AQUEOUS MOBILE BATTERIES

Argonne National Laboratory (ANL), Chemical Engineering Division, Argonne, IL 60439 (U.S.A.)

This project is directed toward the development of improved lead–acid, nickel/iron, and nickel/zinc batteries for future application in electric vehicles. Key program goals for the battery characteristics are a specific energy of 56 Wh/kg based on the 3-h discharge rate, a peak specific power of 104 W/kg for 30 s at a 50 percent depth of discharge (DOD), and an 80 percent DOD cycle life of 800 cycles with an original equipment manufacturer price of $70/kW h (1981 dollars). Achievement of these battery goals will provide capability for a performance and cost competitive electric passenger car with an urban range of 100 mi. The battery R & D is carried out by industry subcontractors with project management and technical support provided by ANL. Performance and life verification testing of the industry-developed technology is performed by the ANL National Battery Test Laboratory (NBTL).

In September 1981, the number of battery contractors was reduced from eight to three. This action caused available funds to be focused, during 1982, on the most promising battery technologies. A selection of contractors for continuing R & D in 1982 was made by ANL and DOE based on the total funding available, the individual contractors funding requirements, and a detailed evaluation of each contractors technological capability and commitment. Based on these factors, continued support of Globe (lead–acid), Westinghouse (nickel/iron), and Eagle–Picher (nickel/iron) was warranted. Recognizing that the nickel/zinc battery offers sufficient potential in the long range to justify continued government support, a limited R & D program aimed specifically at overcoming life limitations was recommended for this battery system.

Battery R & D subcontracts are currently active with Globe Battery Division of Johnson Controls in the lead–acid area and with Westinghouse and Eagle–Picher Industries in the nickel/iron area. These contracts presently extend through the end of 1982. The battery R & D efforts by the industrial contractors during this period are directed toward providing cells and multicell modules to NBTL for verification testing. The present status of the technology is compared with the key 1982 objectives and 1986 goals in Table 1, where the demonstrated accomplishments are verified test results obtained on multicell modules at NBTL through June 1982.

Progress in cell development and battery subsystem design (chargers, watering systems, electrolyte management systems) has allowed the construction of full-sized battery packs. Globe Battery Division (lead–acid), Westinghouse (nickel/iron), and Eagle–Picher (nickel/iron) delivered full-sized batteries to the Jet Propulsion Laboratory for in-vehicle testing and evaluation.

TABLE 1

	Present status	1982 objectives	1986 goals
Lead–Acid			
Specific energy[a] (Wh/kg)	41	45	56
Specific power[b] (W/kg)	104	104	104
Cycle life[c]	508	650	800
Nickel/Iron			
Specific energy[a] (Wh/kg)	48	54	56
Specific power[b] (W/kg)	103	104	104
Cycle life[c]	816	800	800
Nickel/Zinc			
Specific energy[a] (Wh/kg)	68	—	56
Specific power[b] (W/kg)	131	—	104
Cycle life[c]	200	—	800

[a] At the 3-h discharge rate.
[b] Peak power (30-s average) at 50 percent state of charge.
[c] Cycling at greater than 80 percent depth of discharge, life to 75 percent retained capacity.

Internal ANL technology R & D support activities encompass post-test analyses, charge procedure development, assessment of the projected availability and cost of critical battery materials, and selected research studies on limiting technological problems. Among the 12 research studies conducted, Laser Raman spectroscopic and neutron diffraction studies defined the chemical and structural changes occurring in lead–acid battery electrodes, field measurements of arsine and stibine emissions permitted definition of the ventilation requirements of an electric vehicle lead–acid battery needed to ensure safe operation, investigations on nickel electrodes defined the overcharge requirements, a new theory was developed explaining the passivation phenomena observed in zinc electrodes, procedures and equipment were developed to permit quantitative measurement of battery separator characteristics, and effects on the battery of pulse discharges imposed by motor controllers were quantified.

Battery contractor R & D will continue to be the primary emphasis of this project during 1983. In lead–acid battery development, improved specific energy and cycle life are required. In nickel/iron battery development, increased specific energy and cost reduction will be stressed. A decision will be made in December 1982 whether to continue the R & D efforts at Globe, Eagle–Picher, and Westinghouse. This decision will be based on an evaluation of the status and progress of the technology development and an assessment of the prospects for significant future technology advancements with continuing R & D support.

Internal ANL battery-related activities will continue in the areas of post-test analyses, improved battery charging procedures, pulse discharge characterization, and thermal management studies.

Recent publications

1 C. C. Christianson, N. P. Yao and F. Hornstra, Near-term batteries for electric vehicles, *8th Energy Technology Conference and Expo, March 9 - 11, 1981, Washington, DC.*

2 G. Cook *et al.*, Annual synopsis of Argonne's aqueous battery support research, Argonne National Laboratory, *Report ANL/OEPM-82-3*, March 1982.

3 G. Cook *et al.*, Annual synopsis of battery support research, fiscal year 1980, Argonne National Laboratory, *Report ANL/OEPM-81-3*, May 1981.

4 W. DeLuca, A. Tummillo, F. Hornstra *et al.*, Effects of pulsed-current discharge waveforms on lead–acid traction cell performance, *1982 SAE Congress, Detroit, MI, February 22 - 26, 1982.*

5 J. D. Jorgensen, R. Varma, F. J. Rotella *et al.*, Hydrogen content and lead vacancies in β-PhO_2 active battery plates, *Proc. Symp. on Neutron Scattering, August 12 - 14, 1981, Argonne IL*, American Institute of Physics, in press.

6 J. D. Jorgensen, R. Varma, F. J. Rotella *et al.*, Lead deficiency and hydrogen content in battery electrode β-PbO_2, *J. Electrochem. Soc., 129* (8) (1982) 1678 - 1681.

7 J. D. Jorgensen, R. Varma, F. J. Rotella *et al.*, Lead deficiency and hydrogen content in lead dioxide battery-active material, *Electrochem. Soc. Meeting, Denver, CO, October 11 - 16, 1981, Extended Abstracts, 81-2* (1981) 1458 - 1459.

8 J. Lee, K. Choi, C. C. Christianson and N. P. Yao, Three-dimensional thermal modeling of EV batteries, *ECS Fall Meeting, Detroit, MI, October 17 - 22, 1982.*

9 M. B. Liu, G. M. Cook and N. P. Yao, Passivation of zinc anodes in KOH electrolytes, *J. Electrochem. Soc., 128* (8) (1981) 1663 - 1668.

10 M. B. Liu, G. M. Cook and N. P. Yao, The relationship between electrolyte conductance and current distribution in porous zinc electrode in KOH electrolyte, *J. Electrochem. Soc., 129* (6) (1982) 1390 - 1392.

11 M. B. Liu, G. M. Cook and N. P. Yao, Transient current distributions in porous zinc electrodes in KOH electrolyte, *J. Electrochem. Soc., 129* (2) (1982) 239 - 246.

12 M. B. Liu, G. M. Cook and N. P. Yao, Vibrating zinc electrodes in Ni/Zn batteries, *J. Electrochem. Soc., 129* (5) (1982) 913 - 920.

13 M. B. Liu, R. Faulds, G. M. Cook and N. P. Yao, Conductivity of KOH electrolyte supersaturated with zincate, *J. Electrochem. Soc., 128* (10) (1981) 2049 - 2052.

14 M. Liu, B. Faulds, G. Cook and N. P. Yao, Current distribution in porous zinc electrode. II. The effect of electrolyte conductance, *The Electrochemical Society Meeting, Minneapolis, MN, May 10 - 15, 1981.*

15 R. O. Loutfy, D. G. Graczyk, R. Varma *et al.*, Stibine/arsine monitoring during EV operation — summary report on preliminary tests at ANL and at LILCO, Argonne National Laboratory, *Report ANL/OEPM-81-1*, February 1981.

16 J. F. Miller, J. B. Rajan, F. Hornstra *et al.*, Status of improved lead–acid, nickel/iron and nickel/zinc batteries being developed under DOE's electric vehicle battery program, *The Electrochemical Society Meeting, Detroit, MI, October 17 - 22, 1982.*

17 R. Varma, G. Cook, W. Molinarolo and N. P. Yao, *In situ* monitoring of electrode surface phases by laser Raman spectroscopy during anodization and sulfation of tetrabasic lead sulfate in sulfuric acid, *159th Meeting of ECS, Minneapolis, MN, May 10 - 15, 1981.*

18 R. Varma, G. Cook and N. P. Yao, Anodization and sulfation of tetrabasic lead sulfate in sulfuric acid: *in situ* monitoring of electrode surface phases by laser Raman scattering, *J. Electrochem. Soc., 128* (5) (1981) 1165 - 1168.

19 R. Varma, G. M. Cook and N. P. Yao, Raman spectroscopy for *in situ* monitoring of electrode processes, Argonne National Laboratory, *Report ANL/OEPM-82-2*, April 1982.

20 R. Varma, G. Cook, N. P. Yao (CEN) *et al.*, Lead deficiencies in lead dioxide battery active material, *American Physical Society Meeting, Phoenix, AZ, March 16 - 20, 1981.*

21 Y. Yamazaki and N. P. Yao, Current distributions in soluble battery electrodes II. Experimental, *J. Electrochem. Soc.*, *128* (8) (1981) 1658 - 1662.
22 Y. Yamazaki and N. P. Yao, Current distribution in soluble battery electrodes I. Theoretical, *J. Electrochem. Soc.*, *128* (8) (1981) 1655 - 1658.
23 N. P. Yao, Near-term battery support, DOE Battery and Electrochemical Contractors' Conference, electrochemical storage systems program summary, *U.S. DOE Report CONF-810642 (Summ.)*, June 1981, pp. 30 - 35.
24 N. P. Yao, Near-term electric vehicle batteries, DOE Battery and Electrochemical Contractor's Conference, electrochemical storage systems program summary, *U.S. DOE Report CONF-810642 (Summ.)*, June 1981, pp. 3 - 6.
25 N. P. Yao, U.S.A. EV Battery Programme, *J. Power Sources, 7* (4) (1982) 317 - 329.
26 N. P. Yao, C. C. Christianson and F. Hornstra, Prospect of advanced lead–acid, nickel/iron and nickel/zinc batteries for electric vehicle applications, *16th Intsoc. Energy Conversion Eng. Conf., August 9 - 14, 1981.*
27 N. P. Yao, C. C. Christianson, T. S. Lee *et al.*, DOE's Electric Vehicle Battery Program — status of improved lead–acid, nickel/iron, and nickel/zinc battery developments in 1981, *EVC Symposium VI, sponsored by the Electric Vehicle Council, Baltimore, MD, October 21 - 23, 1981.*
28 N. P. Yao, C. Christianson, T. Lee *et al.*, Near-term EV battery project — Overview, *4th DOE Battery and Electrochemical Contractors' Conference, Washington, DC, June 2 - 4, 1981.*
29 N. P. Yao, C. Christianson, J. Rajan *et al.*, Development of aqueous batteries for electric vehicles — Summary Report — October 1979 - September 1980, Argonne National Laboratory, *Report ANL/OEPM-81-5*, February 1981.

RESEARCH, DEVELOPMENT, AND DEMONSTRATION OF A LEAD–ACID BATTERY FOR ELECTRIC VEHICLE PROPULSION

Globe Battery Division, Johnson Controls Inc., 5757 North Green Bay Avenue, Milwaukee, WI 53201 (U.S.A.)

The objective of this project is to develop and demonstrate improved and advanced lead–acid battery systems for electric vehicles (EVs). Key technical goals for 1982 are a specific energy of 45 Wh/kg at the 3-h discharge rate, a specific peak power of 104 W/kg for 30 s when 50 percent discharged, and a life capability of 650 cycles at an 80 percent depth of discharge.

In the development of improved state-of-the-art (ISOA) lead–acid batteries, Globe has identified the plate size, plate aspect ratio, number of plates, and acid concentration best suited for EV application. A low corrosion grid alloy was selected to enhance cycle life. In addition, Globe has developed an innovative electrolyte mixing pump that has increased both specific energy and cycle life.

During 1981, Globe delivered two 96-V (23.4-kW h) ISOA batteries to the National Battery Testing Laboratory (NBTL) for preliminary testing.