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DEVELOPMENT OF COMPRESSED MULTIFOIL INSULATION
FOR HIGH-TEMPERATURE BATTERIES AND OTHER APPLICATIONS

by

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ABSTRACT

The Li-alloy/FeS battery operates at $>450^{\circ}\text{C}$ and thus requires an insulated jacket for thermal management. The use of compressed multifoil confined in a lightweight, stainless steel, double-walled jacket at a pressure of less than $100\text{ }\mu\text{m Hg}$ was tested as an insulating medium for a 36-V, 8-kWh Li-alloy/FeS battery. Two battery jackets measuring approximately $48 \times 28 \times 85\text{ cm}$ were fabricated and tested in this program. Test results were encouraging. Product development and marketing are planned by Meyer Tool and Manufacturing, Inc.

I. INTRODUCTION

Worldwide research is being directed to the development of high-performance batteries for electric vehicle propulsion. Several of these battery systems (e.g., sodium/sulfur, lithium/iron sulfide, sodium/metal chloride) require operation at temperatures that range from 300 to 500°C . To be cost effective and energy efficient, these batteries must be enclosed in an insulating jacket that is thermally efficient, lightweight, compact, and inexpensive.

Several types of insulation for such a jacket have been developed by industrial organizations, including the Linde Division of Union Carbide¹ and, more recently, by a collaborative effort between ANL and Meyer Tool and Manufacturing. As part of the collaborative effort, a compressed multifoil insulation consisting of alternating layers of aluminum foil and glass-fiber paper was tested as an insulating medium for Li/FeS batteries. The compressed blanket of multifoil is housed in a lightweight, stainless steel, double-walled vessel at a pressure of $10\text{--}100\text{ }\mu\text{m Hg}$, which is maintained at that level by the use of chemical getters.

In addition to its use for high-temperature batteries, this insulation can be used in other commercial and military applications, such as fuel cells, electronic devices, food storage enclosures, refrigerators, insulated gas lines, and furnace chambers.

II. THERMAL MANAGEMENT REQUIREMENTS

This section outlines some of the important considerations involved in developing an insulated jacket for an electric van battery. The shape, size,

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and performance projections of a Li/FeS battery for four electric vans (General Motors G-van, Chrysler TE van, Ford ETA, and Eaton DSEP) are described in a separate report.²

Figure 1 shows a conceptual design for a Li-alloy/FeS van battery with an insulated jacket. The location of the multifoil insulation within the double-walled jacket is illustrated. The cover is a thin-walled metal sheet backed

Fig. 1. Conceptual Design of Li-Alloy/FeS Van Battery

by several inches of conventional insulation. The electrical and gas lines that connect the battery to the power train and auxiliary systems in the vehicle pass through the cover.

Selected properties of three types of rigid vacuum insulation are given in Table 1. These insulating materials are all sufficiently rigid to resist the collapse of the thin-walled vacuum vessel used to enclose the insulation. As shown in Table 1, the thermal conductivity of the compressed multifoil that we employed in our test jacket was measured to be 65×10^{-5} Btu/h·ft·°F (113×10^{-5} W/m·°C) at Linde. If this value is achieved in practice, one-inch-thick insulation would reduce the heat loss to 1.8 W/ft² (16 W/m²) at Li/FeS battery operating conditions, i.e., inner wall temperature of about 465°C.

The jacket specifications for a full-scale van battery are given in Table 2. The battery jacket weight was calculated for a van powered by a Li/FeS battery. The van design is that developed by Eaton Corp. under the Dual Shaft Electric Propulsion (DSEP) program sponsored by the U.S. Department of Energy. This electric van design includes a Chrysler Corp. minivan body and a 30 kW AC three-phase induction motor. The battery DC output is converted to AC by a compact, transistorized inverter. The battery jacket includes CMF insulation and 10-mil stainless steel. This combination results in a jacket weighing 49 kg or about 8% of the total battery weight, well within our design target of 10%.

Heat loss targets for the components of the DSEP van battery jacket are given in Table 3. A value of 250 W was thus chosen as an interim target and

Table 1. Properties of Rigid Vacuum Insulations^a

Manufacturer	Type	Density		Thermal Conductivity		Heat Loss ^b	
		lb/ft ³	kg/m ³	Btu/(h·ft·°F)	W/(m·°C)	W/ft ²	W/m ²
Linde	Board	21	336	151 x 10 ⁻³	263 x 10 ⁻⁵	4.2	39
Linde	Peg-Foil	13	208	50 x 10 ⁻⁵	87 x 10 ⁻⁵	1.4	13
Meyer Tool	CMF ^c	27	432	65 x 10 ⁻⁵	113 x 10 ⁻⁵	1.8	16

^aDensity and thermal conductivity taken from Linde Report, Ref. 1.

^bOne-inch-thick insulation; temperature gradient, 440°C.

^cCompressed multifoil.

Table 2. Specifications for DSEP Van Battery Jacket^a

Parameter	Specifications
Battery Size	76 x 25 x 188 cm
Battery Weight	594 kg
Jacket Weight	
Compressed Multifoil Insulation	33 kg
Stainless Steel Sheet (10-mil thick)	16 kg
Total	49 kg

^aBasis for calculations: Eaton Corp. DSEP van.

Table 3. Heat Loss Targets for DSEP Van Battery Jacket^a

Component	Heat Loss, W
Insulation	115
Plug	40
Transition	35
Penetrations	60
	250 ^b

^aBasis: Eaton Corp. DSEP van.

^bThis is the design target for a full-scale 200-V van battery. The design target for a 36-V battery was taken to be 100 W.

is used in the battery temperature profile and energy balance calculations that are given in Fig. 2 and Table 4, respectively. The values calculated for the Eaton DSEP van are typical of those that can be expected for Li/FeS batteries that would be designed for the General Motors G-van, Chrysler TE van, or the Ford ETX since the weight and shape for all of these vehicle batteries are similar. The calculations for the five-days-per-week (75 miles/day) schedule for an electric van show that the heating requirement for each week is about 35 h at 250 W (455 kWh/yr). This amounts to less than 4% of the total electrical power consumed in a one-year operation and is easily affordable. Figure 2 also illustrates that forced cooling (4°C/h on weekdays) will be required at night to decrease the battery temperature to its optimum starting temperature of about 440°C. Under typical conditions, no cooling of the battery will be required during the day, although a provision for such cooling is part of our standard design. Unforced cooling on weekends (2°C/h) will decrease the battery temperature to 440°C.

Fig. 2. Battery Temperature Profile for DSEP Van Battery with 250-W Heat Loss

Table 4. Energy Balance for DSEP Van Battery with 250-W Heat Loss

Driving Schedule, miles:

Monday through Friday	375
Weekend	0
Annual (52 weeks/yr)	19,500

Energy Consumption for Charging:

Vehicle Energy Efficiency, Wh/tonne·mile	194
Battery Output/Mile, Wh	409
Battery DC/DC Efficiency, %	75
Charger AC/DC Efficiency, %	90
AC Power/Mile, Wh	606
AC Power to Charger/Year, kWh	11,817

Energy Consumption for Heating:

Hours Heating/Week at 250 W	35
Kilowatt-hours per Year	455
Heating Power as % of Total AC Power	3.7

III. DESIGN AND FABRICATION

The concept of using compressed multifoil was tested by designing and fabricating two jackets (Mark I and II) that were sized to fit a 36 V, 8-kWh Li/FeS battery (three series-connected modules of 12 V each).

A photograph of the first jacket (Mark I) fabricated in this program is shown in Fig. 3. Thermal tests of this jacket showed high heat loss at the rear and front of the jacket. The design of the jacket was modified and a

Fig. 3. Photograph of Mark I 36-V Battery Jacket

second (Mark II) jacket was built to test the new design concept. A sketch of the revised design for the Mark II jacket, showing some of the design improvements made for the rear, is given in Fig. 4. The improvement over the Mark I design was primarily achieved by the use of a stepped termination of the multifoil, in conjunction with a stepped plug of board insulation (rather than folded multifoil) to fill the rear cavity. Loss of heat at the front of the enclosure in Mark I was caused by the heat flow from the hot inner wall to the cold outer wall via the thin stainless steel transition membrane used to obtain a seal, in addition to the axial flow of heat within the insulation due to the aluminum foil. To minimize the axial flow of heat, the Mark II jacket was wrapped with a reduced length of multifoil and the void at the front was filled with a board-type glass-fiber insulation.

Fig. 4. Schematic of Mark II 36-V Battery Jacket Design

For the Mark II jacket, multifoil insulation wraps consisting of alternating layers of type H19 aluminum foil (0.0008-cm thick) and Dexter 233 glass-fiber paper (0.0084-cm thick) were machine wrapped on a prefabricated Type 304 stainless steel shell (0.043-cm thick). A total of 266 multifoil wraps were used. The outer shell, also 0.043-cm-thick stainless steel, enclosed the multifoil and was welded vacuum tight to the inner shell using a thin stainless steel transition membrane. This construction provides for a compressed insulation thickness of 2 cm, which supports the jacket walls when the insulation annulus is vacuum pumped. Further design information on the Mark II jacket is given in Table 5.

Table 5. Design Specifications for Mark II Jacket

Size:		
Outer Dimensions, cm	48 x 28 x 85	
Insulated Wall Thickness, cm	2	
Weight, kg:		
Type 304 Stainless Steel Sheet	8.2	
"Board" Insulation, Glass Fiber	5.0	
Multifoil (Aluminum and Dexter 233 Paper)	16	
Miscellaneous Hardware	2.7	
Total	31.9	
Insulation Description:		
Type H19 Aluminum Foil		
Thickness, cm	0.0008	
Weight, g/m ²	0.17	
Dexter 233 Glass-Fiber Paper		
Thickness, cm	0.0084	
Weight, g/m ²	0.14	
Dexter Paper		
Thickness at 15 psi, cm	0.0056	
Multifoil Insulation		
Layers/cm at 15 psi	159	
Density, g/cm ³	0.57	
Stainless Steel Foil Thickness, cm	0.008	

A thin-screen gas channel running the length inside the case at the four rounded corners allows for effective gas pump-out throughout the entire length of the insulation annulus.

The rear cover of the inner shell is designed to act as a diaphragm, allowing for thermal expansion of the inner shell when it is heated to operating temperature. Both the inner and outer shells incorporate embossed struts to strengthen the case longitudinally during thermal expansion.

The stainless steel sheet metal was embossed, formed, and welded to create the major portion of the inner shell. A thin flange was welded to the front end, and the diaphragm rear cover was seal-welded to the opposite end. The completed unit comprises the inner shell.

Special tooling was designed to support the inner shell on a power-driven rotary machine. The alternating layers of foil and paper under controlled tension could then be wrapped on the inner shell to provide the required insulation thickness.

A perforated metal basket containing -650 g of type 5T707 SAES getter material was attached to the outer surface of the end cover (see Fig. 4). The rectangular outer shell was welded in place to the front flange. A board-type insulation was installed to fill the rear section. The outer rear cover was then seal-welded to the outer shell to form the vacuum annulus. The outer rear cover has tubing stubs to allow for gas pump-out and the connection of a vacuum gauge.

IV. TEST RESULTS

The Mark II jacket and the Mark I jacket modified at the rear in accordance with the Mark II design were tested to determine heat loss and skin temperature. A resistance-heated aluminum block of approximately the size of the three 12-V Li/FeS modules was inserted into the jackets, and the front end was plugged with approximately six inches of conventional insulation. The aluminum block was then heated to a steady-state temperature of 465°C, and the power input was measured to give the overall jacket heat loss. The test results are summarized in Table 6.

Table 6. Heat Loss Test Results for Mark I and II Jackets

	Heat Loss, W	Annulus Pressure, $\mu\text{m Hg}$	Jacket Wall Temperature, °C above ambient		
			Front	Middle	Back
Mark I ^a	208	130	26	12	15
Mark II	168	17	22	10	8

^aTest results shown are for the Mark I jacket after reworking the rear section using the Mark II design concept.

Although our design target for heat loss of 100 W for a 36-V battery jacket was not met, the results are sufficiently encouraging to suggest continued development of this approach. The Mark II test showed that the chemical getter used (SAES, Type 5T707) was successful in reducing the pressure in the insulation annulus to below the 100 $\mu\text{m Hg}$ target. This result suggests that it will be possible to fabricate a battery jacket that will require only a heatup to operating temperature to reach and maintain the required low pressure for the life of the battery jacket.

V. PROJECTED COSTS

Cost estimates for the battery jacket are given in the Linde report already cited.¹ Based upon 1982 costs for materials and labor, an estimated price of \$1650/unit was made for a rectangular jacket using the compressed glass-fiber board insulation for quantities manufactured at 1000 units/year. A cost estimate for the CMF-insulated jacket was made in 1989 by Meyer Tool and Manufacturing. A selling price of \$974/unit was estimated for a production level of 1000 units/year. Further price reduction is possible by amortizing the capital cost over a larger number of units and reducing labor costs by additional manufacturing development.

VI. SUMMARY

The work, to date, has shown that compressed multifoil can be fabricated into a rectangular configuration suitable for use as an insulated jacket for the Li/FeS van battery. The concept appears to lend itself to inexpensive fabrication through the use of automated or semiautomated winding of the insulation under load. If the low thermal conductivity for this insulation exhibited in laboratory tests can be achieved in practice, insulation thickness can be reduced to about 2 cm, with considerable savings in materials cost compared to other high-efficiency insulation that also uses glass-fiber paper. Some additional work is needed to optimize the number of layers, improve the insulation materials, and develop an inexpensive welding procedure. Continued product development and marketing are being planned by Meyer Tool and Manufacturing.

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REFERENCES

1. J. Nowobilski and A. Acharya, Insulation and Enclosure Development for High Temperature Electric Vehicle Batteries, Union Carbide Corp., Linde Division, Final Report, Contract No. DE-AC02-80ET25426, Tonawanda, NY (May 1982).
2. A. A. Chilenskas and G. Barlow, "Li/FeS Battery Design for an Electric Van," Proc. of 1989 SAE Int. Cong. and Expo., February 27-March 3, 1989 (to be published).

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