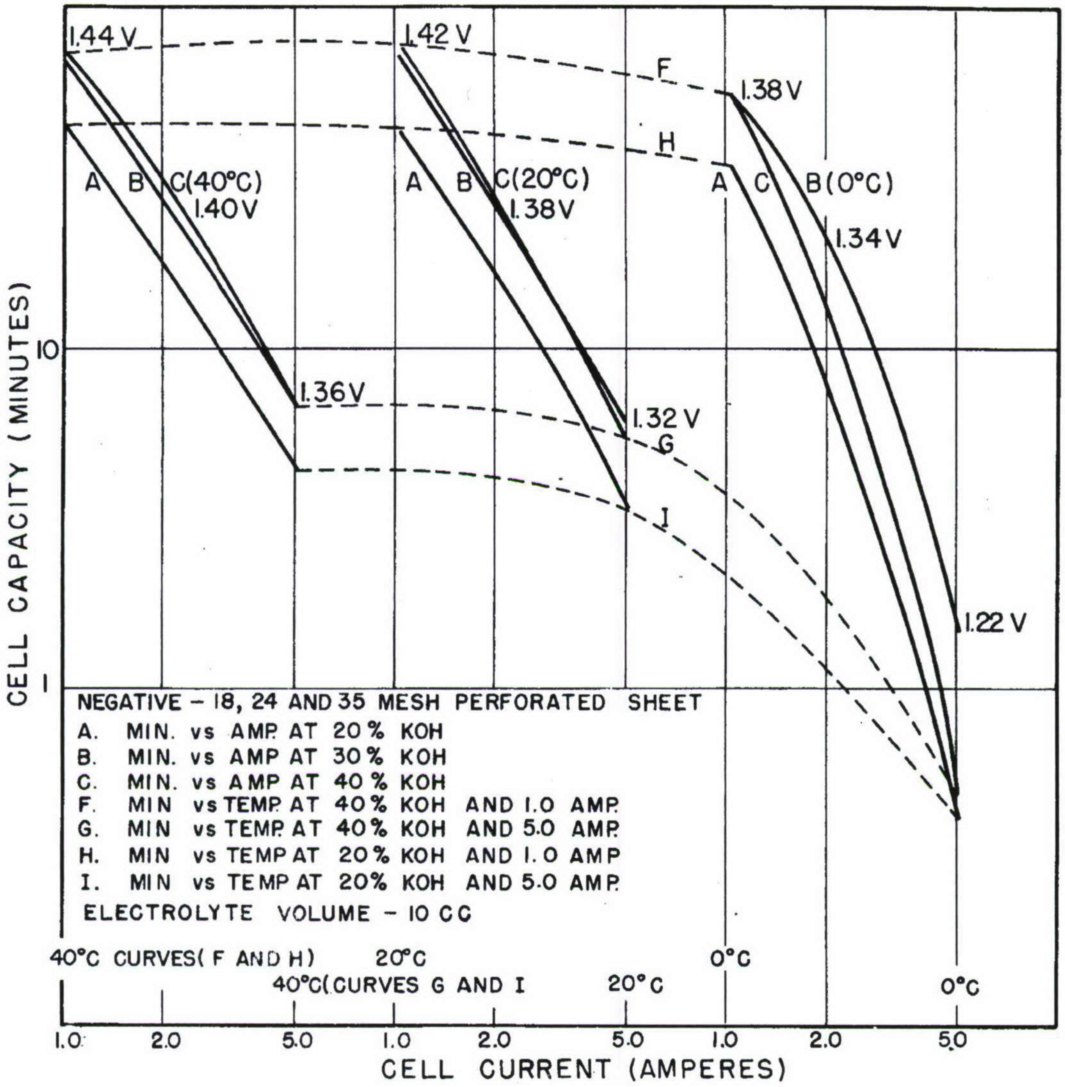

Figure 2 - Cell characteristics of perforated sheet negatives

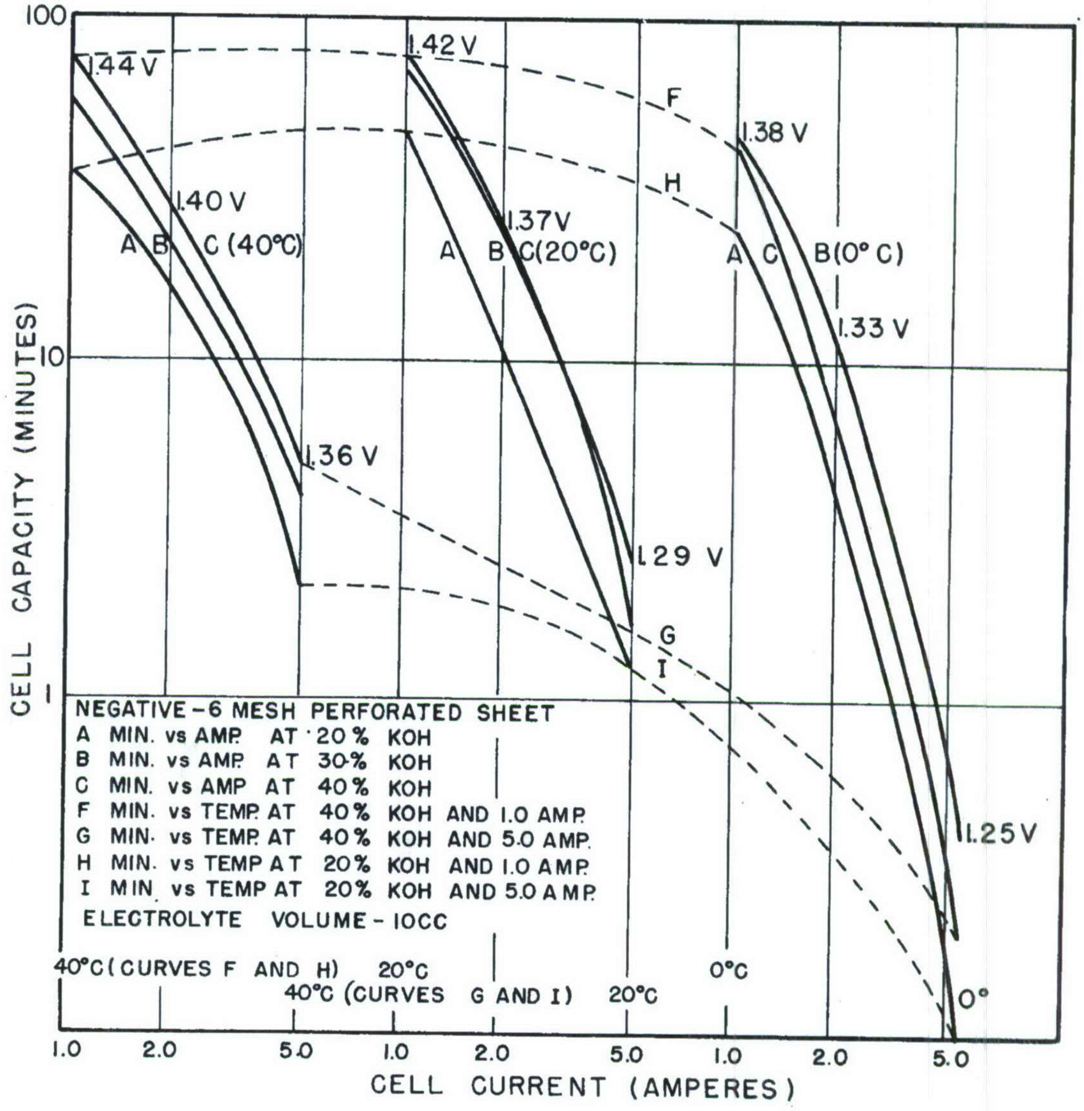

Figure 3 - Cell characteristics of perforated sheet negatives

Figures 2 and 3 are divided lengthwise into three major divisions, each labeled at the bottom from one through nine amperes. These figures for the unit cell current were used for convenience in plotting. If the current density in amperes per square inch is desired, it may be obtained by dividing the areas of the various electrodes into the unit cell current. The vertical scale is labeled from one minute to 100 minutes and is used for the entire chart.

The extreme left division shows relationships at 40°C and is so labeled at the right of the three curves. It contains almost straight curves of negative slope which show the variation of cell capacity in minutes with current at 40°C for three different concentrations of electrolyte, namely, A - 20 percent, B - 30 percent and C - 40 percent.

Moving to the right one division on the graph paper, three more curves are obtained which show the relationship for the same variables at 20° C. Similarly, the third division labeled 0° C shows the relationship for the same variables at 0° C. Since the 40°, 20°, and 0° C sets of curves are equally spaced, it is now possible to draw a new set of curves showing the effect of temperature on cell capacity.

If the points in the 40°, 20°, and 0° C divisions corresponding to one ampere and 20 percent potassium hydroxide are connected, the curve labeled "H" is obtained which shows the variation of cell capacity with temperature at one ampere current and 20 percent potassium hydroxide as electrolyte. Now, however, the bottom x-axis is no longer logarithmic and labeled in amperes but is linear and labeled in temperature. 40° C is at the extreme left as labeled, 20° C is at the point corresponding to 1 ampere on the left of the second division, and 0° C at the point corresponding to 1 ampere on the left of the third division. If each division is W inches wide and corresponds to 20° C and it were desired to obtain the cell capacity in minutes at 25° C for a 6-mesh electrode one would come $(40-25)/20 \times W$ or 0.75W inches from the extreme left in Figure 3. This reading on "H" is 47 minutes, the expected capacity in minutes of a unit cell at 25° C containing 20 percent potassium hydroxide and drawing one ampere of current. A similar curve "F" is drawn showing the variation of cell capacity in minutes with temperature at one ampere when the potassium hydroxide concentration was 40 percent.

The curve "G" is drawn by connecting points corresponding to 40 percent potassium hydroxide and five amperes at three temperatures 40° C, 20° C, and 0° C. Similarly "I" represents the curve for 20 percent potassium hydroxide and five amperes. With these two curves the temperature scale has now shifted so that 40° C is at the point corresponding to five amperes in the left division, 20° C is at the point corresponding to five amperes in the second division, and 0° C is at the point corresponding to five amperes in the third division. If several points were determined such as 30 percent potassium hydroxide and one ampere at 6° C, 30 percent potassium hydroxide and two amperes at 6° C, and 30 percent potassium hydroxide and five amperes at 6° C; a new curve could be drawn which would show variation of cell capacity in minutes with amperes at 30 percent potassium hydroxide and 6° C.

At intervals along each curve in Figures 2 and 3, is recorded the average voltage which can be obtained at that particular point. These values are easy to interpolate since they do not vary appreciably.

A typical discharge curve is shown in Figure 4. The voltage remains nearly constant over the major portion of the discharge.

A few measurements showing the effect of electrolyte volume on cell capacity have been plotted in Figure 5. They indicate that the cell capacity is directly proportional to the electrolyte volume. This relationship is also true for cells using solid sheet zinc negative electrodes.

Cell Capacities - If it is assumed that the same laws hold for perforated sheet that are true for solid sheet, then it is possible to calculate the theoretical capacity of a cell using perforated sheet electrodes from the data in Figure 1 and Table I. For example a 35-mesh electrode 1-1/2 inches square operating with 10cc of 30 percent (387 g/l) potassium hydroxide at two amperes and at 20° C and would have a current density of two amperes divided by 5.54 square inches, which is equivalent to 0.361 ampere per square inch. The 20° C curve in Figure 1 gives a value of K equal to 44.5 minutes for a current density of 0.361 amp/sq in. Ten cc of 30 percent (387 g/l) KOH contain 3.87 grams of potassium hydroxide. The grams of potassium hydroxide per square

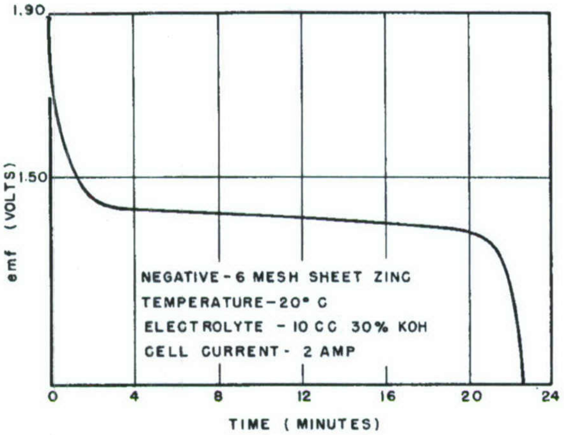

Figure 4 - Discharge curve for perforated sheet negative

inch of negative electrode area is 0.699 (3.87 ÷ 5.54). The capacity in minutes of this particular cell is 31.1 (0.699 x 44.5 minutes). This calculation was made on the assumption that the surface area remains constant throughout discharge. Actually, zinc dissolves during discharge, the size of the holes increases and the surface area decreases. If dissolution of the zinc is assumed to be even over the entire electrode including the inside of the holes, then the surface area at the end of the discharge can be calculated from the ampere minutes produced. Since the efficiency is high, an ampere minute is equivalent to approximately 0.0204 gram of zinc. The final current density at the end of the discharge will give the theoretical capacity in minutes from the curve in Figure 1.

A calculation of this type is moderately involved when done directly. However, it may be performed quite simply by an indirect graphical method. If the mesh, thickness, and hole diameter are given, the area and weight may be calculated readily. If the thickness is decreased by some given amount, a, and the hole diameter is increased by a, as would occur during the even dissolution of zinc from the electrode, the new surface area and

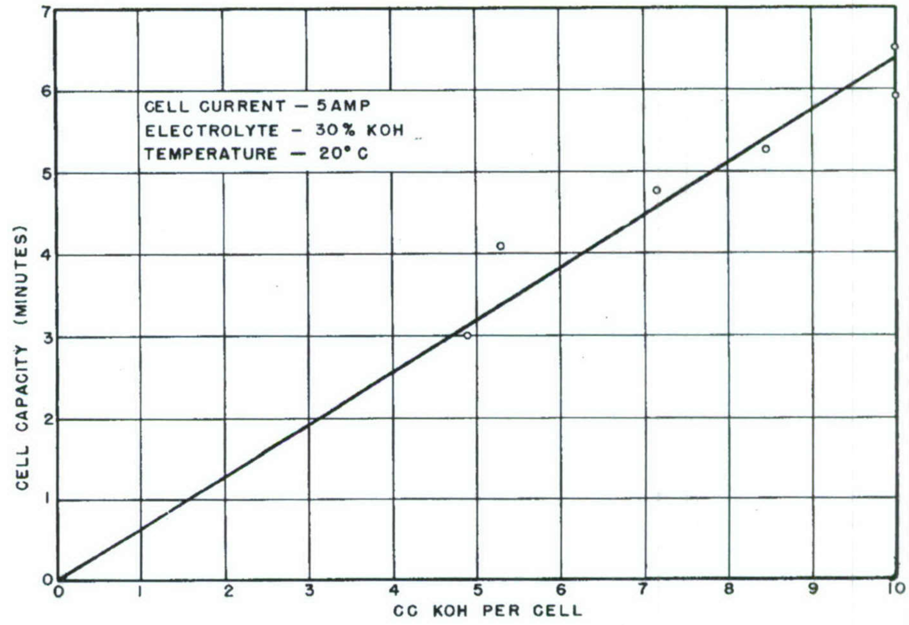

Figure 5 - Variation of cell capacity with electrolyte volume for 35-mesh perforated sheet negatives

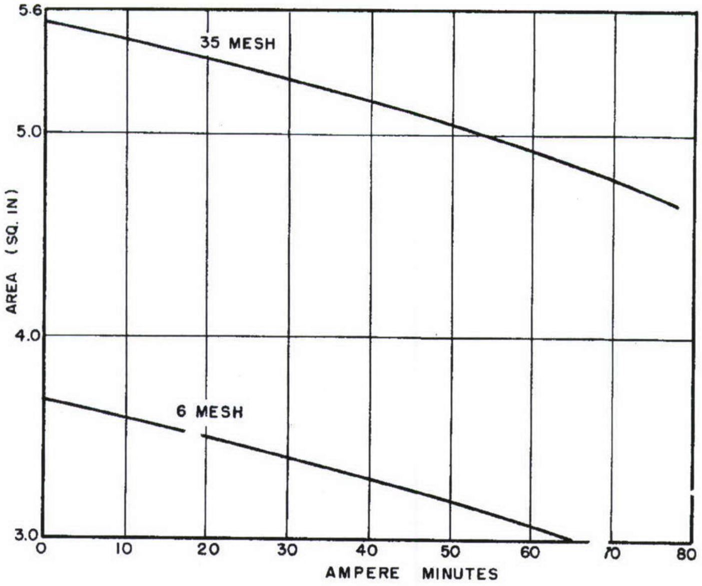

Figure 6 - Variation of electrode area with ampere minutes during discharge of perforated negative

weight may be calculated. The difference in the two weights can be converted to the equivalent ampere minutes. When this calculation is made for several values of a, a curve may be drawn which will show the variation of surface area with ampere minutes drawn from the electrode. Two such curves are shown in Figure 6.

If a calculation is made by this method, some value for the capacity must be assumed initially. For the preceding problem the calculated value of 31.1 minutes might be taken, which would give a value of 62.2 ampere minutes. Figure 6 shows that 62.2 ampere minutes corresponds to a final area of 4.90 square inches. By use of Figure 1, the capacity of this cell is now computed to be 29.6 minutes. If a more accurate result is desired, a new calculation can be made using 29.6 minutes instead of

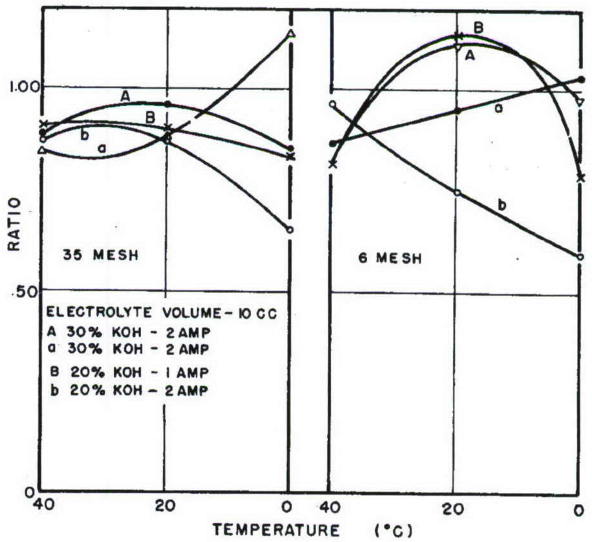

Figure 7 - Ratio of observed capacity to calculated capacity for perforated sheet negatives

31.1 minutes as the basic assumption. This second approximation can be neglected since it would not make any appreciable change in the previous value of 29.6 minutes. In this particular example, the difference between the two methods of calculating capacities is not very large. A much greater difference would be obtained with thinner electrodes.

A number of theoretical capacities were calculated in this manner from the data in Figures 1 and 6. The ratios of observed to calculated capacities are plotted in Figure 7. Although these results are only rough approximations, they do show that in most cases the differences between the actual and calculated results are small. As the volume of electrolyte is decreased these differences should become smaller. Since larger holes allow more effective diffusion of the electrolyte, a 6-mesh screen should give capacities closer to the calculated values than are obtainable with a 35-mesh screen. The results in Figure 7 tend to confirm this conclusion.

A study of Figures 2 and 3 shows that the variation in area of the various mesh electrodes has little effect on cell capacity at the lower current density and the higher temperature. As the current density increases and the temperature decreases, the effect of electrode area on cell capacity becomes much larger. The largest variation would be expected at a unit-cell current of 5 amperes. However, at temperatures other than 20° C, it was not possible to calculate the cell capacities for currents of this amplitude from the data in Figure 1.

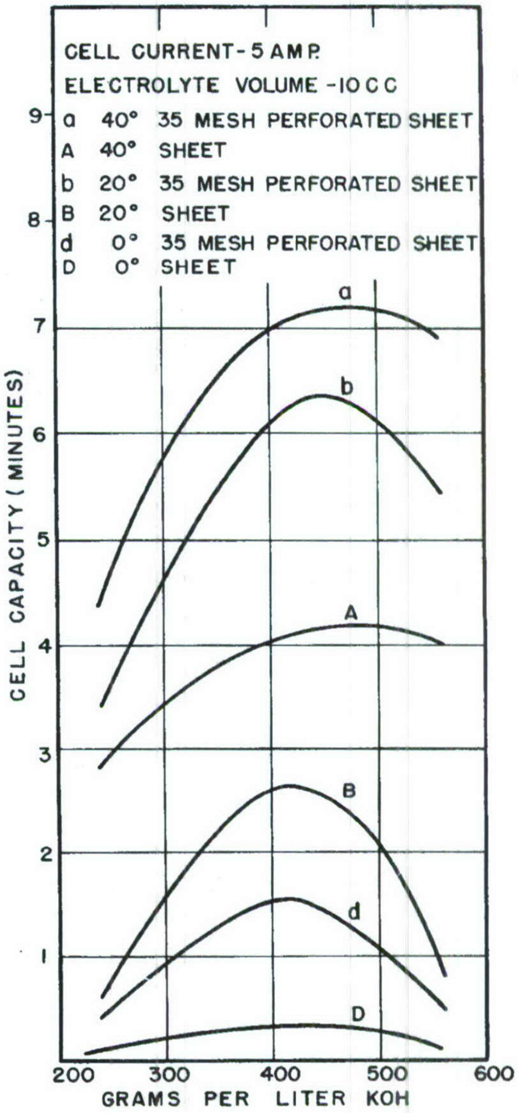

Figure 8 - Effect of surface area on cell capacity at high current densities

Cell capacities for currents of 5 amperes were taken from Figure 2 and plotted in Figure 8 along with capacities obtained with sheet electrodes (1). Although such results have a very high coefficient of variation and are subject to considerable error, they show clearly the high percentage increase in capacity obtained at high current densities from a small increase in electrode area, particularly at lower temperatures. The problems involved in designing a cell to operate at high current densities are in many respects similar to those involved in the design of a low temperature cell.

The data in Figure 1 were obtained from small test cells containing only one negative plate. A number of multiplate cells were constructed and discharged at high current densities. The results are itemized in Table II along with the predicted results as calculated from Figure 1. The difference between the calculated and the actual results are small for both cell capacity and emf. Apparently the data in Figure 1 is applicable over a wide range of working conditions.

TABLE II

Negative Electrode	No. of Negative Plates	Current Density (amp/sq in)	g. KOH (g/sq in.)	Predicted Capacity (Minutes)	Measured Capacity (Minutes)	Predicted EMF (volts)	Measured EMF (volts)
Solid Sheet	5	0.939	0.910	6.4	7.1	1.31	1.34
Solid Sheet	6	.783	.757	8.7	8.7	1.34	1.37
Solid Sheet	7	.671	.650	10.4	10.6	1.36	1.36
Solid Sheet	7	.671	.572	9.2	9.7	1.36	1.36
Solid Sheet	6	.783	.576	6.5	6.4	1.34	1.36
6 Mesh	7	.793	.769	8.5	7.5	1.33	1.30
6 Mesh	6	.944	.913	6.2	4.7	1.31	1.31
18 Mesh	7	.674	.652	10.2	10.7	1.36	1.37
18 Mesh	6	.790	.765	8.6	8.7	1.34	1.35
18 Mesh	5	.935	.905	6.3	8.6	1.31	1.35
35 Mesh	7	.547	.530	12.2	11.9	1.38	1.32
35 Mesh	5	.769	.744	8.8	9.4	1.33	1.32
35 Mesh	6	.642	.621	10.7	9.3	1.37	1.36

Parallel Zinc Strips

Twenty-nine strips, 1-1/2 inches long and 0.3 inch wide, were cut from zinc foil 0.002 inch thick. These strips were then built into an electrode, 0.3 inch deep and approximately 1-1/2 inches square. The strips were assembled, perpendicular to the faces of the electrode and parallel to each other. They were held in a solid outer framework which allowed a spacing of about 0.05 inch between strips. This electrode was then assembled between two positive electrodes, using a Saran screen separator. In this assembly each of the 0.002-inch-thick zinc strips was perpendicular to the positive electrodes and was surrounded by available electrolyte. The total surface area was 27.34 square inches.

Discharge Data - The cell was discharged at 20° C and at 13 amperes, using 18.0cc of 35% (470 g/l) potassium hydroxide as the electrolyte. The results of the discharge are illustrated in Figure 9. The capacity was satisfactory but the voltage dropped off rapidly in sharp contrast to the almost constant voltage obtained from a cell with sheet-zinc electrodes. Two major factors contribute to the decline in voltage during discharge, the increase in effective distance between the electrodes and the increase in electrolyte resistance. Both of these factors cause a large increase in the IR drop through the electrolyte.

As expected, the greatest dissolution of zinc was at the top of the electrode and the edges of the strips since they were the parts of the electrode having the highest current density. In any electro-chemical setup involving a current flow between two electrodes, the current density is always highest on the portions of the two electrodes that are closest to each other. In this particular case the highest current density was at the edge of the strips and resulted in the edges dissolving much more rapidly than the center. As the edges dissolve, the distance between the electrodes increases and causes a corresponding increase in the IR drop. At the same time the specific resistance of the electrolyte is increasing as a result of the increased zinc content. An approximate calculation showed that these two factors are sufficient to account for virtually all the voltage drop occurring during discharge.

Most of the large voltage drops obtained in various cell assemblies at high current densities can be decreased by packing the electrodes closely together. Such an assembly not only eliminates much of the IR loss in voltage but also makes possible the use of more electrodes which results in a desirable increase in electrode area.

Although in actual practice most cell discharges are made through a fairly constant resistance, the laboratory data on the zinc cell has been obtained by using a constant current discharge. As a rule the emf of the silver oxide-zinc alkaline cell is nearly constant and the constant-current discharge curve is almost equivalent to the constant resistance discharge curve. The discharge illustrated in Figure 9 shows a large drop in voltage. If it had been made at constant resistance with the same starting current, the voltage would not have dropped so rapidly, and the current would have declined in direct proportion to the voltage. Since the final current would have been smaller, the cell would have taken longer to complete its discharge.

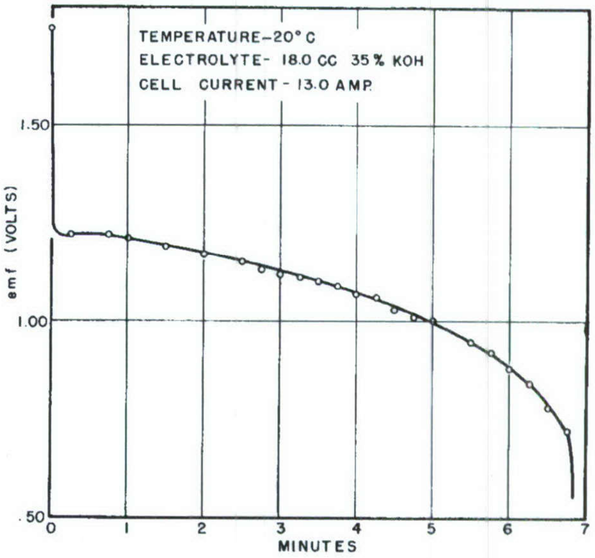

Figure 9 - Discharge curve for parallel strip negative

Cell Capacities - The current density in this cell was 13.0/27.34 = 0.475 ampere per square inch, which corresponds to a value of K in Figure 1 equal to 29 minutes. The grams of KOH per square inch were equal to 0.3095 (18 x 0.4704 ÷ 27.34.) 29 minutes (K) x 0.3095 equals 9 minutes, the calculated capacity of the cell. This value is slightly higher than the measured capacity of 6.85 minutes, probably because of the increase in current density caused by the reduction in surface area as the zinc dissolved during discharge. A final electrode area of 19.5 square inches would give a calculated capacity of 6.9 minutes. Visual inspection of the electrode indicated that the surface area was greatly reduced and would have a value fairly close to 19.5 square inches. Cell capacities of this type of electrode can be determined from the data in Figure 1 by using the final electrode area at the end of the discharge as a basis for calculating the current density.

Zinc-Plated Screen

A consideration of the factors involved, indicates that an electrode consisting of wire screen coated with a deposit of electroplated zinc should give a larger cell capacity than an electrode of sheet zinc, particularly at low temperatures and high current densities. The physical dimensions of an evenly electroplated wire screen may be defined by two factors such as wire diameter and total surface area. These two will define any others such as mesh or size of holes. Any attempt to evaluate the effect of these on cell capacity will be complicated by the fact that the wire diameter

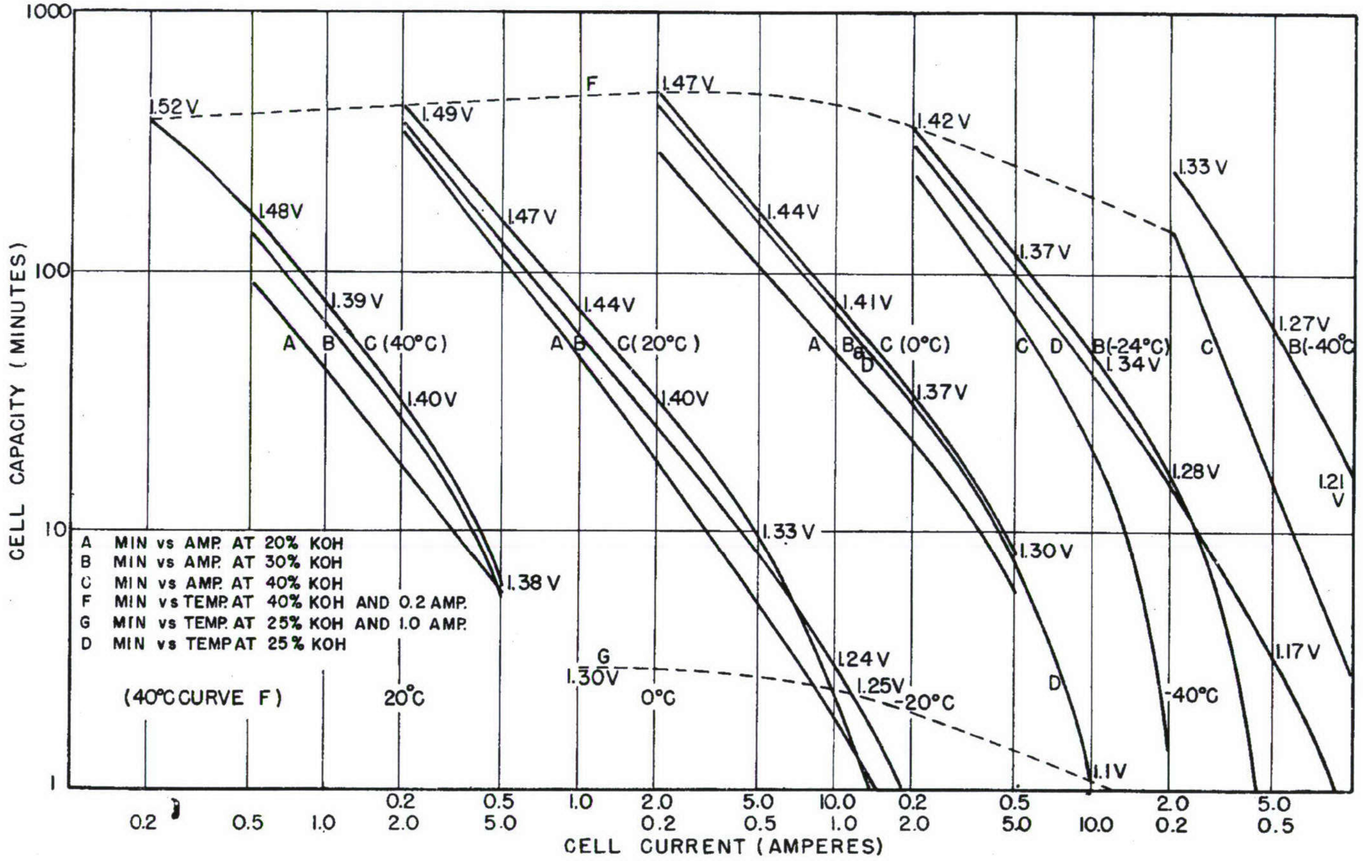

Figure 10 - Cell characteristics of zinc-plated screen negatives

and area decrease during discharge as the zinc dissolves and goes into solution. This is complicated further by the fact that it is fairly difficult to electroplate a metal evenly on a surface.

Other factors in an electroplated deposit that may affect cell capacity are: physical structure of the deposit, purity of the zinc, and physical condition of the surface. These factors are controlled by the electroplating conditions and the composition of the electroplating solution. At least a dozen variables which affect the zinc deposit are present in the composition and operation of a zinc-plating solution. These have never been thoroughly explained or evaluated. Sufficient data is available, however, to make an empirical control relatively simple.

Discharge Data - Some unpublished information, available for cells using 10 cc of electrolyte and electroplated zinc on copper screen negatives, is plotted in Figure 10. For convenience, the values for the unit cell current are given in amperes. Unfortunately, this data was not taken under statistical control and can be interpreted only qualitatively.

Initial Surface Area - The length of straight wire required to make a one-inch-square wire screen equals 2 FM, where M is the mesh and F is the ratio of the length of wire when straight to the over-all length it occupies when in the screen. Figure 11 represents a cross section of wire screen. The two circles represent wires perpendicular to the plane of the drawing and are crossed by a section of wire, ABCE. F equals the ratio of the length of ABCE, which is approximately OO, to the distance AC.

$AC = \frac{1}{M}$, where M is the mesh;

OO' is the hypotenuse of a right triangle having sides $O'Q$ and OQ.

But $OQ = AC = \frac{1}{M}$ and

$O'Q = D$, where D is the diameter of the wire

$$\therefore \overline{OO'}^2 = \overline{OQ}^2 + \overline{O'Q}^2$$

$$= \left(\frac{1}{M}\right)^2 + D^2$$

$$OO' = \sqrt{\frac{1 + M^2D^2}{M^2}}$$

$$F = \frac{OO'}{AC} = \sqrt{\frac{1 + M^2D^2}{M^2}} \div \frac{1}{M}$$

$$= \sqrt{1 + M^2D^2}$$

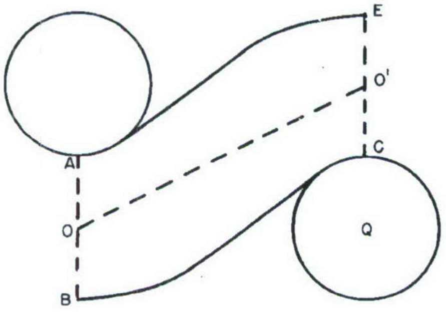

Figure 11 - Cross section of wire screen

The total surface area of the wire in a one-inch-square wire screen equals $2\pi FMD$ and the volume of metal equals $1/2\pi FMD^2$, where D is the diameter in inches.

Cell Capacities - Approximately 2.4 grams of zinc were electrodeposited on 1-1/2-inch square grids of 40-mesh, 0.0095-inch copper wire screen. The average wire diameter of these negative electrodes after plating was approximately

0.015 inch which corresponds to a surface area of about 9.1 square inches. As the zinc dissolves during discharge the surface area decreases and the current density increases. The final current density at the end of the discharge will give the theoretical cell capacity in minutes from the curves in Figure 1. The amount of zinc dissolved can be determined from the ampere minutes obtained in any particular discharge. This information can be used to calculate the approximate wire diameter, total area, and current density at the end of any particular discharge. By substituting this data in Figure 1, it is possible to calculate the capacity of a cell using a sheet-zinc negative electrode and having the same area that the electroplated zinc electrode has at the end of the discharge.

The ratio of the actual capacity to the calculated capacity was found to increase with increasing current density and decreasing temperature. At 20° C and 40°C the ratio was around 75 percent. At 0°C and -24° C the ratio exceeded 100 percent for high rates. This ratio which has been plotted in Figure 12 indicates that it is possible to calculate roughly the capacity of an electroplated zinc-screen negative. The values given on the graph are only a rough approximation and will vary with plating conditions. The low values for 20°C and 40° C are probably caused in part by the zinc completely dissolving off the wire screen in spots and thus causing an excessive reduction of available surface area. Such an occurrence could be caused either by uneven electrodeposition during formation or by uneven current density distribution over the face of the electrode during discharge. It has been shown that the current density at the top of an electrode may be several times that at the bottom.* Whether or not this is true for closely packed electrodes is not yet known.

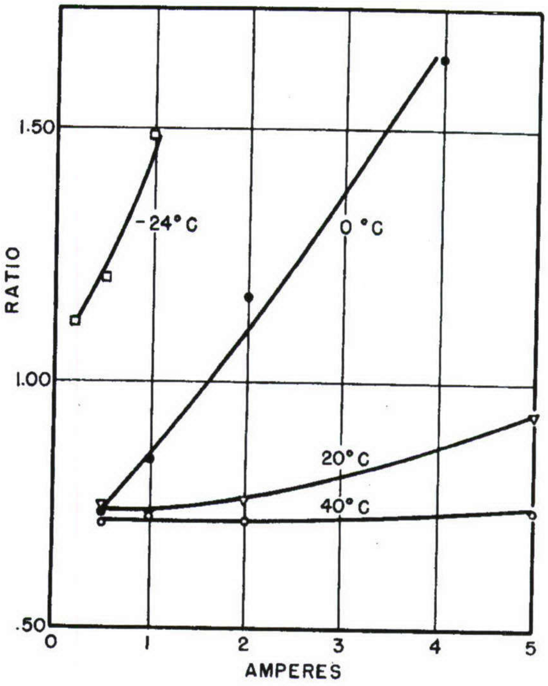

Figure 12 - Ratio of observed capacity to calculated capacity for electroplated negatives

Final Surface Area - If the capacity of a cell is known for a given current and quantity of electrolyte, then the negative electrode area may be calculated, assuming it to be equivalent in operation to a sheet-zinc electrode.

From Equation (1)

$$\underline{C} = WK/A \qquad (2)$$

where $\underline{C}$ is capacity in minutes, W is weight of 100% potassium hydroxide dissolved in the electrolyte, A is area of negative electrode at end of discharge, and K is the function of temperature and current density plotted in Figure 1.

$$\log \underline{C} = \log W + \log K - \log A \qquad (3)$$

---

* This problem will be discussed in a future NRL report.

Log K may be expressed as the function

$$\log K = a + b \log I + c(\log I)^2 \tag{4}$$

where I is the current density in amperes per square inch and a, b,and c are given in Table III. (1)

TABLE III

Temperature	a	b	c
60^0	1.0412	-1.5971	-0.2575
40^0	1.0016	-1.602	-0.210
20^0	0.9242	-1.707	-0.238
0^0	0.4194	-2.61	-0.615
-20^0	-1.5325	-4.959	-1.38

The value of K can be predicted accurately from the parameters in Table III for current densities between 0.470 and 0.0470 ampere per square inch at temperatures between 0^0 and 60^0C, and for temperatures below 0^0C, K can be predicted for current densities between 0.235 and 0.0235 ampere per square inch.

I = Q/A where Q is the discharge current for the cell. Substituting in Eq. (3) and using Eq. (4)

$$\log \underline{C} = \log W - \log A + a + b \log Q - b \log A + c(\log Q)^2 - 2c \log Q \log A + c(\log A)^2. \tag{5}$$

By rearranging terms

$$c(\log A)^2 - (1 + b + 2c \log Q) \log A = \log \underline{C} - a - \log W - b \log Q - c(\log Q)^2. \tag{6}$$

The latter equation is a quadratic in log A which may be readily solved.

Conclusions - When this calculation is applied to the data for electroplated zinc screen at 20^0C and 40^0C, low values of effective area are obtained. Such a reduction of effective electrode area could be caused by bare spots.

On the basis of the available information, calculations of this type can be used as a rough guide in predicting capacities of cells with zinc-plated wire screen negatives. It is highly probable that the physical dimensions of the plated screen are more important in predicting cell capacity than any other group of factors, which might be changed by variations in the operation and composition of the electroplating bath. There is also evidence that under certain conditions the most effective concentration of electrolyte may be somewhat higher than is given in Figure 1.

Zinc-Wire Screen

Cell characteristics were obtained on a number of cells using negative electrodes prepared from 28 x 35 mesh-wire screen. This screen was woven from zinc wire having a diameter of 0.013 inch. Approximately the same results should be obtained with woven-wire screen as were obtained with the electroplated screen because of the great similarity in the physical structure of the two electrodes.

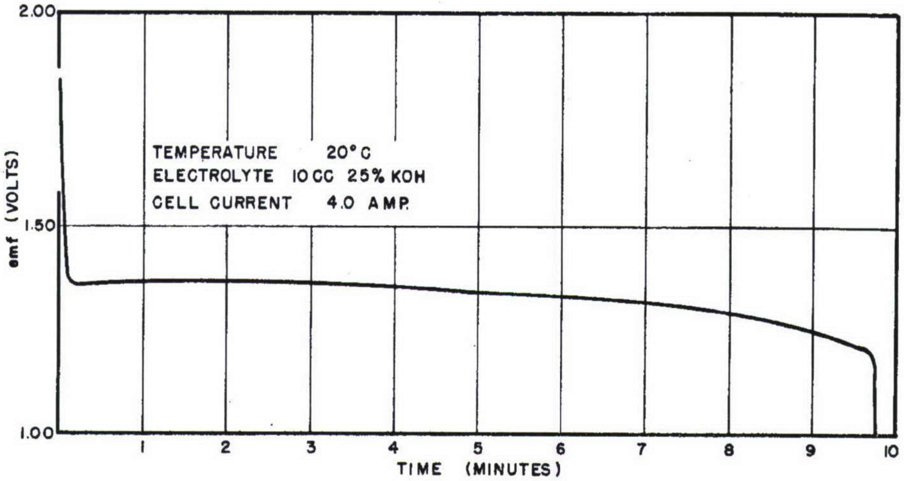

Figure 13 - Discharge curve for wire-screen negatives .

Discharge Data - A typical discharge curve, as shown in Figure 13, has a fairly constant voltage over the major portion of the discharge. The curve is similar to that obtained with electroplated-screen electrodes.

The variation of cell capacity with electrolyte volume for three sets of conditions is shown in Figure 14. There is a tendency for the curves to drop below the straight-line relationship as the electrolyte volume is increased. This tendency may be attributed to the increase in current density resulting from the decrease in area which occurs as the zinc dissolves during discharge.

The capacity of a cell can be calculated from the data in Figure 1 by the same method used with electroplated-screen negatives. The approximate wire diameter, total area, and current density at the end of any discharge are computed. By substituting this data in Figure 1, it is possible to calculate the capacity of a cell using a sheet-zinc negative electrode and having the same area that the electroplated-zinc electrode has at the end of the discharge.

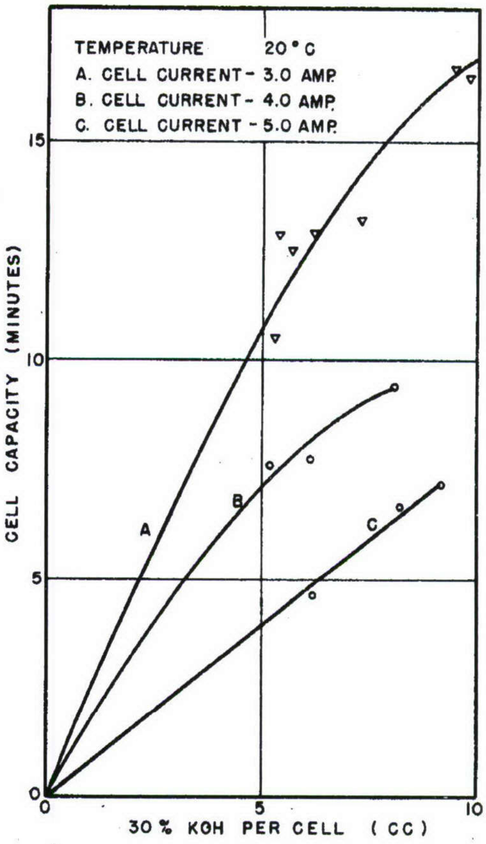

Figure 14 - Variation of cell capacity with electrolyte volume for wire-screen negatives

A large number of cells using wire-screen electrodes were discharged over a wide range of conditions. Current density was varied from 0.5 to 1.0 amperes per square inch; temperature, from -20°C to 20°C; electrolyte volume per unit cell, from 5 to 10 cc; and electrolyte concentration, from 25% KOH to 35% KOH. The measured capacities averaged 25% higher than the calculated values. This ratio was fairly constant over the above range of conditions and was considerably higher in most cases than the ratio of measured to calculated capacities for electroplated-screen electrodes. The higher results obtained by the wire screen can best be explained by the physical differences between the two electrodes. The wire screen had small wires, widely spaced; as a result, the large interstices allowed considerable electrolyte to be available to each portion of the surface area. The electroplated screen had large wires, closely spaced. The small interstices contained very little electrolyte and thus probably tended to limit capacity.

In addition to the current density effects it is highly probable that the physical dimensions of the two types of screens can affect cell capacity in other ways. However, it is still possible to calculate the approximate capacity of a cell with wire-screen or electroplated-screen negatives from the data in Figure 1.

Rectangular Zinc Fiber

An especially prepared experimental sample of rectangular zinc fiber was obtained from the Custom Scientific Company. This fiber was matted together in pieces roughly 2 to 3 inches long, 0.001 inch thick and about 0.022 inch wide. The pieces which were corrugated and somewhat similar in appearance to fine lathe turnings had been cut in long lengths from sheet zinc by means of a special machine. The fiber tended to break up into short pieces during cutting and handling. The result was a fairly continuous mat having a very large surface area and a high degree of porosity. Five grams of the zinc fiber was pressed lightly and as even as possible on both sides of a 1-1/2-inches square silver-screen grid. This negative plate was then placed in a close fitted bag made from 32-mesh Saran screen and assembled between two positive plates in a tight fitting cell case.

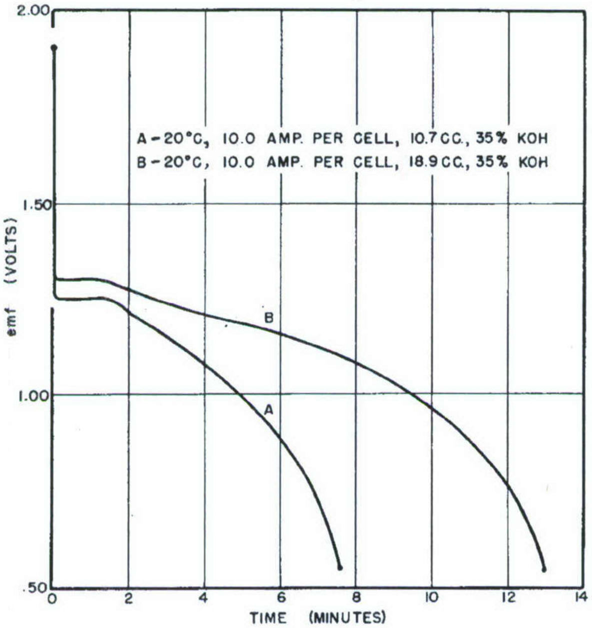

Figure 15 - Typical discharge curves using rectangular zinc-fiber negatives

<u>Discharge Data</u> - Typical discharge curves from two such cells are shown in Figure 15. The sharp decline in voltage during discharge may be explained on the basis of IR drop since both the effective distance between plates and the resistance of the electrolyte increase during the discharge. The high IR drop would be greatly reduced if it were possible to produce a satisfactory reproducible plate which was fairly thin.

More highly compressed plates which required less electrolyte were tested. The effect of electrolyte volume on cell capacity is shown in Figure 16. Since it is difficult to pick a satisfactory end point on such a

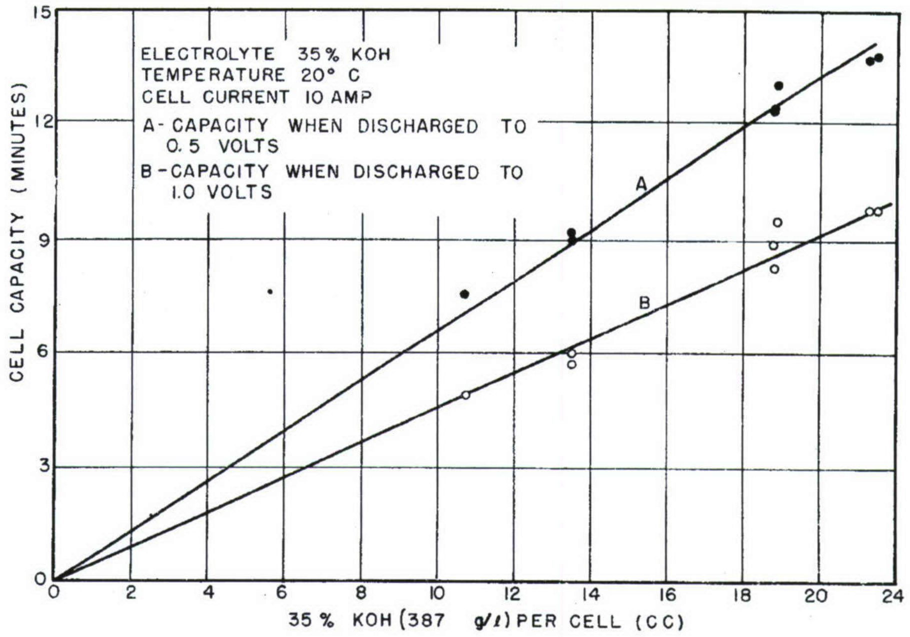

Figure 16 - Variation of cell capacity with electrolyte volume for rectangular zinc-fiber negatives

discharge, the capacity in minutes was measured at 1.0 volt and 0.5 volt. The results show that at both of these voltages the capacity is directly proportional to the electrolyte volume and can be presented graphically as a straight line running through the origin. This same result was obtained using sheet-zinc electrodes and is probably characteristic to a certain extent of most types of zinc electrodes used in the silver cell.

The effect of electrolyte concentration on cell capacity is shown in Figure 17. Maximum capacity is obtained at a concentration of about 35% (470 g/l) potassium hydroxide. Considerably more data is needed for an accurate evaluation of this particular relationship.

The effect of discharge current on the capacity is shown in Figure 18. The relationship is similar to that obtained with other types of zinc electrodes. The ratio of the capacity at 1.0 volt to the capacity at 0.5 volt decreases as the cell current increases. This fact may be explained on the basis of a high IR drop. As the current decreases this IR drop should decrease and

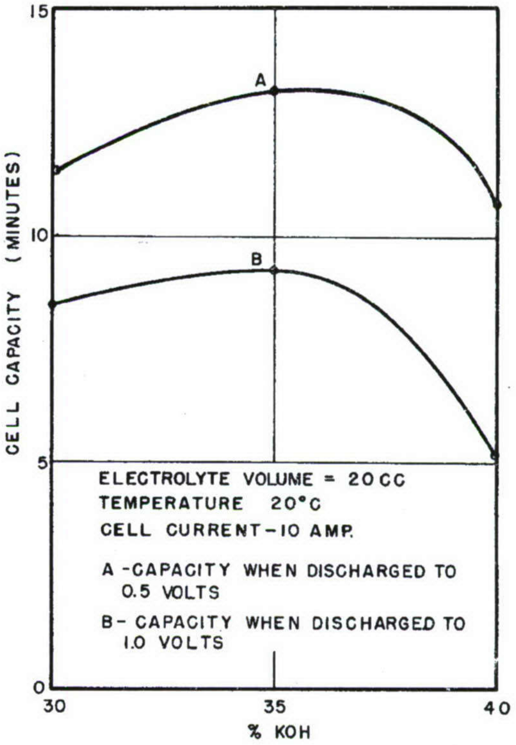

Figure 17 - Variation in cell capacity with electrolyte concentration for rectangular zinc-fiber negative

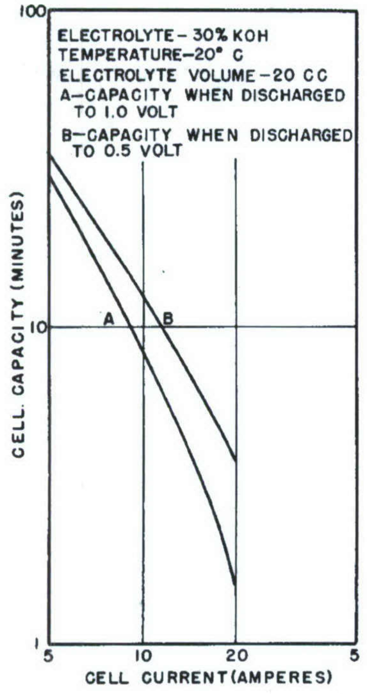

Figure 18 - Variation in cell capacity with current density for rectangular zinc-fiber negatives

the two curves should approach each other as is indicated in Figure 18.

The rectangular zinc-fiber electrode showed excellent possibilities at low temperatures. A cell using 17 cc of 30% (387 g/l) potassium hydroxide at -40°C and 1.0 ampere lasted for 65 minutes. Another cell using 18 cc of 30% potassium hydroxide at -48°C and 0.2 ampere lasted 145 minutes at an average voltage of 1.20. After standing one-half hour, 11.7 minutes more capacity was obtained from the second cell. After standing ten more minutes the cell was discharged at 0.1 ampere for a total of 147 minutes more at an average voltage of 1.24. The difficulty which was encountered in starting this discharge seems to occur frequently in the zinc cell at low temperatures. The cell is incapable of delivering its highest current for a very short time at the beginning of the discharge and must be started with a low current which is rapidly built up to the desired level.

Cell Capacities - Five grams of rectangular zinc fiber 0.001 inch thick has a surface area of about 85.4 square inches. The capacity of a cell using 20 cc of 35% (470 g/l) potassium hydroxide at 20°C and 10 amperes can be calculated from the data in Figure 1 and is found to be 22.4 minutes. The capacity as taken from the 0.5-volt curve in Figure 16 is 13.2 minutes, or about 60% of the calculated capacity. The ratio of observed capacity at 0.5 volt to calculated capacity was fairly constant for all cases and averaged slightly over sixty percent. The low values of observed capacity can be attributed to the fact that cell failure is caused by high internal resistance. Normally, cell failure is caused by failure of the negative electrode; with this type of electrode, however, the IR drop due to internal resistance is so large that the emf of the cell becomes very small long before the negative electrode fails. Since the calculated capacities are made on the basis of negative electrode failure, they will be higher than the observed results. When this factor is taken into account, a fairly close estimate can be made of the cell capacity for any particular design.

Pasted Zinc

Because of the increased surface area, the greatest possibility of improvement should lie in the pasted electrode wherein a mixture of fine zinc particles and a binding agent are pasted on the grid and dried. This type of electrode also presents many difficulties, such as shedding of the active material, and unsatisfactory binding materials. Considerable work was done on the pasted electrode by the Storage Battery Division of Thomas A. Edison, Inc. (7). They had successfully used ondulum a Glyco Products Company product as a binder. Since ondulum is no longer being manufactured,a search was made for other suitable products.

An electrode was pasted with a mixture of water and zinc (New Jersey Zinc Company, No. 1223). Upon adding the electrolyte, the zinc loosened and shed, shorting out the cell. The resultant chemical reaction was so violent that the powdered zinc caught on fire. It is obviously essential that a suitable binder be found which will prevent such occurrences.

Discharge Data - This zinc was tried with various amounts of sulfur and ammonium chloride as a binder. Five grams of the zinc powder were mixed with weighed amounts of sulfur and ammonium chloride and made into a paste with water. This mixture was spread on the grid with a spatula, pressed as smoothly as possible, and allowed to dry. The sulfur and ammonium chloride acted as a binder, probably by the formation of zinc sulfide. The grid consisted of 40 x 40 mesh copper screen one and one-half inch square, zinc-plated for one hour to cover the copper. Plates prepared by this method had varying degrees of hardness and gave varying cell capacities on discharge. Discharge was made at 5.0 amperes per cell using approximately 13 cc of 30% potassium hydroxide solution as electrolyte. The results are shown in Figure 19, where the weight of sulfur is plotted against the weight of ammonium chloride mixed with five grams of zinc. At the point corresponding to the given composition, the cell capacity in minutes was written in. Contour lines were then drawn through the various compositions which would give the same cell capacity. The region of maximum cell capacity is easily outlined by this method. A typical discharge curve is shown in Figure 20. A nearly constant emf is maintained over the major portion of the discharge.

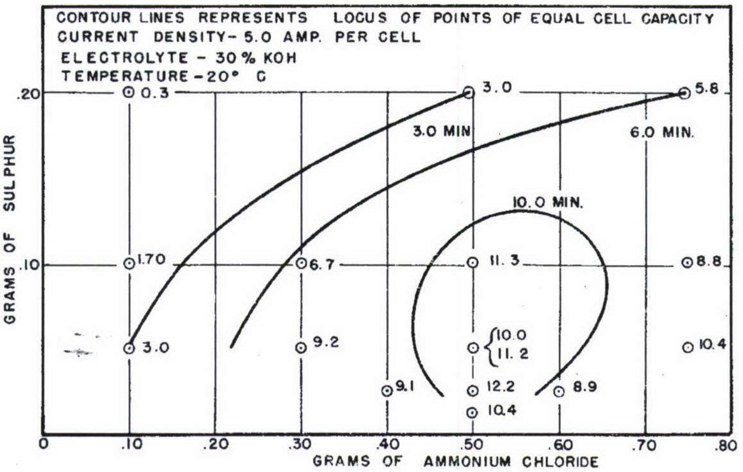

Figure 19 - Cell capacity for pasted zinc negative

Cell capacities as high as 12 minutes were obtained which is more than that obtained using an electroplated-zinc negative with 30% potassium hydroxide as an electrolyte.

These results show good possibilities, but much work remains to be done. Ammonia is liberated by action of the potassium hydroxide on the

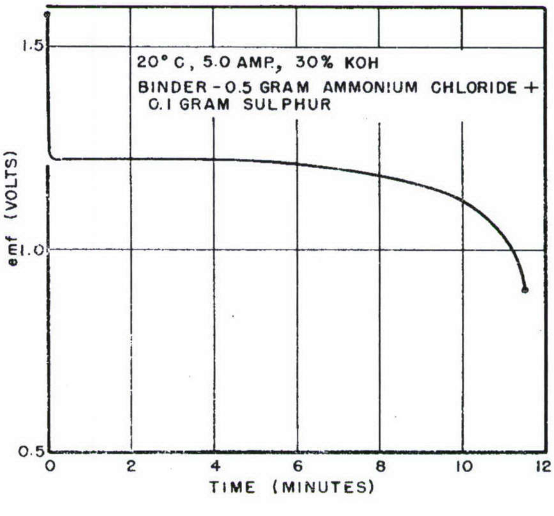

Figure 20 - Discharge curve for pasted negative

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TABLE IV

Cell Type	Calculated Capacity (minutes)	Observed Capacity (minutes)	Calculated EMF (volts)	Observed EMF (volts)
A	29.2	23.7	1.43	1.48
	6.9	5.7	1.34	1.44
	9.7	9.2	1.35	1.45
	43.0	32.7	1.44	1.49
	9.8	9.7	1.35	1.47
B	21.8	25.5	1.46	1.46
	54.5	57.2	1.49	1.39
	25.8	24.1	1.46	1.47
	8.4	10.7	1.42	1.45
	25.8	26.5	1.46	1.47
C	18.9	22.8	1.46	1.44
	7.2	9.3	1.43	1.45
	4.1	5.3	1.40	1.43
	1.7	3.4	1.32	1.37
	39.0	28.5	1.48	1.46
	34.8	30.6	1.49	1.49
	45.0	34.0	1.49	1.47
	40.1	30.6	1.49	1.49
	15.9	14.5	1.45	1.46
	4.1	4.5	1.38	1.41
	5.1	5.7	1.38	1.41
	6.2	6.7	1.38	1.40
D	71.0	68.5	1.49	1.50
E	10.4	13.2	1.43	1.47
	8.7	11.2	1.42	1.46
F	6.2	8.0		

The theoretical capacity of a cell employing a special negative electrode of known surface area can be calculated from the available information on cells using zinc-sheet negative electrodes. The computed and the measured results show a moderate degree of agreement. Therefore, it is possible in many cases to predict the approximate characteristics of a cell using a new type of negative electrode.

RECOMMENDATIONS

On the basis of the information that is needed, and of that which is available, it is recommended that the following types of negative electrodes be given further study and consideration:

(a) Electroformed zinc
(b) Electroplated-wire screen
(c) Zinc-wire screen
(d) Rectangular zinc-fiber.

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ammonium chloride and it is known to decrease cell capacity. Effects must be studied of varying the volume of the electrolyte, the size of the zinc particles, the concentration of potassium hydroxide, and the current density. There was some shedding under the best conditions. Probably there are much better materials which can be used as binders.

Other Types of Negative Electrodes

Because of the increased area, a sprayed zinc electrode should prove more effective. However, little difference was noted in several trials, when the results were compared to those obtained with a cell using sheet-zinc negatives. The sprayed zinc is probably handicapped by the presence of zinc oxide formed during the spraying process.

A few experiments have been performed wherein porous zinc electrodes, having high surface areas and porosities, were formed by the electrolytic reduction of various zinc compounds which had been pasted on a grid. Sufficient success has been obtained with this type of negative electrode to warrant further investigation.

The previously recorded data has shown that wherever the negative electrode area can be measured or computed, it is possible to calculate the approximate capacity of the cell. Similar calculations were made on six cells manufactured or assembled by four different outside agencies. The results are shown in Table IV. Some of these cells were test assemblies, others were in actual production. All are multi-plate assemblies using various types of separators and varying concentrations of electrolyte. Either sheet-zinc, corrugated sheet-zinc, or electroplated wire screen were employed over a moderately wide range of operating conditions.

A somewhat higher correlation was obtained between the observed and the calculated results in Table IV than was obtained with the experimental results given earlier in this report. These results may be attributed to the experimental data having been taken over a much wider range of operating conditions.

CONCLUSIONS

The available data make it possible for a manufacturer to design a cell having certain characteristics.* It must be emphasized that such designs will be approximate and subject to variations. Injudicious use of separators can cause a tremendous decrease in cell capacity. The optimum concentration of electrolyte given in Figure 1 may not be the same for all types of construction. It is advisable to test any new cell with various concentrations of electrolyte and determine the optimum value. Other factors, too numerous to mention, may cause variations in the cell characteristics. It is not possible nor is it practical to evaluate all of the variables that might affect a primary cell. However, the major factors have been presented here in a form that can be used readily by the manufacturer as a guide in the design of a particular cell.

Since the capacity of a silver oxide-zinc-alkaline cell is a function of the available negative-electrode-surface area, it is dependent upon the physical structure of the electrode. Suitable means of increasing the surface area will result in an increased capacity and a more efficient cell. This is particularly true at high current densities and low temperatures. The surface area of such an electrode should be in contact with an adequate supply of electrolyte. The distance between electrodes should be small in order to keep the voltage drop during discharge from being too large.

---

* This problem will be discussed in a future NRL report.

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12 August 1941 NRL Report No. B-1767

NAVY DEPARTMENT

Report of Test

on

Horns, Types H-8 and H-9

Submitted by

Benjamin Electric Manufacturing Company,
Des Plaines, Illinois

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

Number of Pages:	Text - 4	Plates - 3
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Distribution:
BuShips (5)

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Photograph of sample H-9 horn, removed from case . . . . PLATE 3

AUTHORIZATION FOR TEST

1. This problem was authorized by reference (a), and other references pertinent to this problem are listed as references (b), (c), and (d).

Reference:
- (a) BuShips Ltr. S65-4 (355) of 18 July 1941.
- (b) Specification 17S11c of 1 May 1940.
- (c) Benjamin Electric Manufacturing Company's Plans 191505 and 191506.
- (d) NRL Report No. B-1651.

OBJECT OF TEST

2. The object of this test was to determine conformance of the sample horns with the specification, reference (b), and their suitability for Naval use.

ABSTRACT OF TEST

3. The sample horns were set up at this Laboratory in suitable test circuits where their performance was carefully observed for compliance with the specification. An inspection of the sample to determine compliance in the matter of materials, design, and workmanship, concluded the test.

CONCLUSIONS

(a) The subject horns failed to meet the requirements of the specification, reference (b), in the following respects:

Type H-8 - 115 V.D.C.

(1) Power consumption.
(2) Endurance - Failed after 20.75 hours due to an open circuit in the armature.

Type H-9 - 115 V.A.C.

(3) Endurance - Failed after 27 hours due to an open circuit in the armature. When the horn was examined, two of the rivets (pc. 48) securing the anvil (pc. 46) to spring strip (pc. 45) had fallen out.

(b) It will be noted that the acoustical characteristics of the sample horns differ greatly with those of the samples reported by reference (d). The total sound energy is less and the frequencies of the principal components are higher. The notes produced were of a scratchy variety.

RECOMMENDATIONS

(a) It is recommended that the subject horns be not approved for Naval use.

(b) It is further recommended that the manufacturer be invited to experiment with a formed type of diaphragm with the anvil riveted to the diaphragm. It is believed that this type of construction would result in fewer diaphragm failures and the production of a note of higher quality.

DESCRIPTION OF MATERIAL UNDER TEST

4. The sample horns, manufactured by Benjamin Electric Manufacturing Company, were submitted as Navy types H-8 (115 v.d.c.) and H-9 (115 v.a.c.) motor-operated horns. They are identical in design, except for the windings of the motors.

5. The motor is housed in a cast bronze case, having three (3) mounting lugs and a connection box cast integral with the case. The connection box is tapped for two (2) 3/4-inch (IPS) terminal tubes.

6. A terminal block of phenolic material is located in the connection box and is accessible by removing a cast bronze cover. An engraved nameplate of nickel-copper alloy is secured to the outside of the connection box by two (2) zinc plated steel drive screws.

7. The motor is equipped with sleeve bearings, each of which is lubricated by a wick type oiler which is accessible by removing the connection box cover.

8. These horns differ from those reported by reference (d), in that the anvil is not mounted on the diaphragm. The anvil is riveted to a laminated strip of spring steel, the ends of which are clamped between two rubber gaskets located between a steel ring and the case flange. A hammer button, secured to the opposite side of the strip with the same rivets, strikes the diaphragm when the anvil is struck by the ratchet on the armature.

9. The spring steel diaphragm, protected by glyptal paint over zinc chromate paint, is assembled between flat rubber gaskets and is clamped between the case and projector by eight (8) fillister-headed brass machine screws threaded into the case.

10. A hexagon head brass adjusting screw, having a steel insert in its end, is threaded into the bottom of the case and may be secured by a brass locknut. The insert presses against a steel ball, recessed in the end of the armature shaft and, when properly adjusted, the shaft is forced forward, causing the ratchet to engage the anvil. Forward movement of the armature shaft is resisted by a flat bronze spring, mounted inside the motor endbell, and pressing a bronze washer located against a shoulder on the armature shaft.

11. Further details are shown by photographs, Plates 2 and 3, and drawings, reference (c).

METHOD OF TEST

12. Following tests to determine their electrical and acoustical characteristics, at rated voltage and frequency, the sample horns were subjected to tests for inclination, endurance, and temperature rise.

13. Due to the failure of the sample horns under the endurance test, no further tests were conducted.

RESULTS OF TEST

14. The test results obtained were as follows:

Requirements	Test Values	
	Type H-8 (Serial No. 4998)	Type H-9 (Serial No. 4997)
Voltage: 115 volts	115 volts	115 volts
Current: Type H-8 direct; H-9 a.c. 60 cycles.	Direct	Alternating
Amperes: Not specified.	0.67 ampere	0.72 ampere
Watts: Shall not exceed 75 watts	* 77.05 watts	61.5 watts
Sound pressure output: Shall be not less than 90 decibles at 18 feet in a soundproof room.	Total noise 98 db	Total noise 96 db
Pitch of note: 100-600 CPS	Complied	Complied
Inclination: Shall operate in any position when supplied with rated voltage and frequency ± 10 per cent.	Complied	Complied
Endurance test: Shall operate 1500 cycles of "one minute on" and "one minute off," the first 750 cycles at 60° C. and the second at 0° C. ambient temperatures.	*Unsatisfactory (See Conclusions)	*Unsatisfactory (See Conclusions)
Temperature rise: Maximum temperature shall not exceed 115° C. during the endurance test. (55° C. rise at 60° C. ambient temperature.)	Complied 52.1° C. above 60° C. ambient	Complied 32.6° C. above 60° C. ambient
Agreement with test plans: Blueprint plans of sufficient detail to show all essential components of the equipment to be tested shall be furnished, and shall check with the equipment.	Complied except for electrical data.	Complied except for electrical data.

*Denotes failure to comply with the specification.

Note: Due to the early failure of these samples, no further tests could be conducted.

CONCLUSIONS

15. The subject horns failed to meet the requirements of the specification, reference (b), in the following respects:

Type H-8 - 115 V.D.C.

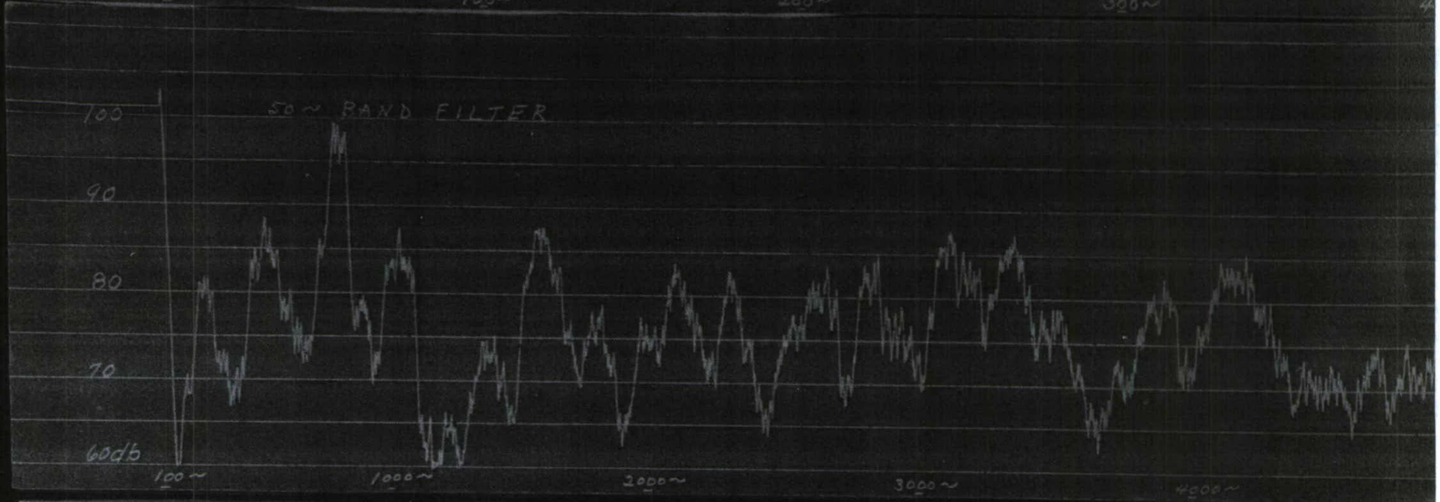
(1) Power consumption.
(2) Endurance - Failed after 20.75 hours due to an open circuit in the armature.

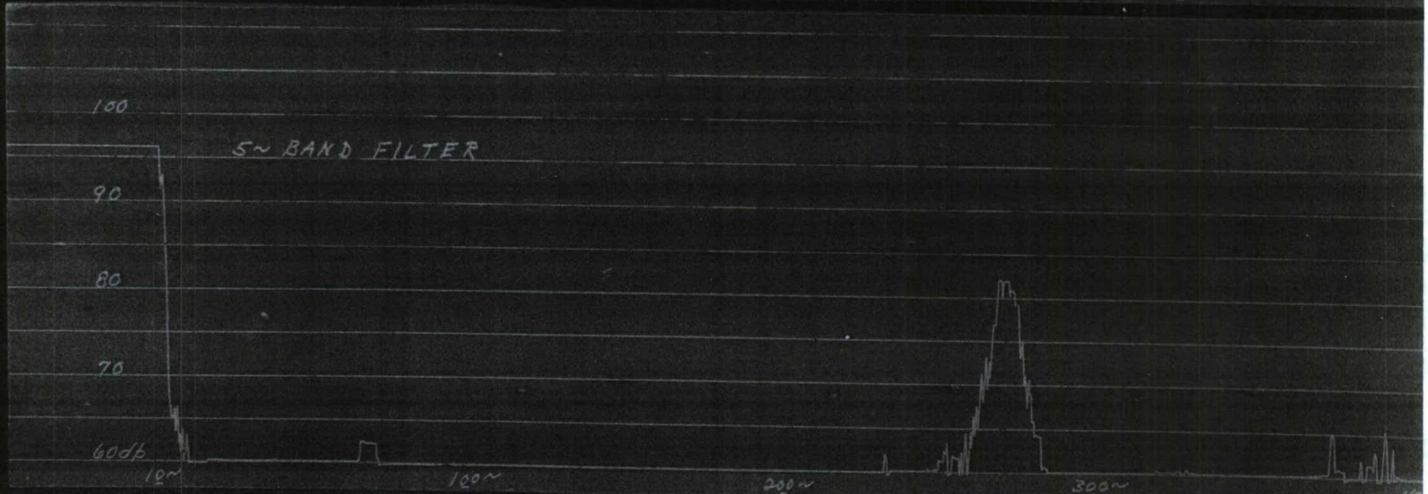
Type H-9 - 115 V.A.C.

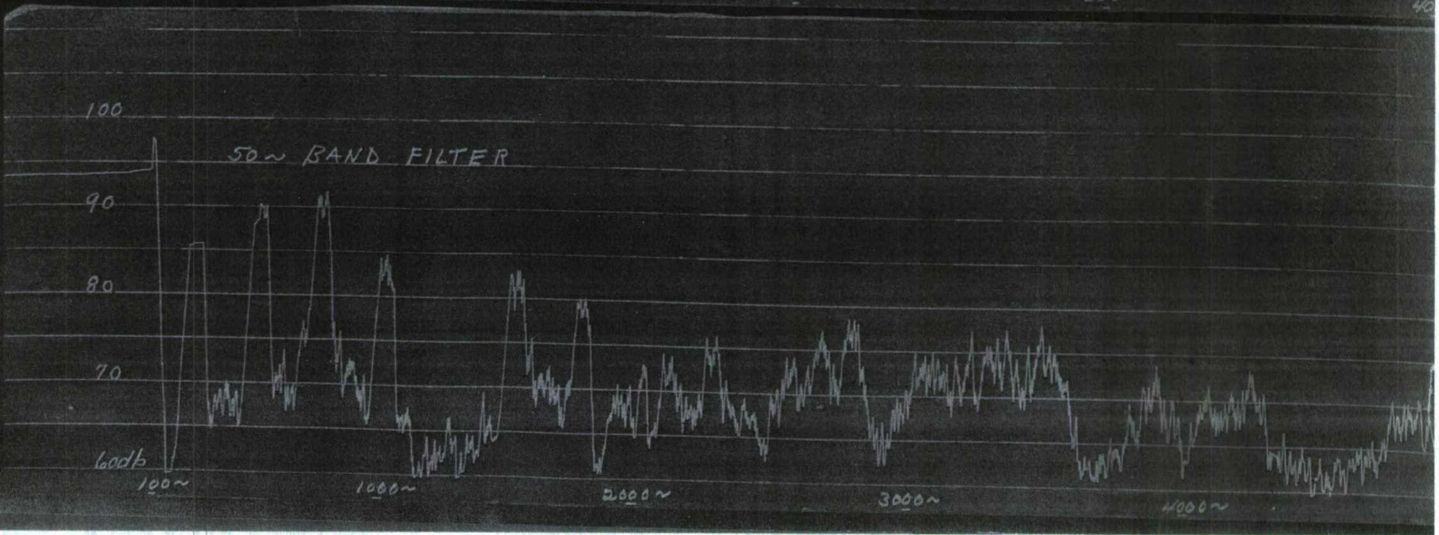
(3) Endurance - Failed after 27 hours due to an open circuit in the armature. When the horn was examined, two of the rivets (pc. 48) securing the anvil (pc. 46) to spring strip (pc. 45) had fallen out.

16. It will be noted that the acoustical characteristics of the sample horns differ greatly with those of the samples reported by reference (d). The total sound energy is less and the frequencies of the principal components are higher. The notes produced were of a scratchy variety.


5~ BAND FILTER
100
90
80
70
60db
10~
100~
200~
300~


50~ BAND FILTER
100
90
80
70
60db
100~
1000~
2000~
3000~
4000~

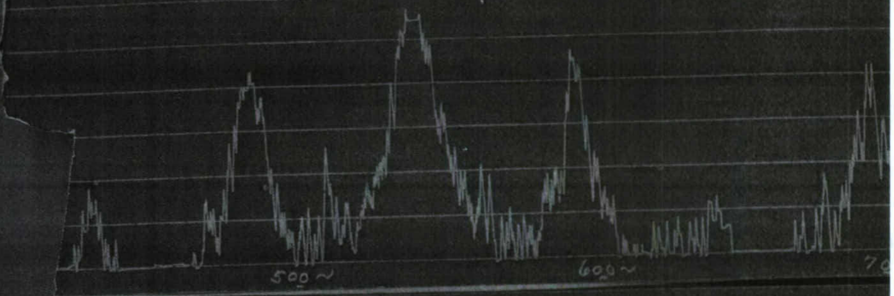

5~ BAND FILTER
100
90
80
70
60db
10~
100~
200~
300~


50~ BAND FILTER
100
90
80
70
60db
100~
1000~
2000~
3000~
4000~

BENJAMIN ELECTRIC MFG. CO

TYPE H-8 HORN

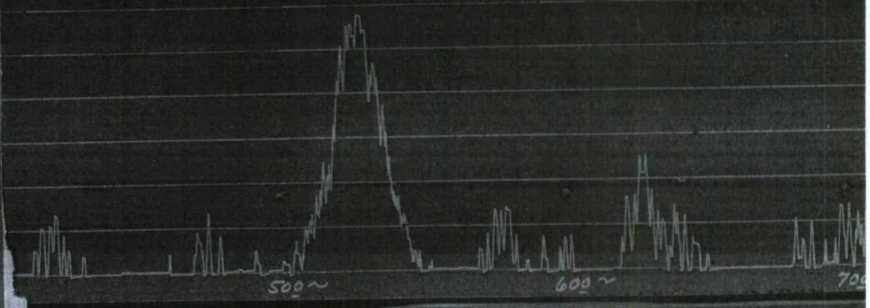
SERIAL NO 4998



SERIAL NO. 4998

TYPE H-9 HORN

SERIAL NO. 4997



SERIAL NO. 4997

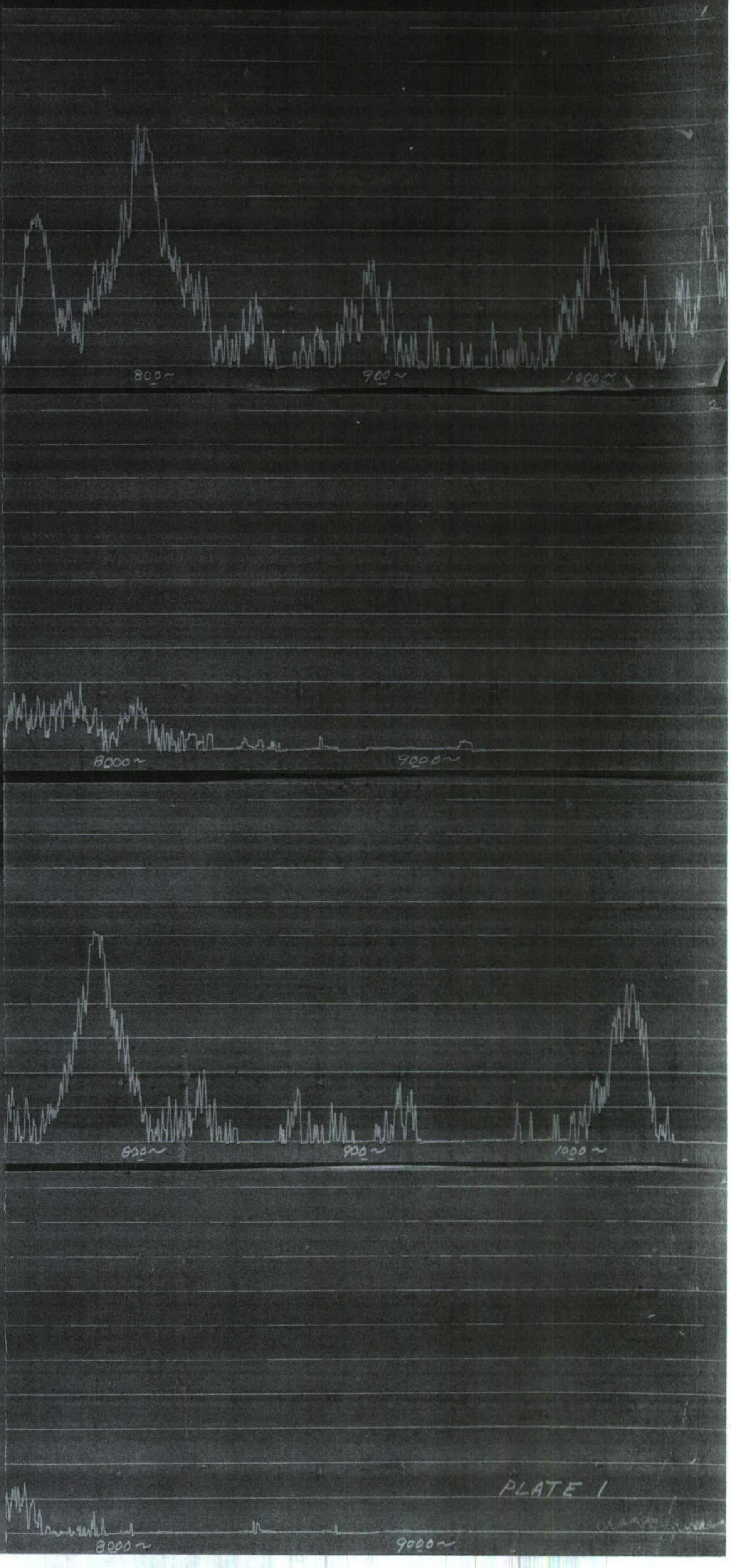


PLATE 1

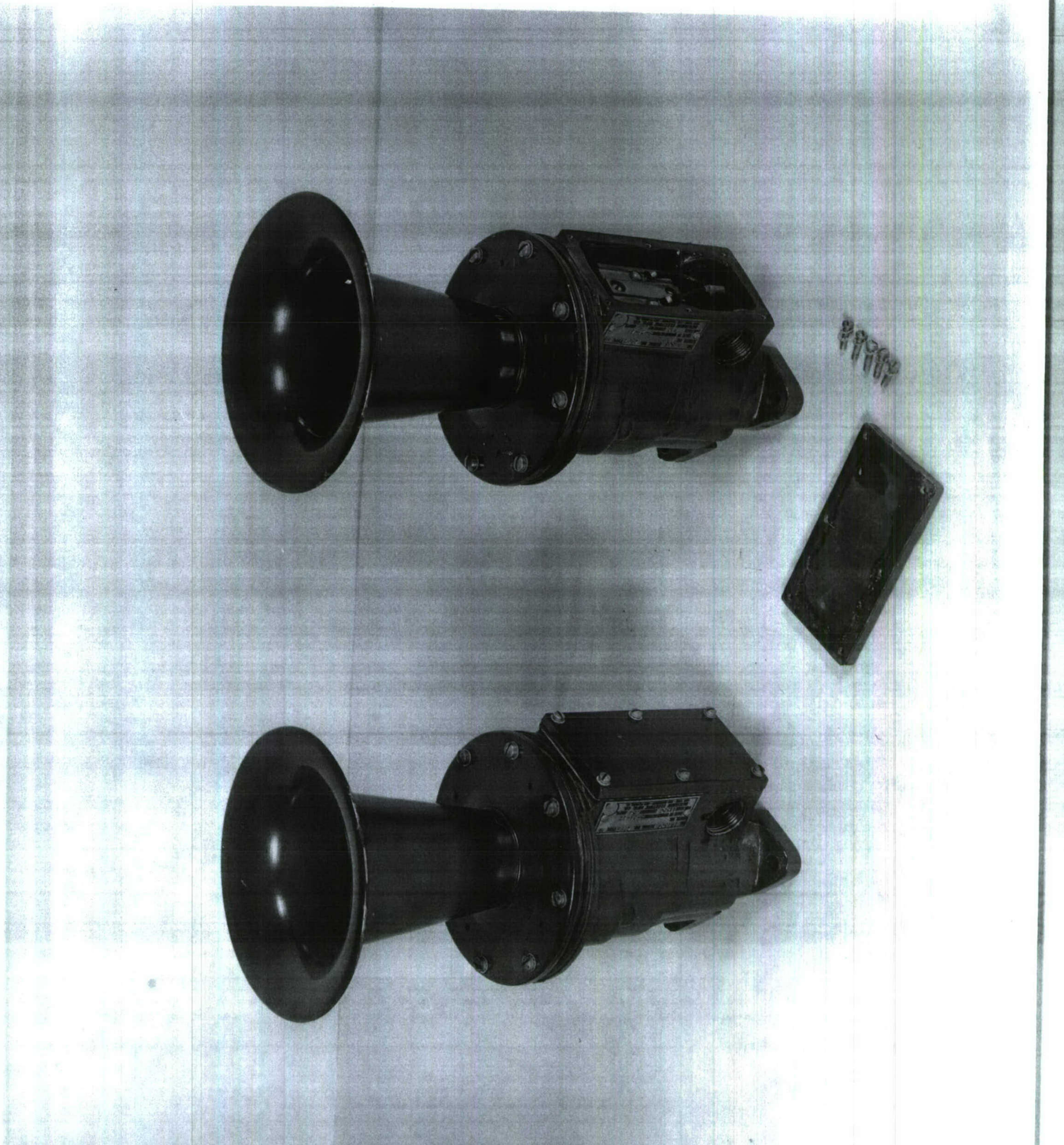


PLATE 2

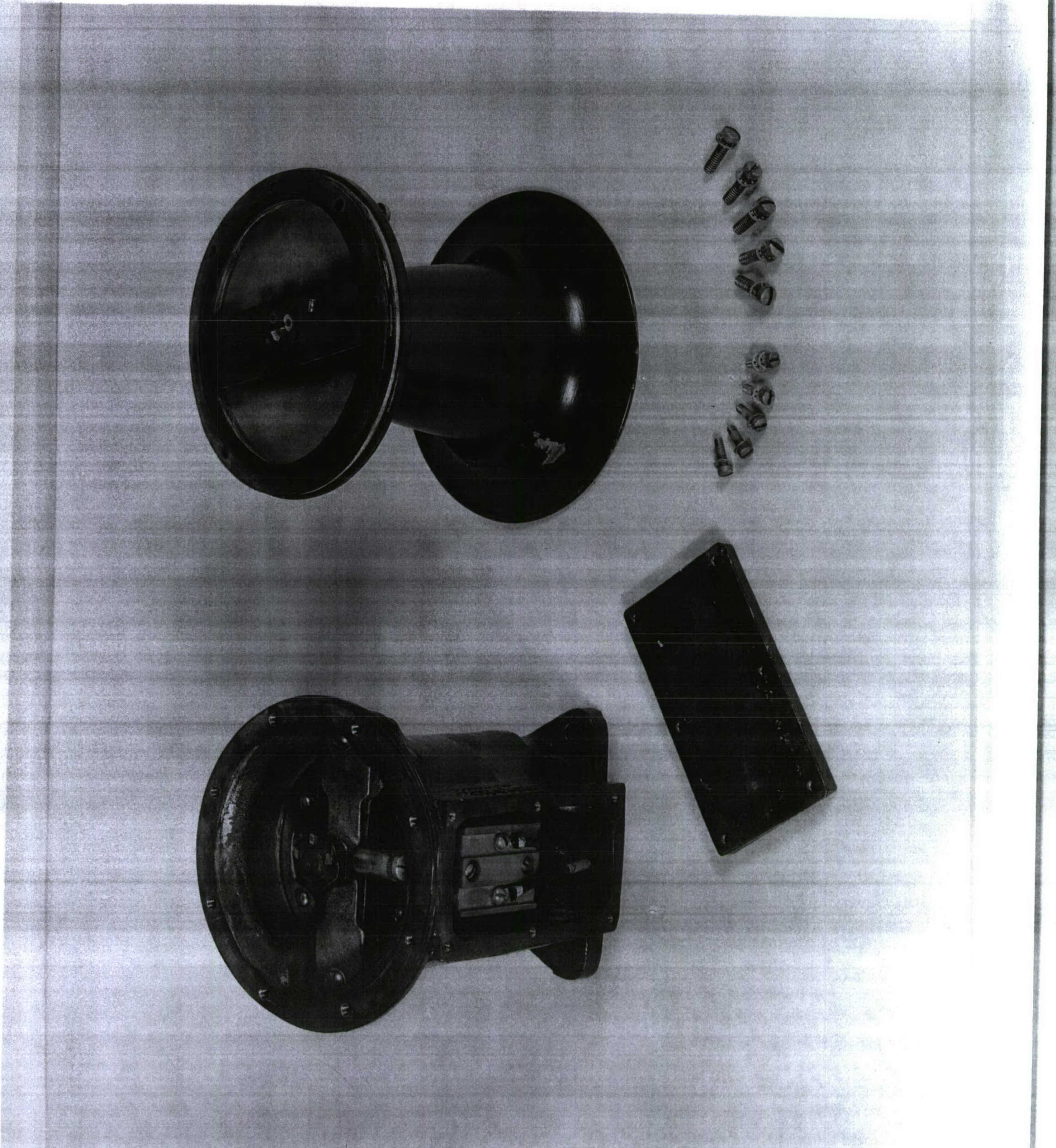


PLATE 3