CONF-950518--8

UCRL-JC-119686
PREPRINT

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J. F. Cooper
D. Fleming
R. Koopman
D. Hargrove
A. Maimoni
K. Peterman

This paper was prepared for submittal to the
Spring Meeting of the Electrochemical Society
Reno, NV
May 21–26, 1995

February 22, 1995

Lawrence Livermore National Laboratory

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Testing of a Refuelable Zinc/Air Bus Battery

by
John F. Cooper, Dennis Fleming, Ronald Koopman, Douglas Hargrove, Arturo Maimoni, and Keith Peterman
Lawrence Livermore National Laboratory • Livermore CA 94550

Abstract

We report tests of a refuelable zinc/air battery of modular, bipolar-cell design, intended for fleet electric busses and vans. The stack consists of twelve 250-cm^2 cells built of two units: (1) a copper-clad glass-reinforced epoxy board supporting anode and cathode current collectors, and (2) an polymer frame providing for air- and electrolyte distribution and zinc fuel storage. The stack was refueled in 4 min. by a hydraulic transfer of zinc particles entrained in solution flow.

Introduction. We have developed a novel high energy-density battery with provisions for rapid refueling by hydraulic transfer of zinc pellets entrained in electrolyte flow. The battery is intended to enable fleet electric vehicles (such as busses and delivery vans) to operate nearly continuously, with 10-minute refuelings at intervals of about 4-6 hours. The liquid discharge products removed at the time of refueling are recycled to produce new zinc fuel and fresh electrolyte by a combined electrochemical/mechanical process. (Fgiure 1). Refueling and zinc recovery operations use equipment located at the fleet's home base and operated by fleet personnel, thus allowing market introduction prior to establishing a commercial service infrastructure [1-3].

Technical Approach. Our cells are constructed of two reproducible units: a glass-reinforced, epoxy board with copper cladding on each surface (1.4-mm electronic circuit board) and a 7.6-mm thick polymer frame. The board supports both anode and cathode current collectors and has copper bridges to connect the opposite surfaces into a bipolar configuration. The polymer frames act as insulating separators between cathode and anode faces, and contain flow channels to allow circulation of air and electrolyte. The metal baskets containing zinc pellets are separated from the air-electrodes by microporous polymer separators (Pall RAI Manufacturing Company, Inc.; Hauppauge, N.Y.). The cells are divided vertically into two spaces of about 250 cm^2 each: the lower volume contains the galvanic cell, while the upper volume (310 cm^3) contains the zinc pellet fuel which gravity feeds into the cell on demand.

These cells make use of a bridging phenomenon which prevents the packing of particles of zinc falling into a narrow gap between air electrode and a bipolar transfer plate. When the width of this gap is only a few times greater that of the particles, the

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particles form bridges spanning the gap. The bridging maintains a quasi-stationary packed-particle bed of low hydraulic resistance to electrolyte flow. The dynamic behavior of the beds and discharge characteristics of these cells have been described earlier [1-3], as observed on scales of 80-, 600- and 1000 cm^2 anodes. The cells of the current battery are tripled 80 cm^2 units.

Refueling is accomplished by transfer of zinc 1-mm particles to individual hoppers above each cell by entrainment in a rapidly moving flow of electrolyte.

Technical Results. A twelve-cell stack (Figure 2) was refueled in 4 minutes, at a rate of 4 cells/minute plus a 1 minute startup. The cells were filled by 0.5 mm zinc cut wire cylinders or 0.75 ± 0.25 mm shredded zinc particles, which were allowed to fall into hoppers from the overlying fill tubes (Figure 1). The particles are far too heavy to form a slurry. Rather, the zinc particles were driven along the base of the 2.5 cm diameter fill channel by the shear of a low velocity (0.15 m/s) supernatant flow. This technique essentially isolates the fragile interior of the cell from any abrasive effects of a high velocity slurry, and allows the battery to be refueled with a low total flow (5 liters/minute) and pressure drop (2 kPa [0.3 psi]).

Refueling at this rate extrapolates directly to the refilling of a 55 kWh battery in 10 minutes. Such a battery would consist of hydraulic connections to produce a system of three parallel branches of three series-connected batteries each. Refueling steps would be as follows: (1) shut off air circulation through cells; (2) electrically disconnect batteries under conditions of open circuit; (3) drain and refill; (4) reconnect electrically. Shutting off air flow and allowing existing oxygen within the air-cathode chambers to be depleted is necessary to prevent short circuiting of the cells through metal bridging in the fill tubes.

We have recycled battery electrolyte to produce zinc fuel pellets by (1) deposition of zinc in a mossy morphology, and (2) cold compacting of the finely-divided zinc by a proprietary technique into cylindrical pellets of 1 mm diameter and 1 mm length. These pellets have 60% of theoretical density of zinc, require no binders or corrosion inhibitors of any kind, and are sufficiently light to allow transport by the shear produced by a 0.15 m/s supernatant fluid flow.

Single cell tests of the bipolar cells yield polarization curves consistent with the earlier results for the 80 cm^2 cells--the interelectrode configuration of which was replicated in the 250-cm^2 cells [1,2].

Heat rejection required the use of heat fins (Aavid Engineering, Inc.; Nassau NH). Under conditions of natural convection, the fins attached to 3 surfaces of the storage tank rejected >300 W of waste heat, without forced air circulation. This is sufficient for the time average heat load of the system at 50 A, when evaporative and other body losses are included. The thermal

inertia allows high power excursions without significant temperature increases.

Plans . At this writing, we are conducting a series of tests of multicells in preparation for a test of the battery on board a moving electric bus furnished by the Santa Barbara Metropolitan Transit District. This test is intended to study the effects of roadway vibrations on the self-feeding mechanics of the cell--which heretofore have been tested only in stationary units or on shaker tables. The tests will place a multicell zinc/air battery in parallel with a lead/acid battery of equivalent voltage. This diode-protected unit will be operated in series with the power train to assess its function as a power-leveled hybrid.

Applications. This work is motivated by the potential application to shuttle and transit busses, to fork lift trucks, and to delivery and passenger vans--vehicles which need high daily use to effectively recover their initial investment cost. Fleet vehicles can make use of the home base and its existing service personnel for both zinc fuel recovery and refueling, eliminating the need for "prior support infrastructure" that limits other concepts for refuelable or reconstructable-cell batteries electric vehicles.

Acknowledgments: Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48. We gratefully acknowledge the support of the U.S. Department of Transportation, Federal Transit Administration, through CALSTART, Inc. (Burbank, CA).

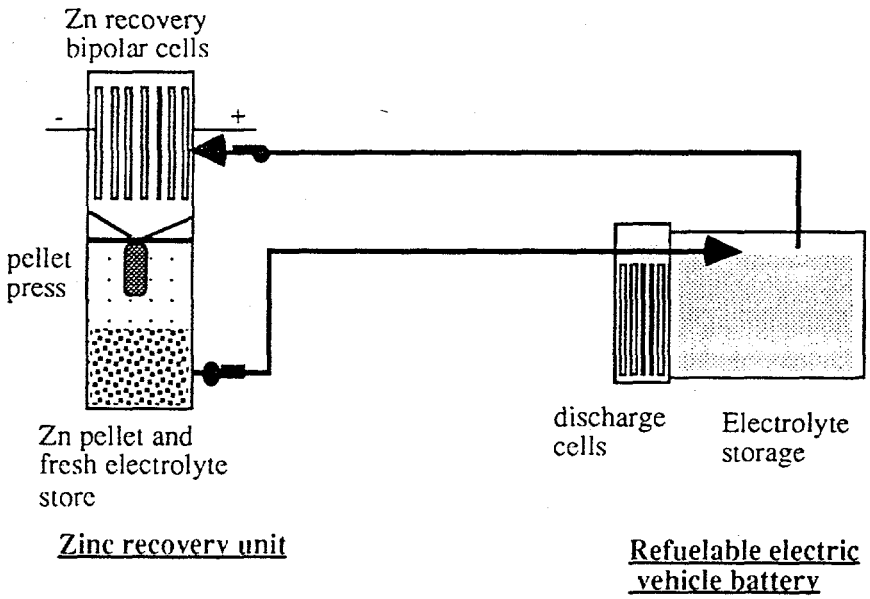

Figure 1. The zinc/air battery is refueled by a rapid transfer of 1-mm zinc pellets entrained in 12 M KOH recycled electrolyte. The pellets falling into hoppers above each cell through slots in a common feed tube. Spent electrolyte is withdrawn for recycling in a fixed unit located at the home base of the fleet or at another service site. Zinc is recovered from the spent electrolyte by electrolysis, and is subsequently pressed into 1 mm pellets.

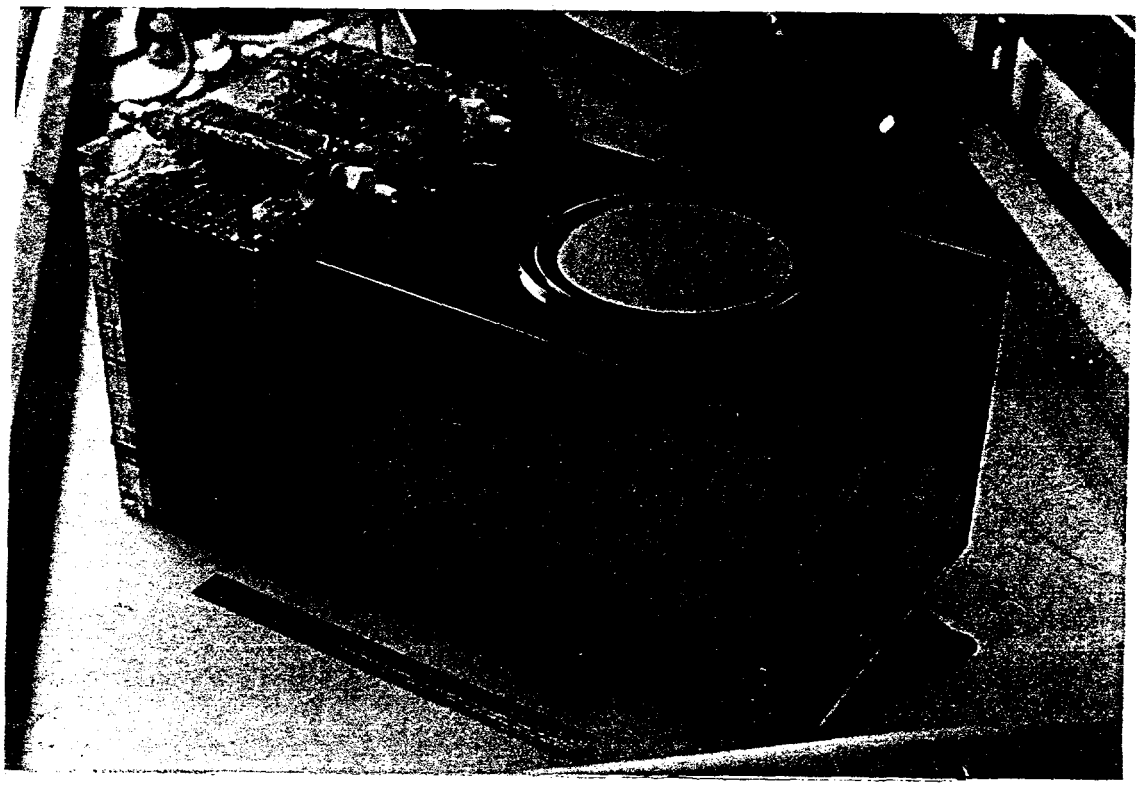

Figure 2. Assembled 12-cell stack and electrolyte storage tank.

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