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CONSTRUCTION OF 850 AND 4,000 AMPERE-HOUR SILVER-ZINC CELLS USING INORGANIC SEPARATOR

Charles Grun

Molecular Energy Corporation

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13. ABSTRACT

A 30 ampere-hour (A.H.) Silver-Zinc cell using government supplied inorganic separator 3420-25-FM was constructed and cycled for 120 50% cycles. 18% capacity loss was observed on cycle #85 and 43% on cycle #120. Some separator cracking was observed on negative separator envelope when dissected after cycle #120.
Two 850 A.H. cells (NR-1 type) and two 4,000 A.H. (Dolphin type) Silver-Zinc cells were constructed using the inorganic 3420-25-FM separator. Testing of these cells will be carried out by the government.

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Report MEC 10-73

Construction of 850 And 4000 Ampere-Hour Silver-Zinc Cell Using Inorganic Separator

Final Report

Prepared For NAVSEC

Contract No. N00024-73-C-5043

by

Molecular Energy Corporation
132 Floral Ave.
Murray Hill, N.J. 07974

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1. Introduction

1.1 The objective of this total program is to evaluate the performance of an inorganic separator in large silver-zinc cells for use in submersible vehicles. The inorganic separator type 3420-25-FM has been specifically developed for the silver zinc cell and has been supplied for this program by the government.

1.2 This program is organized on the basis of two major phases. The first of these is the construction phase which is the only obligation of this contract and the report.

1.3 This phase consists of the construction of two 850 and two 4,000 ampere-hour cells to the design goals of Military Specification MIL-B-24207 (SHIPS) and MIL-B-24409 (SHIPS) using the inorganic separator. The two cell types are generally known as the NR-1 and Dolphin type cells.

1.4 The second phase of the program will be the testing and evaluation of the cells constructed during the first phase. This second phase will be conducted by the Naval Ship Engineering Center.

2. Work Performed

2.1 Test Cell - 30 Ampere Hour Size

2.1.1 In order to determine the cycling characteristics of this separator and gain familiarity in handling of this material a test cell was designed, constructed, tested and dissected.

2.1.2 The design consisted of 4 positive and 5 negative electrodes about 2.4" x 4.8" containing a total of 103 gm of silver and 128 gm of zinc oxide mix per cell. Each electrode was placed into a separator

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envelope consisting of a separator pocket constructed from 2 pcs of inorganic separator cemented to a frame 7/32" wide. The electrodes within the envelopes were assembled into a cell. The cell was activated with a concentrated solution of potassium hydroxide.

2.1.3 The cell was cycled for 120 cycles, alternating between charges at 1.5 and 3 amperes to 2.05 volts and discharges at 7.5 and 15 amperes for 15 ampere hour output capacity.

2.1.4 At completion of cycling the cell was dissected and the separator closely examined. Some of the conclusions derived were as follows:

a. Excellent capacity was maintained for the cell for about 85 "50%" depth of discharge cycles. Capacity loss at this point was 18%. Capacity loss at 120 cycles was 43%.

b. Average negative shape change was 21% at the 120th cycle.

c. Some separator film cracking was observed on the negative separator envelope. These cracks were mainly near the frame area.

d. The resistance of the separator was somewhat high. It was estimated that for the 850 ampere-hour cell at the 3 and 5 hour rate, the plateau voltage would be about .03 to .04 volts below the specification goal.

2.1.5 A letter report No. MEC 1-73 covering the above test in detail was submitted to NAVSEC Code 6157D on March 16, 1973.

2.2 <u>850 Ampere-Hour Cell (NR-1)</u>

2.2.1 <u>Design</u>

2.2.1.1 The 850 ampere-hour cell was initially designed with the following parameters:

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Positives	* (Silver Electrode)
Electrodes	26 full 4 half
Size	13-3/8 x 3.6 x .028" thk ful .014"thk half
Silver Powder per cell	3,062 gm
Grid type	Ag exmet 5 Ag 9-2/0

Negatives	(Zinc Oxide Electrode)
Electrodes	28
Size	13-3/4 x 3-3/4 x .061" *
Zinc Oxide per cell	2,810 gm
Grid type	5 Ag-38-1/0
Inter-separator	1 sheet of KT paper pressed on each face of electrode

*Includes one layer of KT paper on each side of electrode

Separator (Type 3420-25-FM)	
Separator size	14-7/8 x 4-11/32"
Positive frame	7/32 x .020"
Negative frame	7/32 x .040"
Cement	Epoxy-Allbond-clear

Cell Case	
Inside Dimensions	4.45 x 4.25 x 16-9/32"
Material	Acrylic 3/8" thick

2.2.1.2 The design was based on initial receipt of separator which was .013" to .014" thick, when measured at a presure of about

3 psi. The later shipment of separator which averaged .015 to .016" thick required the removal of one positive half electrode and the 1/4" thick central spacer assembly. The cell as assembled has therefore 26 full and 3 half positive electrodes. The silver content per cell is 3,000 gm. From previous experience with the NR-1 type of cell, this quantity of silver powder is more than adequate to meet the capacity design goals of MIL-B-24207.

2.2.2 <u>Construction - Assembly</u>

2.2.2.1 The cell assembly proceeded smoothly with exception of two items. The separator film was very fragile when bent, and extreme caution was required in handling it. In addition, the separator as received had to be screened since some areas had cracks, insufficient amount of film, or film material in modular form. The second item consisted of inserting the pack assembly into the cell case. Since the inorganic separator does not expand when wet, one needs a flush cell pack thickness fit in the dry state as a minimum - to maintain some internal cell pressure in the wet state. This means that the cell pack has to be compressed during its insertion into the case. This was accomplished by compressing the cell pack up to about 1" from the cell case opening and then pushing the cell case into the pack up to the compression clamp. This was repeated until the cell pack was fully inserted into the case.

2.2.3 Shipment

2.2.3.1 The two 850 ampere-hour cells will be shipped in the dry state. A filling kit consisting of electrolyte and accessories to activate the cells will be shipped with the two cells but in a seperate container.

2.2.3.2 The shipping crate for the two cells consists of a 23.5 X 13 X 25" wooden box mounted on a pallet. The wooden box is divided into two compartments, one for each cell. A 3" layer of expanded polystyrene lines the bottom of the box. The cells are wrapped in polyethylene bags and then placed into the compartments in their normal vertical position. The compartments are then filled with expanded polystyrene cushioning material and closed with the wooden top. The box is then strapped with metal bands. Since the shipping box is mounted on a pallet, the cells will remain in their normal vertical position during shipment.

2.2.3.3 To remove the cells from the shipping container, remove the top of the wooden box, discard some of the cushioning material, and lift cellfrom box.

2.2.4 Cell Instructions

2.2.4.1 The operating instruction for the 850 ampere-hour cell (OSZ 107) are attached as Appendix 1.

2.3 4,000 Ampere-Hour Cell (Dolphin)

2.3.1 Design

2.3.1.1 The 4,000 ampere-hour cell has been designed with the following parameters.

Positives	(Silver Electrode)
Electrodes	46
Size	14 15/16 X 8½ X .032"
Silver powder per cell	11,891 gm
Grid type	5Ag 14 - 2/0
Negatives	(Zinc Oxide Electrode)
Electrodes	47
Size	14 7/16 X 8½ X .077"*
Zinc Oxide per cell	15,343 gm
Grid Type	5 Ag - 38 - 1/0
Interseparator	1 sheet of KT paper pressed on each face of the electrode

*Includes one layer of KT paper on each side of electrode.

Separator	(Type 3420-25 FM)
Separator size	16 1/16" X 9 3/32"
Positive frame	5/16 X .020"
Negative frame	5/16 X .060"
Cement	Epoxy-Albond clear
Cell Case	
Inside dimension	9½ X 9½ X 18"
Material	Rubber lined epoxy fiberglass

2.3.1.2 Since the above design was based on initial receipt of separator which was .013" to .014" thick and subsequent separator averaged .015" to .016" thick, one positive and one negative assembly had to be removed from above design. The cell was therefore assembled with 45 positive and 46 negative electrodes. The active silver powder and zinc oxide per cell was therefore 11,632 and 15,016 gms respectively.

2.3.2 Construction - Assembly

2.3.2.1 The cell assembly of the 4,000 ampere-hour cell proceeded smoothly with the exception of the two items mentioned in 2.2.2.1. These consisted of separator screening to avoid faulty separator areas and the need for cell pack compression before insertion into cell case.

2.3.3 Shipment

2.3.3.1 The two 4,000 ampere-hour cells will be shipped in the dry state. A filling kit consisting of electrolyte and accessories to activate the cells will be shipped with the two cells but in a separate container.

2.3.3.2 Two shipping crates were constructed for the two 4,000 ampere-hour cells. Each consists of a 26" X 18" X 18" wooden box mounted on a pallet. A 3" layer of expanded polystyrene lines the bottom of the box. The cell, wrapped in polyethylene was lowered into the box by straps looped under the cell. (These straps were left there for unloading). The box was then filled with expanded polystyrene cushioning material and closed with the wooden top. The box was then strapped with metal bands. Resting on the pallet, the cell will remain in the vertical position during shipment.

2.3.3.3 To remove the cell from the shipping container, remove top of wood box, discard some of the cushioning material, and lift the cell from box by the strap looped under the cell.

2.3.4 Cell Instructions

2.3.4.1 The operating instructions for the 4,000 ampere-hour cell (OSZ-108) are attached as Appendix II

2.4 Drawings, Engineering - Design Evaluation

2.4.1 Design evaluation drawings for the 850 and 4,000 ampere-hour cells were submitted to NAVSEC SEC 6157D on July 5, 1973.

Appendix I

OSZ 107

OPERATING INSTRUCTIONS

FOR

SILVER - ZINC CELL

P/N XMSZ 850

Cell Assembly Dwg 64-D-10581

Contract No. N00024-73-C-5043

Molecular Energy Corporation
132 Floral Avenue
Murray Hill, N.J.

July 1973

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CAUTION

This cell uses potassium hydroxide as its electrolyte.

Potassium hydroxide should be handled with care. Contact with this electrolyte should be avoided. Use of protective clothing, goggles or face mask is recommended when handling electrolyte. Dilute acetic or boric acid may be used for neutralizing electrolyte on clothing and skin. Boric acid may be used as an eye wash. Rinse affected areas with water.

Use only electrolyte supplied with the cell. Acid type of electrolyte will destroy the cell. Do not allow the electrolyte to remain in open containers for prolonged periods of time since it will absorb carbon dioxide and be degraded.

1. General

1.1 The XMSZ 850 is a prototype silver-zinc cell, using an inorganic separator (3420-25-FH) which has been specifically developed for the silver-zinc cell. The internal dimensions of the cell approximate those presently used on the NR-1 battery. The objective is to evaluate the performance of this cell using the inorganic separator under an NR-1 type regime.

1.2 The nominal capacity of this cell is 900 ampere-hours at the 5 hour rate. The average voltage at this rate is about 1.48 volts. Silver oxide and zinc are the active electrodes in this cell. The electrolyte is a 45% solution of potassium hydroxide.

1.3 This cell is furnished in the dry unformed condition. It must be activated and formed before operational use. The procedures for activation, forming, charging and discharging of this cell are given in this manual and should be closely followed for best performance.

2. Cell Description - Physical

2.1 The XMSZ 850 cell is constructed in an acrylic cell case with internal dimensions of 4.2" x 4.4" x 16.3". The wall thickness of the acrylic case is 3/8". The overall outside dimensions of the cell case with cover (excluding terminals) is 4.9" x 5.1" x 16.9". The cell has four terminals. The two terminals near the red stripe on the cover are connected to the positive electrodes. The two remaining terminals are connected to the negative electrodes. Each terminal is tapped with a 3/8-16 thread to a depth of 11/16". Silver plated copper bolts are provided to tie down connectors to the terminal. The distance between terminal centerlines is 2.3".

2.2 The cell is provided with a flash arrester assembly which limits access of air to the cell and prevents flame in the vicinity of the cell from igniting any gas within the cell. The flash arrester assembly seals to the cell cover with an "O" ring.

2.3 The cell is braced with 3 sets of one inch angle irons. One is positioned at the bottom. The remaining two are located 6 and 12 inches from the bottom. The bracing restricts swelling of the cell pack and minimizes stresses on the cement joint of the fabricated cell case. These braces should not be removed from the cell.

3. Cell Description - Electrical

3.1 The XMSZ-850 is a silver-zinc rechargeable cell with a nominal capacity of 900 ampere hours at the 5 hour rate. The average voltage at this rate is about 1.48 volts. The capacity at the 270 ampere rate is in excess of 840 ampere hours. The average voltage at this rate is 1.45 volts.

3.2 This is a low rate cell. It has been designed to safely discharge its full capacity at rates up to 270 amperes. For rates higher than 270 amperes, the ampere-hour capacity discharged should be limited to avoid overheating of the cell.

3.3 The cell can be recharged at rates up to 90 amperes. The preferred charge rate is 40 to 60 amperes.

4. Electrochemistry

4.1 The fabricated electrodes in this cell are silver and zinc oxide. The silver or positive plate is porous and has a very large active surface area. The zinc oxide or negative electrode is pressed into a silver grid and covered with a porous separator. The positive and negative electrodes are both inserted into separate inorganic separator bags to prevent shorting between electrodes. The electrolyte is a concentrated solution of potassium hydroxide.

4.2 The chemical reaction which occurs on charge and discharge is shown by the following simplified equations:

$$\underset{\text{Discharged Cell}}{ZnO + Ag} \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftharpoons}} \underset{\text{Charged Cell}}{Zn + AgO}$$

During charge the zinc oxide is converted into zinc and silver into silver oxide. During discharge the process is reversed; zinc converting into zinc oxide and silver oxide into silver. The electrolyte though not shown in the equation, allows the above reaction to proceed. Its reactions at the positive and negative

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electrodes are equal and opposite, so that there is no net change in electrolyte composition between charge and discharge. Specific gravity measurements cannot therefore be used to determine the state of charge of the cell.

4.3 The initial discharge of a fully charged cell will have a drooping voltage curve for about 5 to 10% of its discharge capacity - depending on the discharge and partially on the charge rate. The remainder of the discharge voltage will be relatively flat in the range of 1.45 - to 1.56 volts for the anticipated NR-1 discharge rates. The discharge voltage will drop rapidly when the cell capacity is exhausted.

4.4 For a fully discharged cell, the initial charge voltage will run about 1.68 volts for 10% to 20% of the cell capacity. The remainder of charge will be at the higher voltage level of about 1.95 volts. The charge voltage rises sharply above 2.0 volts when the cell is fully charged.

5. Forming the Cell

5.1 The XMSZ-850 cell is supplied in the dry unformed state and has to be filled and formed before use.

5.2 A filling kit is supplied with each cell. It contains the following items:

Item	Description	Quantity
1	1 Quart polyethylene bottles each containing 1 quart of electrolyte (45% KOH)	3 pcs.
2	Polyethylene funnel	1 pc.
3	Electrolyte adjustment assembly	1 pc.
4	Cotton	2 oz.

5.3 To fill the cell, remove the flash arrester assembly from the cell. Insert the funnel into center cell cover hole and pour electrolyte from supplied bottles into the cell through the funnel. Add electrolyte until at the end of 10 minutes it remains about 1/8" above the top of the separator. Since the cell case is transparent the level can be easily monitored through the side. Approximately 2.5 quarts of electrolyte will be required to fill the cell. Wipe up any electrolyte which might have dripped on the cell terminals or cover. Install the flash arrester previously removed from the cell.

5.4 Allow the cell to soak for a minimum of 72 hours. During this soak, monitor the electrolyte level once a day. If below separator height, add electrolyte to 1/8" above separator.

5.5 Just before start of charge, check electrolyte level and adjust if not between separator height or 1/8" above it. Charge the cell at 40 amperes to 2.03 volts.

5.6 Discharge the cell at the 5 hour rate (170 amperes) till the cell reaches 1.31 volts. If the discharge capacity is in excess of 900 ampere hours the cell is considered formed and may be recharged for operational use. If discharge capacity is below 900 ampere hours repeat the formation cycle till capacity is met. If capacity is not met within 3 formation cycles contact the manufacturer.

6. <u>Charging the Cell</u>

6.1 After formation, the recommended way of charging the cell is at a constant current rate of 60 to 70 amperes to a cut-off voltage of 2.03 volts.

6.2 If it is required that the cell be charged within a shorter time, the cell may be charged at 90 amperes to 2.03 volts. The cell is then rested for 30 minutes and the charge continued at 60 amperes to 2.03 volts.

6.3 If the cell is to be connected to a float charge, it must be fully charged before placing it on float. The above charge methods may be used, to fully charge the cell. The allowed float voltage for this cell is 1.92 to 1.96 volts.

6.4 The ampere-hour efficiency of this cell is close to 100%. The cell therefore need not and should not be overcharged.

7. <u>State of Charge</u>

7.1 If a cell's open circuit voltage is 1.85 to 1.86 volts the cell is at least 60% charged. An open circuit voltage reading of 1.85 to 1.61 volts indicates that the cell is from 50 to 90 percent charged. A reading of 1.58 to 1.60 volts indicates that the cell is from 0 to 50% charged.

8. Discharging the Cell

8.1 This cell can be safely discharged at 270 amperes for its full capacity. The nominal capacity at the 170 ampere discharge rate is 900 ampere hours. At the 270 ampere rate the discharge capacity is in excess of 840 ampere hours.

8.2 Before discharging the cell, make sure that the intercell connectors are held tightly against the cell terminals. The recommended torque for tightening the supplied 3/8-16 bolts on the intercell connector is 80 to 100 inch-pounds.

Caution: Use only the supplied terminal bolts or 5/8-16 bolts which are less than 5/8" long.

9. Storage of Cell in Wet Condition

9.1 If the cell in the wet condition is expected to be stored for more than 30 days, it should be discharged prior to storage. Storage temperatures should be kept below 90°F. However storage temperatures in the range of 10° to 60°F are preferred.

10. Cell Maintenance

10.1 The cell maintenance consists mainly of keeping the cell top clean, occasionally monitoring the open circuit voltage of the charged cell and checking the electrolyte level.

10.2 The cell and terminal tops must be kept clean and free of electrolyte. If electrolyte is observed on the top of the cell remove it with a moist rag and then dry the surface thoroughly.

10.3 The open circuit voltage of the fully charged cell on stand should be 1.84 to 1.86 volts if it has been charged recently - within 15 days. A voltage below 1.84 volts may indicate internal shorting. If the voltage is below 1.84 volts, recharge the cell to 2.03 volts and place on open circuit charged stand, monitoring the open circuit voltage daily. A continually dropping voltage below 1.84 volts indicates that the cell is shorted internally.

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10.4 The electrolyte level should be checked monthly. The electrolyte level should be maintained between the top of the separator and 1" below this top when in the charged state. The electrolyte level reading should be taken within 4 to 12 hours after completion of charge or after about 24 hours of float. The electrolyte level can be monitored by looking at the level through the side of the cell case. If electrolyte level is more than 1" below top of separator, add 42% potassium hydroxide till about 1/4 to 1/2" below separator top.

Caution: Do not add acid type of electrolyte to this cell.

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Appendix II

OSZ 108

OPERATING INSTRUCTIONS

FOR

SILVEP-ZINC CELL
P/N XMSZ 4,000

Cell Assembly Dwg 64-D-10586

Contract No. N00024-73-C-5043

Molecular Energy Corporation
132 Floral Avenue
Murray Hill, N. J. 07974

August 1973

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CAUTION

This cell uses potassium hydroxide as its electrolyte.

Potassium hydroxide should be handled with care. Contact with this electrolyte should be avoided. Use of protective clothing, goggles or face mask is recommended when handling electrolyte. Dilute acetic or boric acid may be used for neutralizing electrolyte on clothing and skin. Boric acid may be used as an eye wash. Rinse affected areas with water.

Use only electrolyte supplied with the cell. Acid type of electrolyte will destroy the cell. Do not allow the electrolyte to remain in open containers for prolonged periods of time since it will absorb carbon dioxide and be degraded.

1. General

1.1 The XMZ 4,000 is a prototype silver-zinc cell, using an inorganic separator which has been specifically developed for the silver-zinc cell. The dimensions of the cell conform to those of the Dolphin cell-MIL-B24409 (SHIPS). The objective is to evalute the performance of this cell using the inorganic separator under a Dolphin type regime.

1.2 The nominal capacity of this cell is 4,000 ampere-hours at the 10 hour rate. The average plateau voltage at this rate is about 1.48 volts. Silver oxide and zinc are the active electrodes in this cell. The electrolyte is a 45% solution of potassium hydroxide.

1.3 The cell is furnished in the dry unformed condition. It must be activated and formed before operational use. The procedures for activation, forming, charging and discharging of this cell are given in this manual and should be followed closely for best performance.

2. Cell Description-Physical

2.1 The XMSZ 4,000 cell is constructed in a rubber lined epoxy fiberglass cell case with a hard rubber cover. The overall dimensions are 10 X 10 X 20" high. The cell has two terminal assemblies each consisting of 3 copper terminal posts silver brazed to a base. One terminal assembly .. marked positive is connected to the positive electrodes. The remaining terminal assembly is connected to the negative electrodes. Each terminal post has two 9/32" holes for connecting of intercell connectors. The terminals are also provided with a channel for circulating of cooling water. The water fitting is permanently attached to the terminal and accepts a 1/4" ID flexible tube.

2.2 The cell is provided with a flash arrester assembly which limits access of air to the cell and prevents flame in the vicinity of the cell from igniting any gas within the cell. The flash arrester assembly seals to the cell cover with an "O" ring.

2.3 The cell is also provided with an electrolyte level indicator which provides a visual indication of the electrolyte level.

2.4 A flushing valve is installed on the cell cover. This allows air to be introduced into the cell when required.

2.5 A set of wooden braces is provided with the cell to contain any bulging of the cell case. Before filling the cell with electrolyte make sure that these braces are installed on the cell.

3. Cell Description - Electrical

3.1 The XMSZ 4,000 is a silver-zinc rechargeable cell with a nominal capacity of 4,000 ampere-hours at the 10 hour rate. The average voltage at this rate is about 1.48 volts. At the one hour rate of 3,420 amperes the average voltage is 1.35 volts.

3.2 This is a medium rate cell. It has been designed to safely discharge its full capacity at rates up to 3,500 amperes. For rates higher than 3,500 amperes the ampere-hour capacity discharged should be limited to avoid overheating of the cell.

3.3 The cell can be recharged at rates up to 340 amperes. The preferred charge rate is 200 amperes.

4. Electrochemistry

4.1 The fabricated electrodes in this cell are silver and zinc oxide. The silver, or positive plate is porous and has a very large active surface area. The zinc oxide or negative electrode is pressed into a silver grid and covered with a porous separator. The positive and negative electrodes are both inserted into separate inorganic separator bags to prevent shorting between electrodes. The electrolyte is a concentrated solution of potassium hydroxide.

4.2 The chemical reaction which occurs on charge and discharge is shown by the following simplified equations.

$$\underset{\text{Discharged Cell}}{ZnO + Ag} \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftharpoons}} \underset{\text{Charged Cell}}{Zn + AgO}$$

During charge, the zinc oxide is converted into zinc and silver into silver oxide. During discharge the process is reversed; zinc converting into zinc oxide and silver oxide into silver. The electrolyte though not shown in the equation, allows the above reaction to proceed. Its reactions at the positive and negative electrodes are equal and opposite, so that there is no net change in electrolyte composition between charge and discharge. Specific gravity measurements cannot therefore be used to determine the state of charge of the cell.

4.3 The initial discharge of a fully charged cell will have a dropping voltage curve for about 5 to 10% of its discharge capacity- depending on the discharge and partially on the charge rate. The remainder of the discharge voltage will be relatively flat in the range of 1.35 - to 1.56 volts for the anticipated Dolphin type discharge rates. The discharge voltage will drop rapidly when the cell capacity is exhausted.

4.4 For a fully discharged cell, the initial charge voltage will run about 1.68 volts for 10% to 20% of the cell capacity. The remainder of charge will be at the higher voltage level of about 1.95 volts. The charge voltage rises sharply above 2.0 volts when the cell is fully charged.

5. Forming the Cell

5.1 The XMSZ-4,000 is supplied in the dry unformed state and has to be filled and formed before use.

5.2 A filling kit is supplied with each cell. It contains the following items:

Item	Description	Quantity
1	1 Gallon polyethylene bottles each containing 1 gallon of electrolyte (45% KOH)	3 pcs.
2	Polyethylene funnel	1 pc.
3	Electrolyte adjustment assembly	1 pc.
4	Cotton	2 oz.

5.3 To fill the cell, remove the flushing valve with adapter from the cell. Make sure that cell is braced. (See para. 2.5). Insert funnel into this hole and pour electrolyte from supplied bottles into the cell. Add electrolyte until at the end of 10 minutes it remains about 1/8" above the top of the separator. The electrolyte level can be monitored with the electrolyte level indicator. A dark circle between 3/8" to 9/16" diameter on the indicator indicates the correct level. The level should be tracked with the level indicator during filling. The first three dark circles (1/8" diameter) will appear in sequence when the electrolyte level is 1 1/2", 3/4" and 3/8" from the top of the separator. A full dark circle (5/16 diameter) will appear when the level is 3/16" from the top of the separator. The diameter of this dark circle will start to increase when the electrolyte level reaches and goes beyond the top of the separator.

5.4 Approximately 2.5 gallons of electrolyte will be required to fill the cell. Wipe up any electrolyte which might have dripped on the cell terminals or cover. Install the flushing valve with adapter previously removed from the cell.

5.5 Allow the cell to soak for a minimum of 72 hours. During this soak monitor the electrolyte level once a day. If below separator height, add electrolyte to 1/8" above separator.

5.6 Just before start of charge, check electrolyte level and adjust if not between separator height or 1/8" above it. Charge the cell at 200 amperes to 2.03 volts.

5.7 Discharge the cell at 392 amperes (10 hour rate) till the cell reaches 1.39 volts. If the discharge capacity is in excess of 3,920 ampere-hours the cell is considered formed and may be recharged for operational use. If discharge capacity is below 3,920 ampere hours repeat formation cycling till capacity is met. If capacity is not met within 3 formation cycles contact the manufacturer.

6. Charging the Cell

6.1 After formation, the recommended way of charging the cell is at a constant current rate of 200 amperes to a cut-off voltage of 2.03 volts.

6.2 If it is required that the cell be charged with a shorter time, the cell may be charged at 350 amperes to 2.05 volts. The cell is then rested for 30 minutes and the charge continued at 200 amperes to 2.03 volts.

6.3 If the cell is to be connected to a float charge, it must be fully charged before placing it on float. The above charge methods may be used to fully charge the cell. The recommended float voltage for this cell is 1.92 to 1.96 volts.

6.4 The ampere-hour efficiency of this cell is close to 100%. The cell therefore need not and should not be overcharged.

7. State of Charge

7.1 If a cell's open circuit voltage is 1.85 to 1.86 volts, the cell is at least 60% charged. An open circuit voltage of 1.85 to 1.61 volts indicates that the cell is from 50 to 90 percent charged. A reading of 1.58 to 1.60 volts indicates that the cell is from 0 to 50% charged.

8. Discharging the Cell

8.1 This cell can be discharged at 3,420 amperes for one hour. The discharge time at this rate should not be exceeded since the cell may overheat. The nominal capacity of this cell at the 400 ampere rate is 4,000 ampere-hours.

8.2 Before discharging the cell, make sure that the inter-cell connectors are held tightly against the cell terminals. Loose connections will cause a considerable heat rise at the terminals.

8.3 For high rate discharge in the 3,000 ampere range it is recommended that some water cooling be provided to the terminals. A cooling channel is provided in the terminal block for this purpose. It terminates with two water fittings at the end of the terminal block.

9. Storage of Cell in Wet Conditions

9.1 If the cell in wet condition is expected to be stored for more than 30 days, it should be discharged prior to storage. Storage temperatures should be kept below 90°F. However storage temperatures in the range of 10 to 60°F are preferred.

10 Cell Maintenance

10.1 The cell maintenance consists mainly of keeping the cell top clean, occasionally monitoring the open circuit voltage of the charged cell and checking the electrolyte level.

10.2 The cell and terminal tops must be kept clean and free of electrolyte. If electrolyte is observed on the top of the cell remove it with a moist rag and then dry the surface thoroughly.

10.3 The open circuit voltage of the fully charged cell on stand should be 1.84 to 1.86 volts if it has been charged recently - within 15 days. A voltage below 1.84 volts may indicate internal shorting. If the voltage is below 1.84 volts, recharge the cell to 2.03 volts and place on open circuit charged stand, monitoring the open circuit voltage daily. A continually dropping voltage below 1.84 volts indicates that the cell is shorted internally.

10.4 The electrolyte level should be checked monthly. The electrolyte level should be maintained between the top of the separator and 3/4" below this top when in the charged state. The electrolyte level reading should be taken within 4 to 12 hours after completion of charge or after about 24 hours of float. The electrolyte level is to be monitored with the electrolyte level indicator (see below). If electrolyte level is more than 3/4" below top of separator, add 45% potassium hydroxide electrolyte till about 3/8" below separator top.

Caution: Do not add acid type of electrolyte to this cell.

11. Electrolyte Level Indicator

11.1 The electrolyte level indicator provides five level readouts as follows:

Observation	Level
One dark 1/8" dia. circle	1 1/2 to 3/4" BTOS[(1)]
Two dark 1/8" dia. circles	3/4" to 3/8" BTOS
Three dark 1/8" dia. circles	3/8" to 3/16" BTOS
One dark 5/16" dia. circle	3/16" to 0" BTOS
One dark 5/8" dia. circle	Greater than 1/8" above top of separator

(1) BTOS - Below top of separator