NASA TECHNICAL MEMORANDUM

NASA TM X-52137

NASA TM X-52137

FACILITY FORM 602

N66-14763 (ACCESSION NUMBER) (THRU) 1

13 (PAGES) (CODE)

(NASA CR OR TMX OR AD NUMBER) 03 (CATEGORY)

GPO PRICE $

CFSTI PRICE(S) $

Hard copy (HC) 1.00

Microfiche (MF) .50

ff 653 July 65

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TECHNICAL PAPER proposed for presentation at National Conference on Spacecraft Sterilization Technology sponsored by the National Aeronautics and Space Administration Pasadena, California, November 16-18, 1965

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION · WASHINGTON, D.C. · 1965

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E-3204

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INTRODUCTION

The heat sterilization of spacecraft required for lander missions has created a problem, specifically the inability of some components to withstand this temperature environment. This is especially true of secondary batteries, which are expected to function normally and be capable of hundreds of charge-discharge cycles after sterilization. These batteries, however, either experience a significant decrease in capacity or will not operate after undergoing the sterilization cycle of three 36-hour periods at 145° C. This failure or decrease in capacity can be attributed mainly to degradation of the separator material, and possibly, the electrodes.

Because of this fact, considerable time and effort are being expended to obtain batteries capable of being sterilized without degradation. Some progress has been made, and laboratory batteries have been built that can operate for a few cycles after sterilization although with some capacity decrease. These batteries could perform satisfactorily where limited cycling is required, but a flight-ready unit that could operate for hundreds of cycles after sterilization is not presently available. No existing cell can be sterilized without experiencing some degradation.

What possibilities are there that a secondary unit capable of hundreds of cycles can be produced? Besides the approach being followed by the Jet Propulsion Laboratory, a few companies have investigated the possibility of producing a sterilizable primary or secondary unit. This paper is concerned with the approaches being used by these laboratories and the current status of their work. The Astropower Laboratory of Douglas Missiles and Space Company and the Eagle-Picher Company are working with the silver-zinc system. They base their hopes to achieve a sterilization capability on novel separators. Electro-Optical Systems, Inc., a subsidiary of the Xerox Corporation, is developing an electrically regenerative fuel cell that should be capable of sterilization, and Gulton Industries, Inc. has tested sterilizable components for a battery with an inorganic separator.

In some cases, the work being carried on in this area is the result of efforts in other directions. This is the case with two programs which the NASA-Lewis Research Center is funding. The primary objective of these programs is not to obtain a sterilizable battery, however the batteries from both programs show that they can be sterilized and operated for useful periods of time after high-temperature storage. The following resumes present in more detail the aforementioned approaches.

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DOUGLAS MISSILES AND SPACE COMPANY, ASTROPOWER LABORATORY

The contract with Douglas' Astropower Laboratory, NAS3-7639, is intended to produce an improved secondary silver-zinc battery utilizing a sterilizable inorganic separator that can operate efficiently over an extended temperature range (50° to 210° F) for at least 1500 cycles at a 25-percent depth of discharge. Standard silver-zinc cells are limited in that they operate best over a narrow temperature range (50° to 120° F) and have very limited short-cycle lives (100 to 200 cycles) at shallow depths of discharge. Any variation in temperature or depth of discharge reduces the performance significantly.

The silver-zinc battery is a desirable power source in that it is capable of providing twice the power per unit weight of the next best system, silver-cadmium. Astropower has developed a separator that may allow the silver-zinc battery to compete with the other secondary batteries in terms of life, while exceeding them in energy density and operating-temperature range. This capability results from the fact that the inorganic separator withstands high temperatures, resists oxidation, and inhibits dendritic growth and the migration of the soluble electrode species.

Two-plate cells have operated for more than 2700 cycles at 25° C and 2200 cycles at 100° C. At higher temperatures, however, the number of cycles declines to a point where only 30 cycles are obtained at 150° C. All these tests were carried out at 20-percent depth of discharge. Charge-discharge characteristics of two typical cells are shown on figures 1 and 2. Calculations based on these data indicate that ampere-hour efficiencies are comparable to commerical cells. In addition to the attributes already mentioned, it has been found that the battery can be sterilized and subsequently cycled at room temperature after the sterilization. Figure 3 shows the performance of a cell that had been sterilized and then tested. This cell ran for over 2000 cycles after sterilization. It must be pointed out that these cells are not sealed and that during the test electrolyte was added. No attempt has been made to seal the cell since the preliminary objective was to determine the performance capability of the inorganic separator. Results of the testing of two-plate cells have indicated that there is much to be gained from further development of this unit.

The next step in development will be to design, build, and test a multiplate cell. Initially, a 5-ampere-hour multiplate cell will be developed. The assembly techniques and manufacturing processes will be selected so that an easy translation from this cell to any size or capacity can be made. A preliminary look at the multiplate cell indicates that a design capable of passing environmental tests and performing for at least 1500 cycles over a wide temperature range (25° to 100° C) is feasible. A preliminary design for the multiple cell has been completed, and work is proceeding toward tailoring the components to the design. The target date for completion of the evaluation of the 5-ampere-hour cell is December 1966.

EAGLE-PICHER COMPANY

Eagle-Picher has reported that it has a silver-zinc battery capable of sterilization. An 8-ampere-hour unit has withstood three 36-hour cycles at 145° C with no apparent degradation. Similar designs, unsterilized, have shown an activated-stand capability of over a year. Cells built in April 1965 were sterilized and have undergone a charge-stand-discharge cycle 12 times since April. Eagle-Picher has sold similar cells to a number of companies for testing. They feel a more thorough testing of these units is desirable. NASA-Langley Research Center and Avco are among those performing tests, but the results are not available as yet.

ELECTRO-OPTICAL SYSTEMS, INC.

Another program, which is in a more advanced state of development, is underway at Electro-Optical Systems, Inc. (EOS). The device being developed is an electrically regenerative hydrogen-oxygen fuel cell. The battery consists of a cell stack that is utilized as a fuel cell during the discharge period and a water electrolyzer during the charge period. Integral gas-storage tanks contain the hydrogen and oxygen generated during charge and the electrolyte holds the water generated on discharge.

Such a device offers a number of advantages for space application which existing secondary batteries do not, including the potential for sterilization. Cells have been operated over a range of temperatures from 70° to 150° C. No extensive testing has been done at the higher temperatures, the majority of tests having been run at 70° to 100° C. Single cells, 6-cell batteries, and 34-cell batteries have been tested in the aforementioned ranges. Figure 4 shows the discharge characteristics of a single cell at 125° C. At this temperature, the cell performs very efficiently in short-time tests. However, life data has not been obtained. Figure 5 shows a charge-discharge curve of a cell operating at 150° C. Charge voltage is somewhat lower and discharge voltage is higher than at lower operating temperatures. Figure 6 shows cell performance at 75° C after a 67-hour soak at 150° C. For comparison, performance at 75° C prior to the heat soak is shown. A slightly higher charge voltage and a lower discharge voltage were observed after the 150° C exposure. Work is now underway at EOS to eliminate this loss, which appears to be associated with oxidation of the oxygen electrode.

The present performance capability of the six-cell fuel cell is as follows:

Watt-hours per pound	10-12 (35-min. discharge)
. . . .	17-20 (60-min. discharge)
Operation temperature, $^{\circ}$C.	Up to 150°
Power level, W	90

Thermal sterilization capability	Sterilizable
Cycle life at full depth (90° C)	> 300
Operating current density, discharge, mA/cm^2 . .	100
Overload capability	2:1

The basic design, the materials of construction, and the operating characteristics all indicate that this secondary fuel cell should be capable of efficient operation after sterilization.

GULTON INDUSTRIES, INC.

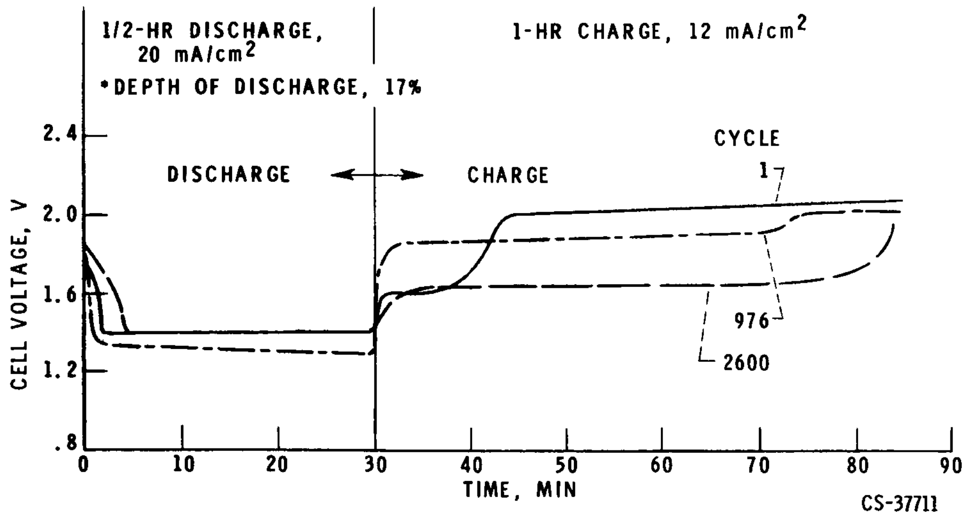
Gulton Industries has indicated that it has performed sterilization tests on nickel-cadmium cells and some work on another sterilizable system. It was found that the nickel electrode degraded during sterilization. Gulton Industries has, as of this date, two electrodes and an inorganic separator, which can be sterilized, although these components have not been tested together in a cell.

CONCLUSIONS

It appears that two or three of the approaches that have been proposed for obtaining sterilizable secondary batteries have a chance of meeting the requirements for a lander mission. Of the two approaches discussed in detail in this paper, the Douglas silver-zinc cell must still be developed into a finished sealed cell capable of withstanding the environmental conditions that would be imposed by such a mission. There seems to be little question, however, that this cell can withstand the rigors of thermal sterilization and perform satisfactorily. The major problems to be solved lie in the conversion of a laboratory device into a reliable piece of flight hardware.

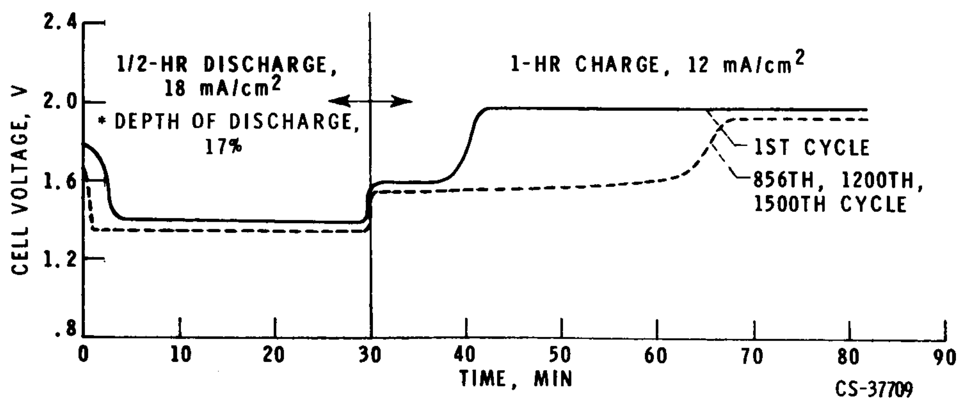
The electrically regenerative fuel cell has operated both as a single cell and as a multicell unit with a cycle life >300 at 70° to 90° C. It has also operated at 150° and at 75° C after a 150° C storage of 67 hours. Work now underway on the electrodes and membrane should enhance reliability, improve cycle life considerably at all temperatures, and enhance sterilization capability.

The approaches offered by Gulton Industries and Eagle-Picher offer some promise, based on the information available to the author at this time. As more test data become available, a more accurate appraisal of their merits, relative to the other methods discussed, will be possible.



*BASED ON LOW RATE CAPACITY (16-HR DISCHARGE).

FIGURE 1. - CHARGE-DISCHARGE CYCLE TEST OF DOUGLAS SILVER-ZINC SECONDARY CELL AT 25° C.



*BASED ON LOW RATE CAPACITY (16-HR DISCHARGE).

FIGURE 2. - CHARGE-DISCHARGE CYCLE TEST OF DOUGLAS SILVER-ZINC SECONDARY CELL AT 100° C.

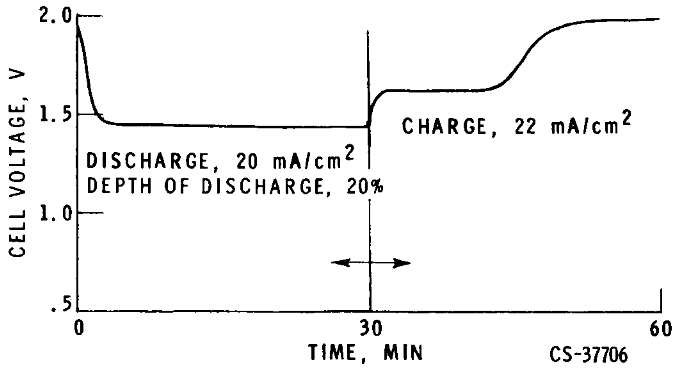


FIGURE 3.- DISCHARGE-CHARGE CURVE OF DOUGLAS SILVER-ZINC SECONDARY CELL AT ABOUT 25° C FOLLOWING HEAT STERILIZATION.

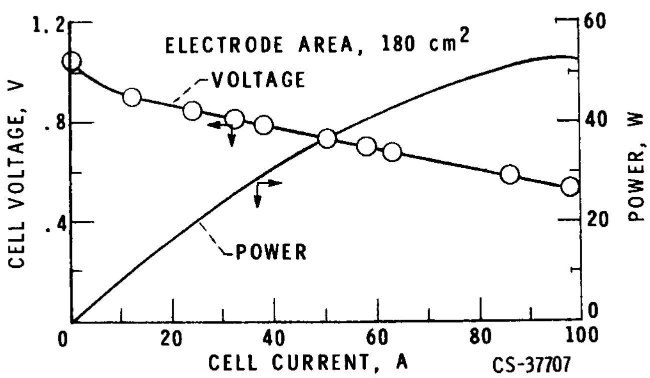


FIGURE 4. - ELECTRO-OPTICAL SYSTEMS, INC. CELL PERFORMANCE AT 125° C.

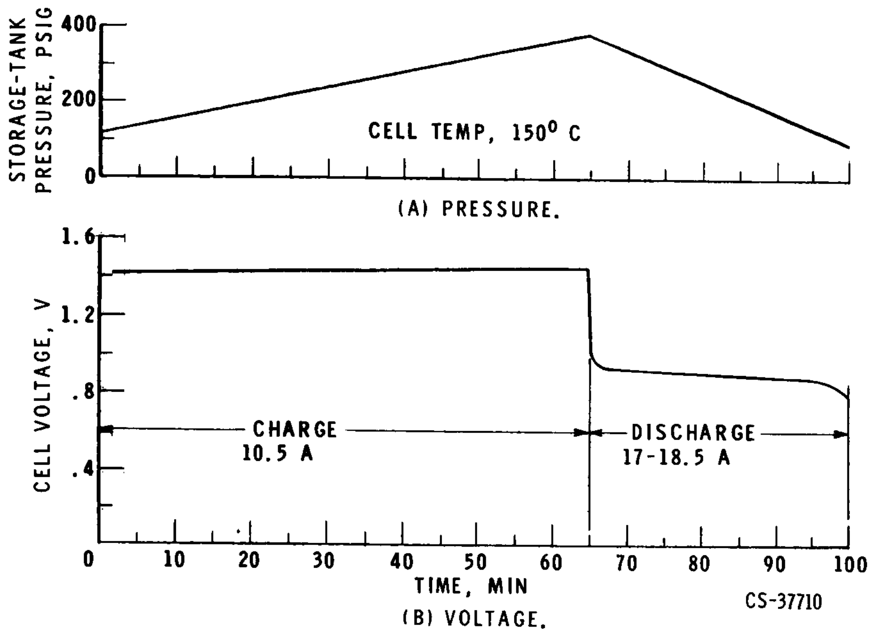


FIGURE 5. - HIGH-TEMPERATURE TEST OF SINGLE-CELL REGENERATIVE HYDROGEN-OXYGEN FUEL CELL AT 150° C.

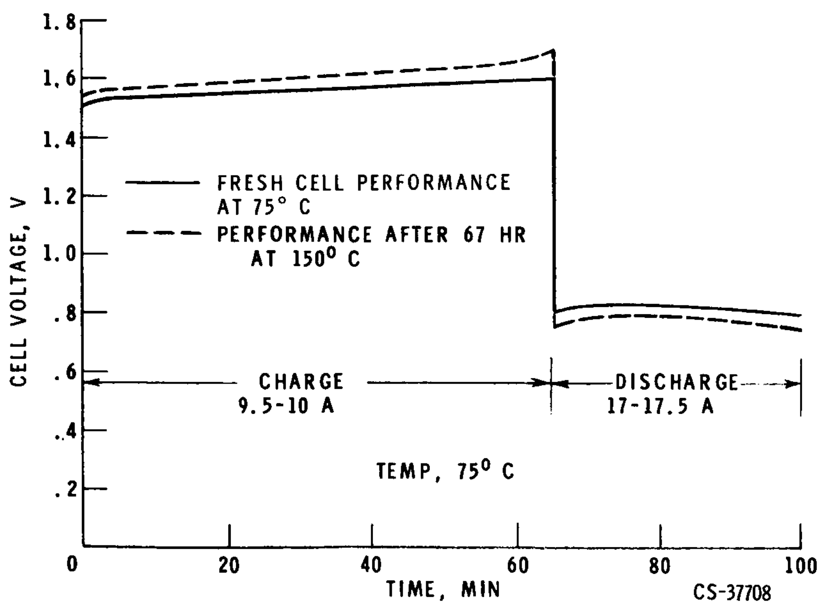


FIGURE 6. - EFFECT OF HIGH-TEMPERATURE STORAGE ON CELL PERFORMANCE.