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ALUMINUM/AIR BATTERY PROGRAM

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The goal of the aluminum/air program is to develop and demonstrate a battery capable of providing an electric vehicle with the range, acceleration, and rapid-refueling capability of today's conventional automobile. The motivation for this goal is the prospect of a significant decrease in our dependence on liquid fuels through the use of electric vehicles capable of widespread use in the automotive market. Benchmark goals for the total cost of vehicle operation and for total energy use are to achieve equivalence with internal combustion engine vehicles using synthetic liquid fuels derived from coal.

Our approach to these goals involves parallel developments of (1) cell configurations and battery processes that are scalable to vehicle size, using as models anodes and air-cathodes adapted from existing technologies; (2) cost-effective anode and cathode materials and structures; and (3) electric propulsion systems optimized for Al/air battery characteristics and low cost. Through 1982, the program has emphasized the research and development of battery processes.

Aluminum/air cells and cell stacks have been routinely operated under conditions anticipated for automotive battery applications. Small scale (25-cm^2 anode) cells were operated to establish a baseline for comparison with larger cells and cell stacks. In small cell tests, peak net energy yields were over 4.0 kW h/kg Al; peak power densities were 6.3 kW/m^2 (0.15-cm interelectrode gap) or 5.0 kW/m^2 (0.32-cm gap), using an Al–0.05 Ga–0.1 Mg alloy and the Diamond-Shamrock standard air electrode, in 4 M NaOH + 1 M $Al(OH)_3$ + 0.06 M $Na_2Sn(OH)_6$ at 60 °C. A large cell (0.1 m^2), the MO series, was operated with a crystallizer to stabilize concentration of aluminate at 2.7 M and to establish compatibility of cell and crystallizer processes (September 1980). A refuelable aluminum/air cell (M1-LLNL series) was tested in single, bicell, and six-cell stacks (M2 series). The cell provides for anode current collection to the dry side of a rectangular plate of aluminum (167 cm^2) soldered to a copper-clad support sheet. Air-electrode and separator ribs are on a flexible diaphragm and are advanced pneumatically against the anode during discharge. The six-cell stack was operated to exhaustion of the anodes, during which the electrolyte composition was allowed to rise to 3 M $Al(OH)_3$ (three times saturation level). Cell stack efficiency replicated that of baseline cells by 15 percent because of improvements in air distribution and cathode current collection. Shunt current losses and pumping power requirements were estimated at below 1 and 2 percent, respectively, compared to the anticipated average cell power level. A series of refuelable wedge-shaped cells were experimentally investigated to determine feasibility of continuous feed, full anode utilization, and partial recharge capability, in both aluminum/water and aluminum/air configurations. Both systems utilized parallel tracks of copper as both solution-side current collectors and interelectrode separators. The wedge configuration was found to replicate the performance of the M2 six-cell stack in a single cell configuration, and continuous anode feed and the utility of the tracks as current collectors have been demonstrated. A prototype cell has been developed that is constructed of two removable air-cathode cassettes that are fabricated by numerical-control machining. These prototype cells will provide the cell-stack portion for the M3 experimental phase (integration of cell stack, heat rejection system, and crystallizer).

A mathematical model for the crystallization process was developed on the basis of 1980 crystallizer kinetic studies and applied to the modeling of an adiabatic crystallizer for vehicular applications. The model predicts seed requirements of approximately 20 kg for a 40-kW (peak) battery system.

Solution-side current collection was investigated in cells with idealized geometry and with provisions for rapid switching between dry-side and solution-side modes. Junction resistance (between knife-edge and anode) was found to be 0.042 ohm-cm for linear contacts. Relative hydrogen evolution rates were approximately the same for dry- and solution-side modes.

A number of aluminum–alloy/electrolyte combinations were evaluated by experimental determination of polarization curves for aluminum dissolution and water reduction (hydrogen evolution), using a gas-coulometer.

Vehicle operating cost estimates were updated to 1981 aluminum prices, based on cost input data from the Reynolds Metal Company. Costs of \$2 to \$3.50/gal-equivalent were estimated on the basis of an alloy derived from 5-A metal and with the assumption of achieving 115 percent of the energy yield of RX808. The range assumes a comparison automobile of between 35 and 50 ton-miles/gal efficiency.

Research is planned in both power cell development and electrode development in 1983. The salient objective of Power Cell R & D is to complete the M3 experimental phase, in which a multicell stack of wedge-shaped cells is integrated with a crystallizer and heat rejection system and operated over the range of conditions anticipated for vehicular applications. The purpose of this phase is to acquire data of scientific and engineering value from a system of significant scale and using a replicable cell configuration that appears to satisfy both stationary applications and automotive needs. The data gathered will allow straight-forward extrapolation to the properties of a full-scale battery for any application using the alkaline electrolyte. Attention will be given to the evolution of anode shape and topography during extended discharge, evolution of crystallizer particle size distribution and morphology, change of composition of the electrolyte, and optimization of cell geometry using computer modeling of reaction and potential distribution over time.

The long range objective of anode research at LLNL is to determine what factors limit (and what is the limit to) the efficiency of the aluminum anode. This work involves the investigation of aluminum-dissolution and water-reduction kinetics on high-purity single- and poly-crystals and on the role of trace metals (100 ppm levels of Sn, Mg, Ga, In, and Zn) on electrode kinetics. The effects of distribution of impurities and the role of grain boundries on electrode efficiency will be investigated.

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ALUMINUM/AIR BATTERY DEVELOPMENT

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The objectives of this contract are to develop, test, and demonstrate hardware components for the aluminum/air battery. The principal task is to design, construct, and test a six-cell subscale (200 cm^2), rapidly refuelable aluminum/air battery. In addition, parametric cell tests using subscale cells will be conducted along with tests of components and systems studies.

Current collection techniques have been studied and improvements integrated into hardware to be used for six-cell testing. Modification of the test stand is currently in progress and will include provisions for remote sensing and control by computer-actuated interfacing.

Previous studies were made of two subscale and one full-size rapidly refuelable battery designs involving a moving cathode (Mark 1-2) and a moving anode (Mark 1-1 and Mark 1-3). The moving anode design was selected for further study because of simpler mechanical design and equivalent electrochemical performance. This design is being used to construct a six-cell subscale module to conduct parametric testing including mass and thermal balances. In addition, current collection techniques will be optimized, and rapid refuelability and complete anode utilizations will be demonstrated.

Technical objectives for 1983 are to design and fabricate a full-size wedge battery and evaluate performance in comparison with the moving anode design.