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Energy storage and the environment: the role of battery technology

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Abstract

Batteries can store energy in a clean, convenient and efficient manner. Battery-powered electric vehicles are expected to contribute to a cleaner environment. In today's world, batteries are used everywhere: in electronic watches, pocket calculators, flashlights, toys, radios, tape recorders, cameras, camcorders, laptop computers, cordless telephones, paging devices, hearing aids, heart pacers, instruments, detectors, sensors, memory back-up devices, drug dispensing, wireless tools, toothbrushes, razors, stationary emergency power equipment, automobile starters, electric vehicles, boats, submarines, airplanes and satellites. Worldwide, about 15 billion primary batteries, and well over 200 million starter batteries are produced per year. What is the impact of this widespread use of batteries on the environment? What role can battery technology play in order to reduce undue effects on the environment? Since this paper is presented at a lead/acid battery conference, the discussion refers, in particular, to this system. The following aspects are covered: (i) the three "E" criteria that are applicable to batteries: Energy, Economics, Environment; (ii) service life and environment; (iii) judicious use and service life; (iv) recycling.

Energy, economics, environment

During the past 30 years, many battery systems have made their (sometimes short) appearance. Back in 1974 [1], the proliferation of new battery chemistries was illustrated by the schematic given in Fig. 1.

The building blocks of this 'Babylonian tower of power sources' are the various proposed battery systems, as designated by the chemical formulae of electrode materials and electrolyte. Interestingly, some of the oldest battery systems, such as the lead/acid battery, remain the 'work horses' of industry. It should be added immediately that lead/acid batteries have been improved steadily over the years and that they exist today also in a maintenance-free, sealed form.

During recent years, the 'tower of power sources' has grown more slowly, and a certain disillusionment has taken place with regard to the rapid success of new systems. The criteria applied to battery systems are summarized in Table 1. In the past, battery technology has dealt primarily with the first two criteria. Batteries have been evaluated according to 'price:performance ratios'. But now, as the worldwide consumption of batteries is at such a high level, environmental aspects are commanding increased attention. Battery technology has taken already important strides in finding solutions to environmental issues. Mercury- and cadmium-free dry cells have appeared on the market. Cadmium-free, rechargeable nickel/metal hydride cells are beginning to replace nickel/cadmium batteries. Finally, for some time, lithium batteries free of toxic heavy metals have been available. Today, an important issue is that of energy consumption.

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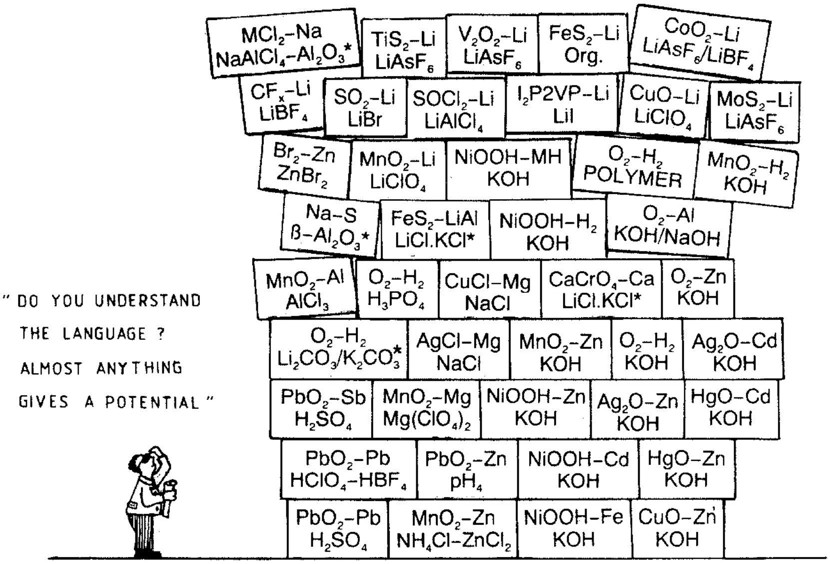

Fig. 1. The Babylonian tower of power sources.

TABLE 1

Battery criteria

Energy	High gravimetric/volumetric energy and power density
Economics	Low manufacturing costs, low maintenance during use
Environment	Free of toxic materials, safe, low energy consumption during manufacture and use, long service life, high reliability, easy to recycle

Unfortunately, the electric energy delivered by means of batteries is relatively expensive. This is especially the case for (small) primary batteries. They can serve only applications where power consumption is correspondingly low. An amazing price is being paid per kW h of packaged, mobile energy (Table 2).

Secondary batteries can deliver energy at a much lower price, since manufacturing costs can be written off over many cycles. In order to store large quantities of electricity economically (i.e., in applications such as load-levelling or in photovoltaic installations), batteries must have the longest possible service life, so that energy-transfer costs are kept at acceptable levels. A real challenge to battery technology! The use of secondary batteries is presenting also the ecological advantage that a smaller overall volume of batteries needs to be recycled. The total annual battery volume that must be disposed of is inversely proportional to service life.

How can, in the light of the parameters given in Table 1, the lead/acid battery defend its position as the leading power source? Lead is a toxic, heavy metal. The lead level in blood should be below 50 μg/dl, and at the workplace, lead-in-air should be below 100 μg m^{-3}. This requires proper handling techniques and clean housekeeping

TABLE 2

Price of electric energy delivered by batteries

Batteries	US $/kW h
Primary batteries	
Button cells (silver oxide)	> 10000
Cylindrical (alkaline manganese)	100–200
Secondary batteries	
Cylindrical (nickel/cadmium)	
500 cycles	5–10
Large lead/acid (tubular)	
1000 cycles	0.40–0.80
1500 cycles	0.25–0.50
2000 cycles	0.20–0.40

during manufacture and recycling. Lead has also the drawback of being heavy. The energy density of lead/acid batteries is correspondingly low. On the other hand, lead/acid batteries have the advantage of a relatively favourable price, a (potentially) long service life, low self-discharge, maintenance-free or sealed construction, and ease of recycling. These are the reasons why the lead/acid battery will not be dethroned in the forseeable future. This conclusion has remained unchanged for the last 30 years [2–4].

Service life and environment

In order to protect the environment, energy consumption must be minimized, wherever possible. This applies also to the manufacture of batteries. In a lead/acid battery factory, the cost of energy consumption (electricity, oil, gas) can reach about 1 to 2 US $ per kW h of manufactured nominal battery energy (that is, for instance, per one 12 V, 84 A h battery). This represents about 2% of the battery retail price. When carrying out a so-called 'total net energy analysis' [5], the energy required to produce the raw materials (lead alloys, separators, cases, lids, acid) starting from ore, minerals and oil, as well as an appropriate fraction of the energy that was required to construct the battery plant, including equipment, must also be considered. Finally, energy is again expended in recycling, after use. In total, energy costs might possibly constitute up to 10% of the sale price of the battery.

In order to limit energy consumption, therefore, batteries should be built for the longest possible (and appropriate) service life. Less energy is needed to make one good battery than two bad ones. Low quality, low reliability and early failures cost energy, money and nerves.

Figure 2 demonstrates how the service life of tubular-plate, stationary batteries under float-charge conditions was increased by the development of a new casting technique for the positive grids. This permitted a decrease in the antimony content of the alloy. The results stem from long-time tests, carried out at the laboratories of the Swiss PTT. The float voltage was 2.20 V/cell. The capacity was tested once per annum at the *C*/10 discharge rate.

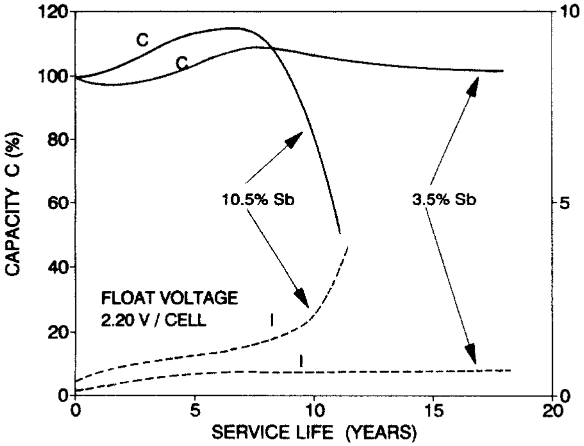

Fig. 2. Service life of tubular-plate, stationary lead/acid batteries, with grids of 10.5 wt.% Sb and 3.5 wt.% Sb, during float service.

In traction batteries subjected to deep cycling during service, appropriate means to retain the positive active mass (i.e., gauntlets for tubular plates, or glassfibre mats for flat plates) are indispensable. Much progress has been made in recent years with regard to the quality of these retainers. A long cycle life can only be achieved if the positive active mass is under mechanical compression [6–8].

Energy could also be saved by improvement of the utilization factor of the active mass and improvement of the charge efficiency. The addition of well-crystallized graphite might offer interesting new possibilities in this area [9–11].

Judicious use and service life

The maximum service life, with minimum consumption of energy, will only be achieved if the user follows correctly the operating instructions. Here, the battery manufacturer has the constant task of educating the user. Regarding stationary batteries, for instance, the selection of the proper float voltage is critical.

This is illustrated in Fig. 3; the data refer to long-term tests carried out at the Swiss PTT laboratories with tubular-plate batteries, containing a 3.5 wt.% Sb alloy. Excellent service life is obtained at the optimum float voltage of 2.20 V/cell.

The user should also be aware of the influence of temperature on the float voltage to be selected, and on the service life. In the temperature range between 10 and 20 °C, the optimum float voltage decreases with increasing temperature by about 3 mV per °C, at higher temperatures somewhat less (Fig. 4). The service life decreases drastically with increasing temperature.

It should also be mentioned that the service life of automotive starter (SLI) batteries depends strongly on temperature. This explains, at least in part, the shorter average life in regions of hot climate [12], as demonstrated in Table 3. It would therefore make sense to build special (thick-plate) batteries for hot climates.

Traction batteries, undergoing deep cycling during service, require an adequate charging regime. The charger must be dimensioned as to supply initially, at voltages below 2.4 V/cell, a sufficiently high charge current, at least *C*/5 or higher.

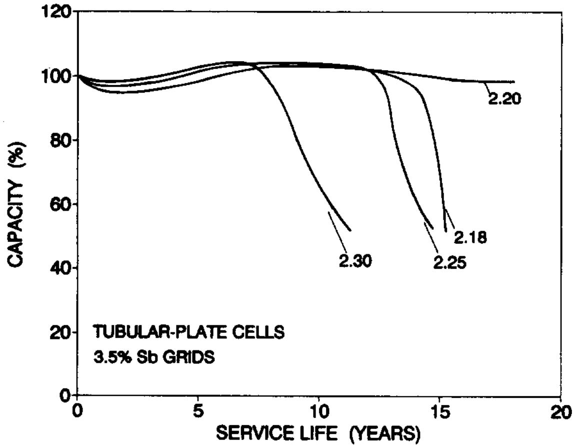

Fig. 3. Influence of float voltage on service life of tubular-plate stationary lead/acid batteries (2.18, 2.20, 2.25 and 2.30 V/cell).

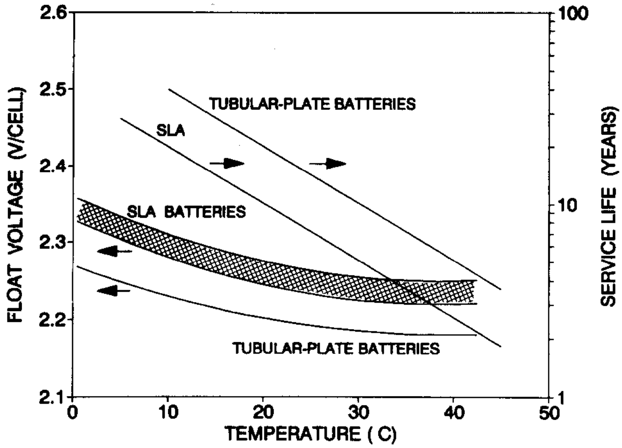

Fig. 4. Influence of temperature on best float voltage, and (estimated) service life of tubular-plate and sealed stationary lead/acid batteries (SLA).

TABLE 3

Average service life of automotive (SLI) batteries [12]

Continent	Years
Europe	5.4
Asia/Pacific	4.1
North America	3.0
Latin America	1.9
Africa/Middle East	1.6

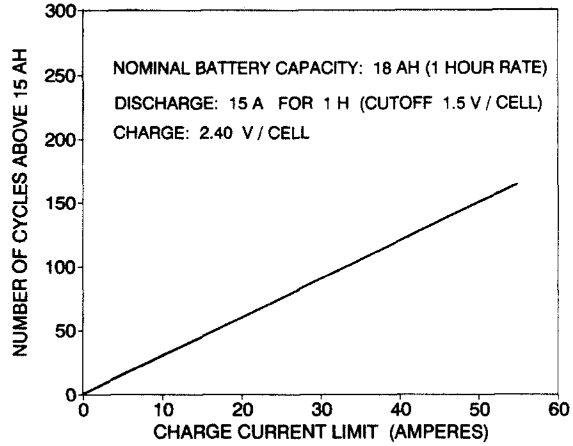

Fig. 5. Cycle life of sealed aircraft batteries as function of initial charge current.

The effect of charge rate on cycle life has been discussed recently by Meissner and Voss [13]. Vutetakis and Wu [14] have confirmed the strong increase in cycle life with increasing charge current for sealed aircraft batteries; their data are summarized in Fig. 5. It should be pointed out that the results deal, at least partly, with a temperature effect on cycle life.

Construction of batteries for ease of recycling

In Europe, the recycling rate of lead/acid batteries is very high, probably about 98%, and certainly ahead of most other consumer goods collected after use for recycling. Strict legislation helps to maintain a high recycling rate, even during periods of low lead prices.

One aim of recycling must be to minimize the waste volume that must be disposed of in land-fill sites. With respect to lead/acid batteries, modern recycling techniques have been realized (such as the Engitec–Impianti process). These recover not only the lead, but also the polypropylene from cases and covers. Such treatment reduces the volume of waste to be dumped by as much as 50%.

Resins, such as acrylonitrile/butadiene/styrene (ABS) or polyvinylchloride (PVC), on the other hand, must be separated from the polypropylene and cannot be re-used at this time. A representative of the recycling industry has stated recently at a BCI Meeting: 'No battery company should build a battery case without asking the question: what happens when this is recycled?' [15]. It is thus necessary for manufacturers and recyclers to work in tandem.

Recycling becomes more difficult if the lead/acid batteries contain foreign metals, such as copper. The use of expanded copper grids for negative plates, or of copper inserts in terminals, complicates recycling. Even more so, batteries should not contain toxic heavy metals, such as cadmium. Marketing 'miracle additives' that contain cadmium sulfate may be lucrative, but is certainly not in the interest of the environment, nor do the additives prolong battery service life to any significant extent.

Concluding remarks

The role of (lead/acid) battery technology with regard to the environment may be summarized as follows:

(i) to develop manufacturing techniques that require a minimum quantity of energy, and to develop batteries of high efficiency in order to minimize energy consumption during use;

(ii) to develop batteries with long service life, minimum maintenance and high reliability; and

(iii) to develop batteries for ease of recycling and with inherent safety.

For the marketing and sales people, it is relevant to repeat the statement: it is better for the environment to sell one good battery than two bad ones.

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