Journal of Power Sources, 11 (1984) 87 - 90

THE NEXT DECADE — LITHIUM BATTERIES

D. LINDEN
78 Lovett Avenue, Little Silver, NJ 07739 (U.S.A.)

Battery development has usually progressed by gradual steps as a result of the use of new materials and engineering in contrast to the quantum jumps resulting from major technological advances that are sometimes experienced in other fields, such as electronics. This is due to the built-in limitation in batteries of specific energy so that improvements are thus limited to the use of materials with higher specific energy, to increasing the efficiency of material utilization and to minimizing the dead space and weight of the non-energy producing components of a battery. The gradual, yet definitive, progress in battery performance over the past 30 years is shown in Fig. 1. This illustrates the relatively limited performance improvement that can be achieved with a given electrochemical system and the more significant improvement when new chemistries are used.

During the last decade, the significant advances in the battery field have been largely due to the use of lithium or other alkali metals as the anode material. The use of lithium as an anode offers many performance advantages over conventional batteries. First is the advantage of a substantial increase in energy density which results in a manyfold reduction in the size of the battery — or an equivalent increase in its service life. Of equal importance is the long shelf life of the lithium systems which presents the opportunity for new types of applications. These include memory back-up, batteries capable of lasting for the life of the equipment (e.g., watches, cameras), long-term standby applications, and a means of improving the logistics of handling batteries in use, storage and inventory. In addition, most lithium systems operate over a much wider temperature range than conventional batteries — and some are capable of extremely high rate discharges (high power density). The lithium systems show signs of achieving the requirements for that 'ideal' battery that has been so elusive.

The successful use of lithium, which was always attractive because of its advantages as an anode material, awaited the availability of compatible electrolytes and materials of battery construction. Once achieved, lithium became a focal point of battery research and development, and is being used or considered for use in almost every type of battery power source. It is being used in primary, secondary, as well as reserve batteries; in both ambient and high temperature battery systems; and in sizes and applications ranging from sub-miniature solid electrolyte batteries with capacities as low as 3 mA h to large standby power supplies with capacities as high as 10 000 A h. A summary of some of the different types of batteries employing lithium as the anode material is given in Table 1.

0378-7753/84/$3.00

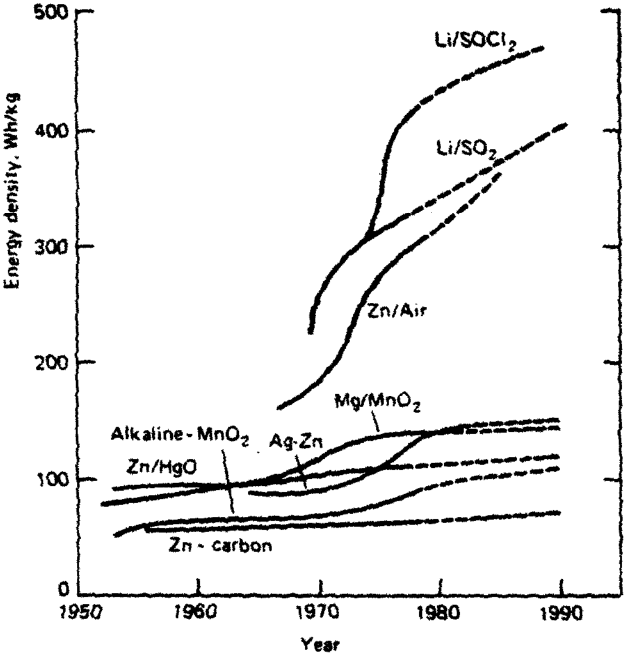

Fig. 1. Advances in the development of primary cells; continuous discharge at 20 °C, 40- to 60-h rate. D- or similar size cell (solid line, historical data: broken line, forecast). After H. HazKany, E. Peled and B. Raz, Primary batteries — a forecast of performance, *Proc. 29th Power Sources Conf., 1980*, p. 56.

Even with the substantial research, development and engineering program on lithium batteries, and the performance advantages of these new electrochemical systems, the development has been slow and lithium batteries have yet to attain a significant share of the battery market. While they have made inroads in military equipment, and in small consumer applications, such as calculators, watches, cameras and computer memory back-up, lithium batteries are still not used in mass consumer or industrial applications. There are a number of reasons for this slow market development.

The battery industry, historically, has been slow in adapting to new developments. Time is required for test and evaluation, for establishing applications and markets, for building manufacturing facilities and for all of the other factors needed to make the new items cost-effective and competitive. Another obstacle has been the justified concern for the safe and reliable performance of these highly energetic batteries. A considerable portion of the research effort on lithium batteries has been concerned with safety and reliability. Confidence in this aspect of lithium battery performance is growing and regulatory agencies have periodically eased their limitations and controls. Further, some of the more advanced and sophisticated battery systems, e.g., the high temperature batteries for electric vehicles and utility

TABLE 1

Lithium anode battery systems

Type of battery	Typical battery systems	Characteristics
Primary batteries		
Solid electrolyte	$Li/LiI/I_2$, $Li/LiI(Al_2O_3)/PbI_2$, PbS, Pb	Solid state, excellent shelf life, long-term, low drain discharge
Solid cathode	Li/MnO_2, $Li/(CF)_n$, etc.	High energy output for moderate power requirements
Soluble cathode		
Organic electrolyte	Li/SO_2	High energy output, high power output, low temperature operation, long shelf life
Inorganic electrolyte	$Li/SOCl_2$, Li/SO_2Cl_2	
Secondary batteries		
Ambient temperature		
Chalcogenides	Li/TiS_2	High energy density, low power
Organic electrolyte	Li/SO_2	High energy density, high power capability
Polymer	Li/polyacetylene	High energy density, experimental
High temperature		
Molten electrolyte	LiAl/FeS	High energy density, very high power density
Solid electrolyte	$Li/LiI(Al_2O_3)/TiS_2$	High energy density, high power capability
Mechanically rechargeable	Li/air	High energy density, rapid refueling for electric vehicle applications
Reserve batteries		
Organic electrolyte	Li/V_2O_5, Li/SO_2	Long unactivated life, moderate energy density
Inorganic electrolyte	$Li/SOCl_2$	Long unactivated life, high energy density
Water (LiOH) electrolyte	Li/H_2O	High energy density, high power output
Spin-activated	$Li/SOCl_2$	High energy density, spin activation

load leveling, are still in the development stage, and deployment is still several years away.

The lithium battery technology is thus ripe for broad commercial and industrial application in the 1985 - 1995 period. Lithium batteries should predominate in the miniature battery market, at least by the late 1980s, capturing the major share of the market for calculators, watches, photographic equipment and memory back-up. The market for the larger lithium primary batteries will develop more slowly. The military and aerospace applications should be almost completely converted to lithium. The lithium battery will also be particularly attractive for special industrial and commercial applications, where lightweight and superior performance will take priority over cost. Later in the period, the lithium battery will be ready for the mass consumer market. Chemical formulations will be developed and designs will be engineered to provide the level of safety needed for this market. This increased production will result in cost reduction and the lithium battery will be competitive with conventional batteries on a service-hour per unit cost basis.

Lithium secondary batteries will also be attractive because of their performance advantage over conventional types for certain applications. In the smaller portable sizes, the lithium battery will have the advantages of light weight and its cycle life will be adequate for most of the uses now handled by sealed lead–acid and sealed nickel–cadmium batteries. In the larger sizes, it is unlikely that lithium batteries will be competitive with conventional batteries for automotive (SLI), traction or stationary applications. However, for the newer electric utility, electric vehicle and large standby power applications, where higher energy density and power density are essential to meet the performance requirements, the high temperature lithium and sodium battery are prime candidates. Continued research and development will, no doubt, be emphasized in the next decade to meet these stringent, yet important, specifications.

With increasing production and cost reduction and increasing confidence in its performance reliability and safety, the lithium battery will become a most important power source for military, industrial and consumer applications.