## Book Review

### *Handbook of Batteries and Fuel Cells*

By David Linden, published by McGraw-Hill Book Company GmbH., Hamburg, F.R.G., 1984; 1024 pp.; price DM 258.80.

The editorial background to this book is impressive. The editor-in-chief, David Linden, was for some years Head of the Power Sources Division of the U.S. Army Electronics R & D Command, and is now a consultant to a leading firm of U.S. battery manufacturers and may, therefore, be expected to have an extensive knowledge of the battery and fuel cell fields and of the developments taking place. Furthermore, he has had the assistance of 53 contributors, each an expert in a particular area. Forty-one of these contributors are authors, either alone or in conjunction with other experts, of one or more chapters in the book.

The 43 chapters are grouped into six parts: Principles of Operation; Primary Batteries; Secondary Batteries; Advanced Secondary Batteries; Reserve and Special Batteries; Fuel Cells.

The opening chapter of Part 1, Basic Principles, gives a simple, brief, but adequate account of what batteries are, how they work, and of the various types that are available. The second chapter, Electrochemical Principles and Reactions, has the intention "to outline the basic principles and electrochemical processes common to primary and secondary batteries and fuel cells" — a difficult task. Starting with elementary thermodynamics the chapter proceeds through the theoretical aspects of electrode processes, double layer capacities, ionic adsorption and mass transport to consideration of electroanalytical techniques and the electrodes used in them. This is a chapter for persons with a scientific background. To the many non-technical readers who will probably refer to the book as a means of helping them to select a battery for their particular application, its significance will not be readily apparent. For such readers an extra paragraph or two at the end of the chapter to explain the connection between its subject matter and practical batteries would probably be helpful.

In the third chapter of this part, Considerations for the Selection and Application of Batteries, what is probably, for many persons, the major purpose of the book is introduced. The various types of primary, secondary, and fuel cells are named, their particular characteristics and suitabilities for different applications are discussed. The effects of different discharge conditions, temperature, and storage conditions on performance are considered in general terms, and a comparison is made of batteries on a performance and cost basis. The text in this, and other, chapters is admirably supported by a large number of Figures and Tables.

Part 2 of the book, Primary Batteries, opens with a chapter which is almost a continuation of the last chapter of Part 1. It describes in greater detail the characteristics of the various types of primary battery and makes further cost comparisons. The effects of temperature and storage time on output are illustrated, but there are no curves for specific output at discharge rates up to several years. Such curves, by showing the rate at which peak output is obtained for each type of battery, would probably be of considerable help to the user in making his preliminary choice of battery. Useful advice is given on recharging primary batteries — don't do it, except perhaps for some Leclanché cells. The chapter concludes with useful lists of battery and cell system identification, dimensions, and designations, as well as a cross-reference guide to the designations used by various manufacturers for similar types and sizes of cells and batteries. National (U.S.A.) and I.E.C. standards are also briefly mentioned.

Each of the next eight chapters is devoted to one particular cell system: the zinc–carbon Leclanché) cell; magnesium and aluminium cells; alkaline manganese dioxide cells; mercuric oxide cells; silver oxide cells; zinc–air cells; lithium cells and solid electrolyte cells. In general, similar treatment is given to each type of cell: a brief historical- general characteristics introduction, followed by an outline of the basic chemistry and electrochemistry, and some details of the manufacturing processes and cell construction before the detailed discussion of cell performance. These chapters have few frills, but are just full of facts, figures, and useful information. Information on the commercial availability of cells is usually given and also advice on the handling and disposal of those types of cell with which hazards could arise. The coverage is good, the chapter on mercuric oxide cells includes both zinc and cadmium anode cells and that on zinc–air cells includes large cells with capacities of up to 1000 A h, which have been in use for many years, as well as smaller cells, especially button sizes, developed more recently. Information is given on standardised sizes, performance characteristics, and manufacturers' cross references for cell sizes for the more popular systems. It is of interest to note that most space is given to lithium batteries with Leclanché batteries taking second place. This is probably a reflection of the number of lithium systems which have been developed, as well as of the complexity and commercial importance of both cell systems.

Part 3 of the book, Secondary Batteries, follows a similar pattern to that on Primary Batteries. There is a short introductory chapter which outlines the main applications and advantages of secondary batteries, the types available, their general characteristics, and makes a preliminary comparison between them. Their cost is referred to briefly as is the position on standardisation on an international and national (U.S.A.) basis.This is followed by twelve chapters, each dealing with a particular system or systems: Lead–acid batteries; sealed lead–acid batteries; vented, pocket plate nickel–cadmium batteries; vented, sintered plate nickel–cadmium batteries; sealed nickel–cadmium batteries; nickel–zinc batteries; iron electrode systems; silver oxide batteries; nickel–hydrogen batteries; silver–hydrogen batteries; rechargeable,

"primary type" batteries and lithium batteries (ambient — meaning normal — temperature). The chapters on lead–acid and nickel–cadmium batteries are the most extensive, and a welcome feature is the attention given to charging and maintenance procedures. The inclusion of a chapter on sealed lead–acid batteries, with its emphasis on charging procedures and safety in use, is also a valuable feature.

The chapter on nickel–zinc batteries is mainly concerned with the work which has been carried out, and is still in progress, to develop this high-energy-density system into a commercial product, particularly for electric vehicle applications. This objective has not yet been attained, mainly on account of life problems associated with the zinc electrode. By contrast, the next chapter, iron electrode batteries, gives details of the rugged, long life, well established nickel–iron system, and then goes on to the new developments which offer the prospect of increased output and the possible use of this battery in electric vehicles; an application for which the iron–air battery is also a possible candidate. Progress in the development of this battery is also described. Brief mention of the silver–iron battery is made in this and the following chapter.

The chapter on silver oxide batteries includes zinc and cadmium anode cells. In addition to the usual performance figures, the characteristics of cells produced by two U.S. manufacturers are given, together with a brief account of the applications of the batteries and recent developments to improve their performance.

In the two following chapters the recently developed, expensive nickel–hydrogen and silver–hydrogen batteries are introduced. Very different from most conventional batteries, they are intended mainly for aerospace applications. Most of the chapter on nickel–hydrogen batteries is, in fact, concerned with three batteries for satellite use, two of which were actually launched. The chapter on silver–hydrogen batteries is limited to the design and performance characteristics of a battery based on this, the higher energy density, system.

A brief description of rechargeable zinc–alkaline–manganese dioxide and rechargeable zinc–silver oxide button cells and of their performance characteristics is given in the chapter on Rechargeable "primary type" Batteries. Attention is drawn to the need to limit the depth of discharge and to the potential use of the silver oxide cell with solar panel charging.

This part of the book concludes with a chapter on Lithium Batteries. This documents the advantages of such systems, the problems involved in their development, the success achieved to date, and the probable course of future development.

Thus far the merit of this book is unquestionable. It is eminently factual and informative, and the few minor errors are so obvious as to be unimportant. Many readers, particularly European ones, will probably regret that more space has not been given to Planté batteries, and it may be considered that some of the other lead systems such as lead dioxide–zinc, lead–perchloric acid–lead dioxide and lead–silver oxide are worthy of mention,

whilst information, possibly as an Appendix, on purity of acid and alkaline electrolytes, and the water used for maintaining electrolyte levels, would probably be useful, particularly to battery users in the less-developed countries. The coverage is, however, good and the requirements of persons seeking information on readily available battery systems and their suitability to requirements are amply met.

The next three parts, Advanced Secondary Batteries, Reserve and Special Batteries, and Fuel Cells, differ from the earlier parts in that they deal with batteries which are either under development or are of a specialised type which are nearly always manufactured to meet particular requirements.

Part 4, Advanced Secondary Batteries, is, in effect, a progress report on the work started under government and industrial sponsorship to develop batteries for vehicle propulsion, load levelling, and energy storage at the time of the oil crisis. The opening chapter outlines the requirements which it was hoped to meet, the characteristics of the systems selected for development, the problems peculiar to each system, the progress made, and the future prospects. The following chapters deal in detail with the work on the specific systems: aqueous redox flow cells, zinc–chlorine batteries, zinc–bromine batteries, metal (zinc, lithium and aluminium)–air cells, lithium–iron sulphide batteries and sodium–sulphur batteries. Work on these systems is, in general, still in progress; much of it on mechanical problems of battery design. Performance characteristics and schematics are given for some systems and, in the case of batteries for EV applications, estimated physical characteristics. The work on sodium–sulphur batteries is limited to that carried out by Dow, G.E., and Ford Aerospace, the extensive work carried out in Europe and elsewhere is not mentioned. Commercial production does not appear to have been achieved yet for any of these advanced batteries.

Production facilities are available for most of the batteries discussed in Part 5, Reserve and Special Batteries, but manufacture is nearly always to meet particular requirements. The first chapter defines reserve batteries, lists the types available, and describes their general characteristics. The following chapters deal with water-activated batteries, lithium–water batteries, zinc–silver oxide reserve batteries, spin activated batteries, ammonia batteries, ambient (*i.e.*, room) temperature lithium anode reserve batteries and thermal batteries. The several alternatives to the magnesium–silver chloride system are discussed in the chapter on water-activated batteries and although some of these are in use, most of the advantages, except of cost, rest with the silver chloride system. Lithium–water batteries are a comparatively new arrival in the field of high energy and power density systems. In principle a simple system, battery design is very complicated, but prototype batteries have apparently been produced. Only general characteristics are given and the most recent reference is dated 1979. Both manually and automatically activated batteries are discussed in the chapter on Zinc–Silver Oxide Reserve Batteries. General characteristics are given together with information on the effects of activating with, and without, connected load. Much of the chapter is concerned with batteries developed some years ago for U.S. military

requirements; there are other types! The chapter on Spin Activated Batteries is concerned with long storage life batteries for use in spin-stabilized projectiles in which the spin of the projectile is used to activate the battery. Originally designed for a short discharge life, less than one minute, the lead–fluoboric acid–lead dioxide system was mainly used. With more recent requirements for longer discharge times the lithium–thionyl chloride system is being used. Some constructional and performance details are given. The next three chapters also are mainly concerned with the construction and performance of specialised, long-storage-life batteries for military and space applications. Ammonia Batteries were developed to meet requirements for longer discharge times and low temperature operation. The set-back force on discharge of a missile is used to break the ammonia container and the liquid ammonia is then forced into the cell(s). Liquid ammonia is preferred to the gas as it gives more rapid and uniform activation. The cells employ an unusual electrochemical system: magnesium–ammonium thiocyanate (potasium thiocyanate)–meta dinitro benzene. The high voltage and capacity of lithium cells are obviously very attractive for use in applications of this type where space is at a premium. Lithium Anode Reserve Batteries have consequently been developed based on the Li–$SO_2$, Li–$V_2O_5$, and Li–$SOCl_2$ systems: the latter system is now preferred. Originally single cell designs were produced, but multi-cell designs are now in production. Some single cells are available commercially. The final chapter in this Part deals with Thermal Batteries, batteries in which the solid electrolyte is inert until it is melted by pyrotechnic heat sources, usually placed between the cells, which are ignited by a percussion primer or an electrically fired squib. The electrolyte is usually lithium chloride–potassium chloride eutectic, the anode calcium or magnesium and the cathode calcium chromate, tungsten oxide or iron sulphide. Recently, lithium anodes have come into use. Originally the discharge life of these batteries was short, tens of seconds, but batteries are now available with a discharge life of an hour or more. Again some constructional and performance details are given.

The final Part of the book deals with Fuel Cells. The first chapter of this part, General Characteristics, gives a brief but very adequate description of fuel cells, their properties, principles of operation, and of the various systems under consideration. The next chapter, Low Power Fuel Cell Systems, briefly describes the systems used in the Gemini and Apollo space programs and for the Space Shuttle Orbiter, and then goes on to describe the small portable fuel cells developed for military purposes using hydrazine or hydrogen, obtained from metal hydride, as fuel; other systems which have been tried or are under development are also described. The chapter concludes with an account of the development in progress of a range of larger, military, indirect methanol fuel cell plants with a reformer and phosphoric acid electrolyte, and of a larger plant, based on the same system, for use in a hybrid fuel cell–battery vehicle power system. This is another chapter where, unfortunately, no mention is made of work carried on outside the U.S.A.

The final chapter is concerned with the development of large Utility Fuel Cell Plants in the range 40 kW - 600 MW. These are mainly based on phosphoric acid electrolyte cells with natural gas, coal gases or liquids, or petroleum products as primary fuels. Field tests of 40 kW plants are apparently in progress and tests on larger plants, 4.5 MW and 7.5 MW, are planned for the mid-1980s. Work is also in progress on molten carbonate and solid oxide fuel cell plants, but is less advanced. The chapter concludes with a Prognosis of the future use of fuel cell power plants and suggests that phosphoric acid electrolyte cell plants will possibly be in early use, but plants based on the other electrolytes are unlikely to be up for serious consideration before the 1990s.

There are six appendices to the book: Definitions, which includes a definition of Ambient Temperature, a term which, with the exception of three chapter authors, is generally incorrectly used in the text of the book; Standard Reduction Potentials; Properties of Battery Materials (fuel cell materials are, in general, omitted); Standard Symbols and Constants; Conversion Factors; Bibliography, a mere two pages from which several important non-American periodicals and battery standards are missing, although these are referenced in many of the chapters; and Major Battery Manufacturers.

The Editor-in-Chief, David Linden, is to be congratulated on undertaking and completing this massive handbook. The coverage is excellent and the control of the text very satisfactory; most of the chapters keep to a common pattern and there is very little repetition.

Obviously this is mainly a reference book, and it is, therefore, regrettable that in the chapters dealing with recent developments, work outside the U.S.A. is largely ignored. The inadequate Bibliography is probably the greatest defect in the book.

A major problem with a book of this type is that whilst further development of generally available products is slow, so that the book will remain up-to-date for many years, progress in the new areas is liable to be rapid, and parts of the book may soon be very dated. With the present book this problem has probably already arisen, and it might have been advantageous if it had been published in two parts; the first dealing with batteries which are generally available and for which development has been largely completed, and a second part containing selected items still under extensive development, this second part could then be updated from time to time to keep in step with the progress in development.

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