High performance nickel–cadmium cells for electric vehicles

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Abstract

A new concept of a cadmium electrode associated with a lighter nickel structure, a multi-cell module technology, allows the proposal of a very promising alternative power source for electric vehicle (EV) batteries, the usable specific energy being 31% of the theoretical value. Every characteristic of this Ni–Cd module (i.e. specific energy and power, energy and power density, energy efficiency, life and reliability) gives the best performing EV battery, to date. Thus, with the efficient support of two major French car manufacturers and the French government, SAFT will launch, during Spring '95, the first pilot line of EV Ni–Cd module manufacturing.

1. Introduction

SAFT has developed and produced, since 1987, high performance nickel–cadmium, 6 V modules, designed for electric vehicle (EV) applications. Although batteries are on trial throughout the world, before the end of 1994 two modules will be produced in large volumes on a new automated pilot line, to meet the launch of electric vehicle mass production by the two French car makers Peugeot and Renault.

The development and the industrialisation of a cadmium electrode designed for long life and high performance, initially foreseen for railway applications (SAFT SRX cells), has enabled SAFT to use a high capacity electrode without any memory effect.

2. Background

Having studied and developed for more than a decade both the nickel–zinc and the nickel–iron couple, SAFT has acquired an extensive expertise on the alkaline EV battery. While waiting for what is probably the next generation of nickel–cathode couple – the SAFT nickel–metal hydride battery – the present nickel–cadmium battery represents the best possible balance between specific energy, specific power, life, reliability and cost per mile.

3. Module design

At present SAFT has available at pre-production quantities three sizes of module, the STM 5-100, STM 5-140 and STM 5-180. All are composed of five cells internally

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TABLE 1

Summary of the main characteristics

			Module	
			1994	1996
General data				
Dimensions				
height (mm)			260	260
width (mm)			190	190
length (mm)			260	260
Weight, typical (kg) (including restraining device)			23.4	21
Rated capacity (V)			6.0	6.0
(Ah)			180	190
Electrical performances (typical values after full charge at 0.2 *C*/5 at 23 °C)				
Capacity	at 23 °C	at 0.2 *C*/5 (Ah)	208	216
		at 1 *C*/5 (Ah)	185	192
	at −18 °C	at 1 *C*/5 (Ah)	160	166
Energy	at 23 °C	at 0.2 *C*/5 (Wh)	1260	1311
		at 1 *C*/5 (Wh)	1065	1108
Specific energy		at 0.2 *C*/5 (Wh/kg)	54	63
		at 1 *C*/5 (Wh/kg)	46	53
Heating during a 200 A full discharge (air cooled)(°C)			27	27
Maximal peak power at 23 °C (15 s/4 V) (W)			4000	4000
Specific power (15 s/4 V) (W/kg)			171	171
Charging efficiency for 80% DOD cycling				
energy			0.70	0.75
faradaic			0.83	0.89
Life (tested on cycling in laboratory at 80% DOD) (cycles)			3200[a]	?
Expected life on vehicle (80% DOD) (cycles)			2000	2000
Maintenance (topping up every...) (cycles)			15	300

[a]Cycling test still going on.

connected in series with respective capacities of 100, 140 and 180 Ah. The two first modules (100 and 140) will go into mass production before the end of 1994.

3.1. Electrodes

The positive electrodes are made of sintered nickel chemically impregnated with a proprietary mix of hydroxides specially designed to minimise the plate swelling and to increase chargeability at high temperature.

The thickness of each plate, which has been optimised to give the best power–energy–cost ratio, is 1 mm.

The negative electrode is a plastic-bonded cadmium electrode. The manufacturing process consists of mixing active material, binder and additives, depositing them on a perforated steel substrate, and drying and laminating the strip produced. The thickness of the cadmium plastic-bonded electrode is adjusted to 0.7 mm. The negative excess capacity is 25%.

This new technology gives to the cadmium electrode the best energy density and life and drastically reduces its cost compared with a sintered electrode. Performance is equivalent to a sintered cadmium electrode.

In addition, a new cathodic structure is presently under development, with the aim of reducing weight while maintaining the performance of the existing sintered electrode. It will be available in 1995 and will allow the increase in the characteristics of the module as described in Table 1.

3.2. Separator and electrolyte

The separator, made of a polypropylene microporous structure to which two non-woven felts are added, gives to the cells a very high reliability and a long life. The initial thickness is 0.30 mm.

The electrolyte, a solution of potassium, sodium and lithium hydroxides optimises high rate discharge performance, life, and energy efficiency. It allows the cell to be discharged at temperatures down to −30 °C.

3.3. Cell case and watering system

The cell case, made of polypropylene with a thermal welded cover, has five compartments. Internal connection is achieved by means of sealed-through-the-wall connections. A single point watering system allows each cell to be filled automatically and also collects the gases produced during overcharge.

Some cases are equipped with unique additions such as:

- a specially designed manifold to assist the interconnection of the water filling system within each module
- a reinforced wall structure to avoid the swelling of the module cases
- an integrated liquid cooling system

3.4. Module weight breakdown (Table 2)

The STM module has been optimised for EV application. The connections and case represent less than 8% of the total weight.

TABLE 2

Module weight breakdown

Items	Typical weight (%)
Electrodes	67.1
Separator	2.7
Electrolyte	22.3
Terminals and connections	2.0
Case, cover and filling caps	5.9
Total module	100.0

4. Electrical performances

4.1. Discharge characteristics

4.1.1. Discharge at 23 °C

The high performance Ni–Cd plate stack delivers full capacity at high currents with a flat discharge profile. Used on an electric vehicle, no power decrease will occur during discharge with peak currents up to 1.5 *C*/5 A. The maximum rate of continuous discharge is only limited by the battery heating. 1.5 *C*/5 A must be considered as a maximum in ventilated conditions.

Typical constant current discharge curves at 23 °C are shown in Fig. 1.

4.1.2. Peak power

Peak discharges of 15 s can be performed up to 6 *C*/5 A, however this module is not designed for this utilisation (Fig. 2(a)). High current peaks can be provided by a starting battery with even more efficiency. Power density (0.8 V_{pc}, 15 s, 50% discharged) is 200 W/kg.

Another important characteristic is the variation of the peak power with the depth-of-discharge. The driver of an electric vehicle needs to be confident that he can achieve the acceleration or maximum speed at any time, especially when the battery is coming close to the end of discharge.

Figure 2(b) gives the variation of the peak power versus the depth-of-discharge.

4.1.3. Energy and specific power

The use of sintered nickel positive electrodes associated with plastic-bonded cadmium negative electrodes and a felt/microporous system separator gives the STM module a high specific energy. This specific energy is slightly sensitive to the rate of discharge as shown in Fig. 3.

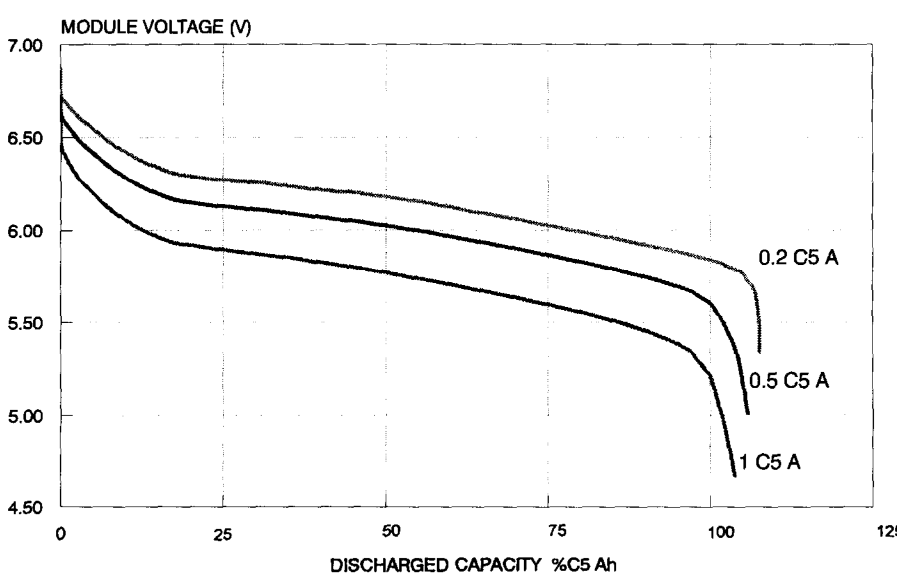

Fig. 1. Typical discharge curves.

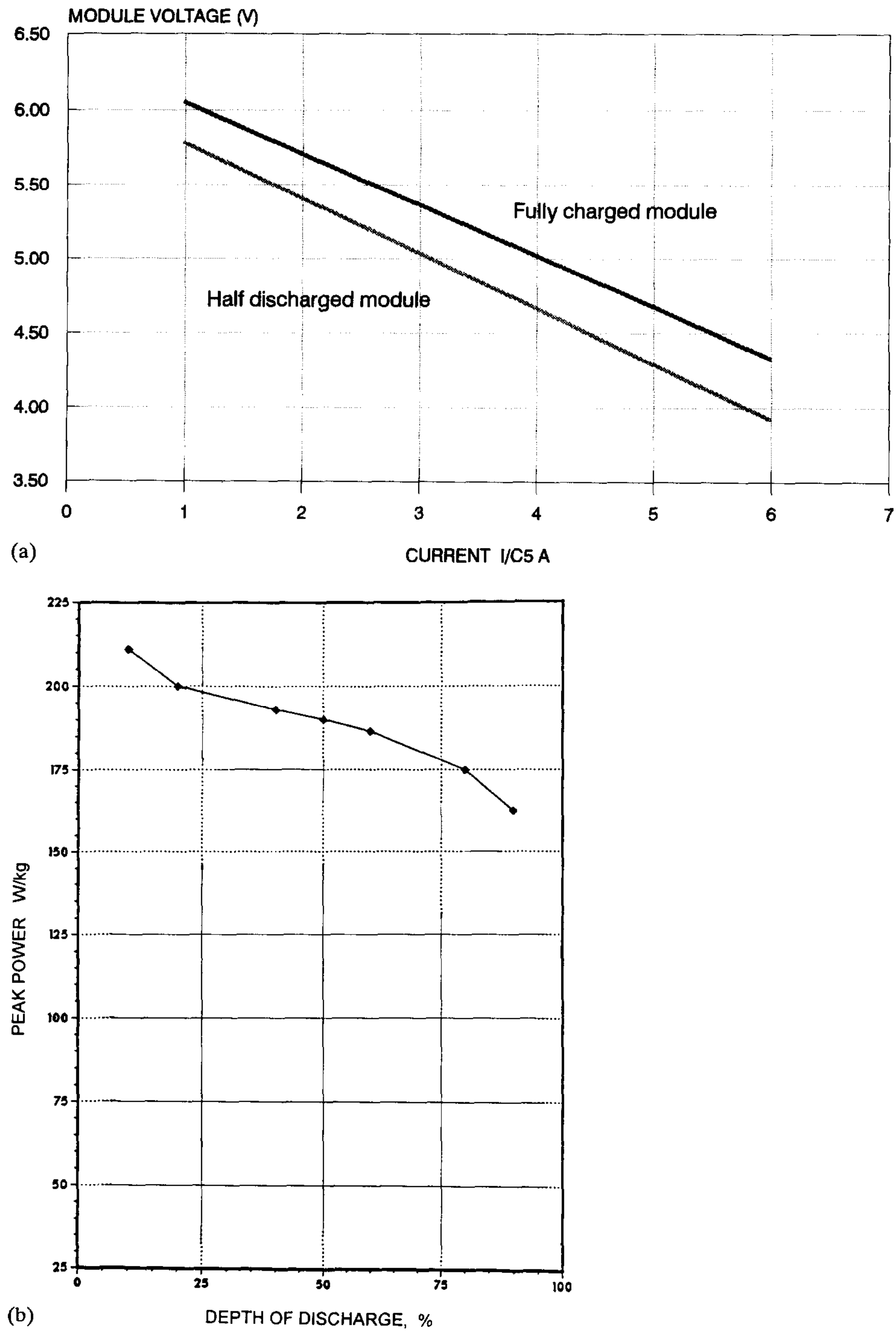

Fig. 2. (a) Power characteristic vs. state of charge. (b) Typical peak discharge.

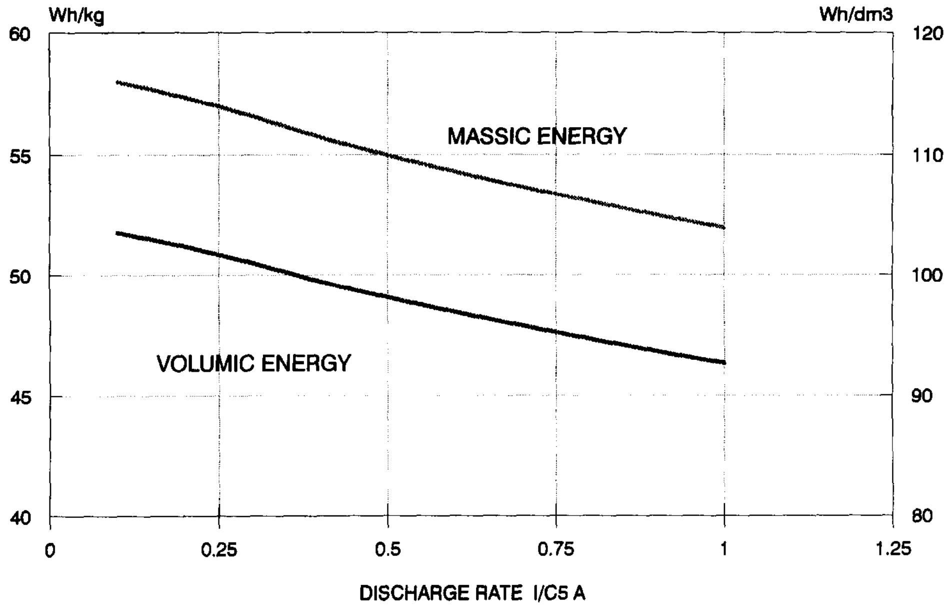

Fig. 3. Specific energy vs. discharge rate.

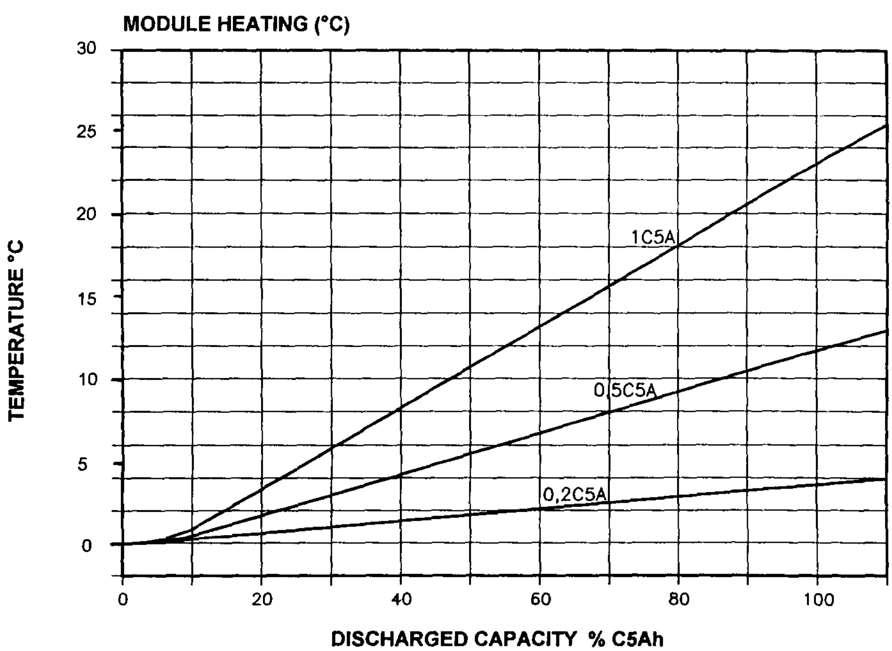

Fig. 4. Module heating vs. state of charge and for different rates.

4.1.4. Discharge at low temperature

The STM module has been designed so that it can be used at temperatures below −20 °C. After full charge at constant current at 23 °C, rest for 24 h at −18 °C (0 °F) and discharge at the 1 *C* rate, 80% of capacity is available. For lower temperature applications, a special electrolyte can be used.

4.1.5. Heating during discharge

The low internal resistance of the STM cells reduces the thermal problems usually found in EV batteries. In particular, module heating has been reduced by 20%, during a full discharge at the one hour rate, compared with other alkaline technologies.

In heavy duty applications, thermal management of the battery should be considered to avoid reduced charging efficiency.

Figure 4 shows the module heating versus the discharge current in air-ventilated conditions.

4.2. Charge characteristics

The STM Ni–Cd module can be charged exactly like all other Ni–Cd batteries and both constant current or constant potential charging can be used.

Charge efficiency, usually limited by the positive electrode, has been optimised by the use of both a special mix of hydroxides in the nickel electrode and an electrolyte containing lithium.

The high energy efficiency allows the battery to cycle with reduced charging factors (less than 1.2 for 80% depth-of-discharge) and thus it is only necessary to add water once a week. For partial charges (first 80% of the capacity) the faradaic efficiency is over 90% and the energy efficiency around 80% (discharge at 0.2 *C*/5).

At high temperatures, charge efficiency is reduced. At 50 °C, after a full charge at constant current, the capacity on discharge is 70% of that obtained at 23 °C.

Figure 5 shows energy and faradaic efficiencies at 23 °C and constant current charging.

4.3. Self-discharge

Figure 6 shows self-discharge versus time at 23 °C.

The stability of the cadmium electrode in KOH solutions gives a low level of self-discharge. Indeed, more than 80% of the rated capacity is available after one month rest at 23 °C. Thus, there is no need to recharge the battery after one month rest time before using it.

4.4. Life

The new technology developed by SAFT and used in the STM module has considerably increased the life of the cadmium electrode. STM modules have performed in our electrical laboratory for more than 3500 cycles at 80% depth-of-discharge and the test is still continuing (Fig. 7).

The expected life of an EV is 8 years; this represents approximately 200 000 km of driving. A Peugeot minibus used in the city of Tours (France) since Aug. '89 has achieved more than 1000 cycles and is still in service. This represents at least 100 000 km and experience shows that it will easily achieve 200 000 km.

Accidental deep discharges with reversed potentials have no effect on the life of the STM module.

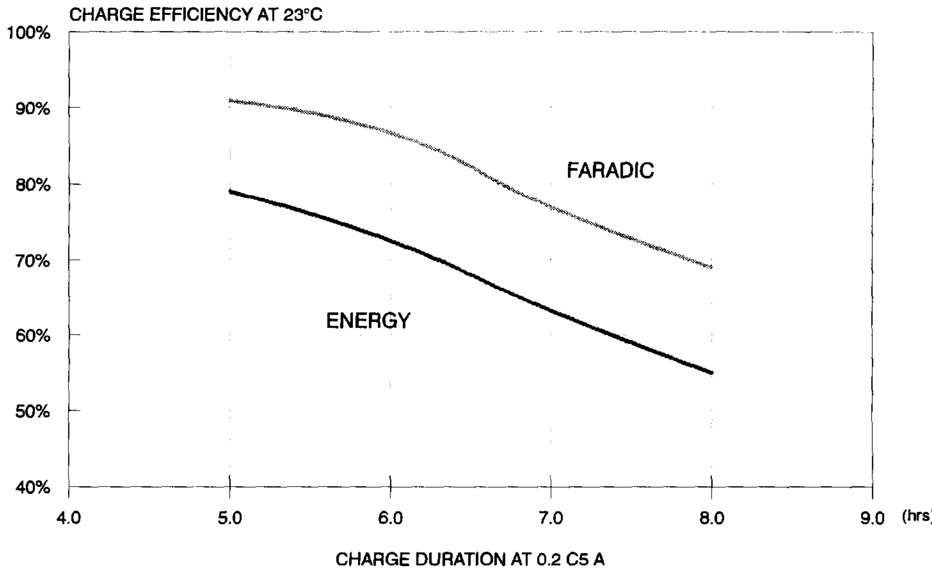

Fig. 5. Charge efficiency vs. charge duration.

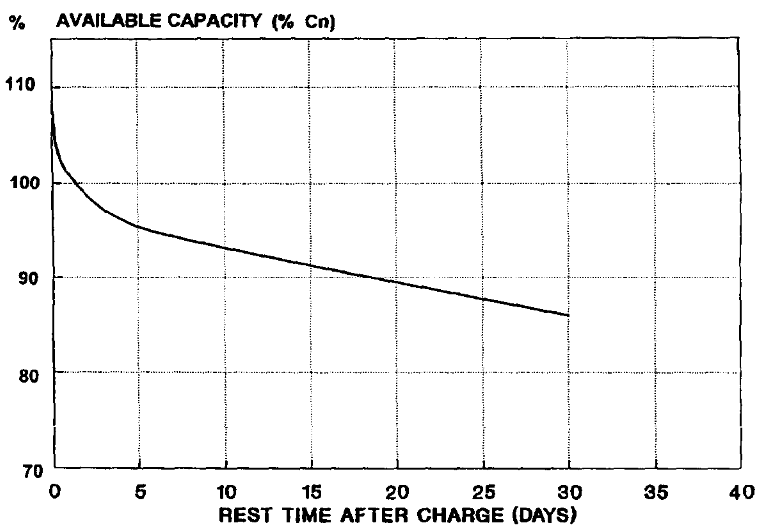

Fig. 6. Charge retention.

5. Electric vehicle trials

For ten years, SAFT has worked in conjunction with a number of different vehicle manufacturers throughout the world. Some of these development programs will be described here as they represent valuable experience which augurs well for the near future.

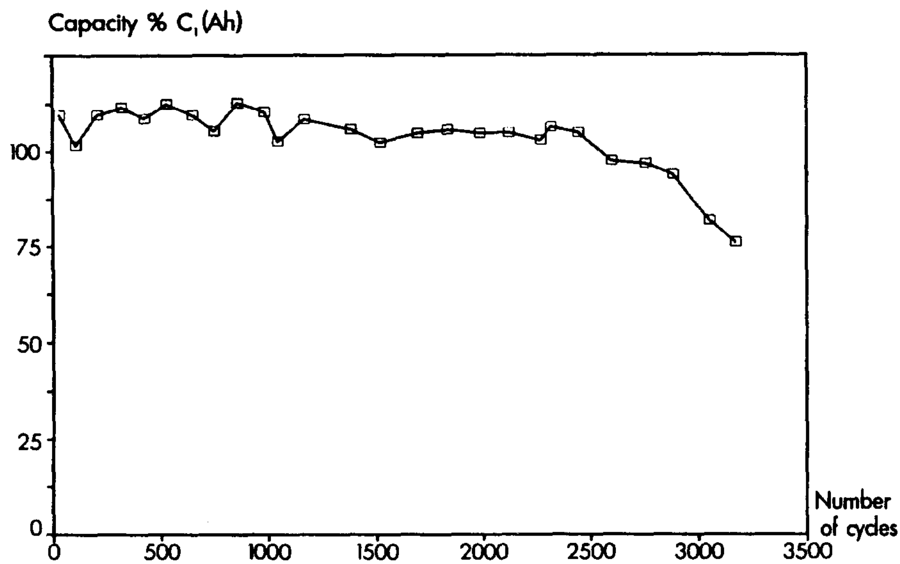

Fig. 7. Cycle life.

5.1. Peugeot and Renault

The Peugeot 205 was the first vehicle to be equipped by SAFT; it was presented at the 7th EV Symposium at Versailles in 1984. Ten years later, Peugeot, during a recent press conference, announced the first quarterly results of the LA ROCHELLE demonstration program. Fifty Peugeot 106 or Citroen AX also equipped with STM modules have been rented to individual people or fleets. These fifty cars have accumulated 220 000 km without any major defect or breakdown. The satisfaction rating is 94%.

SAFT and Peugeot have signed a cooperation agreement which has been extended to Renault, aiming to produce in series the Peugeot 106, the Citroen AX and the Renault Clio and Express at the end of 1994. SAFT has therefore invested in a pilot line in its plant at Bordeaux which will begin pre-production in Spring '95 and will be able to manufacture up to 200 000 modules per year in 1996. Moreover this pilot line will validate all the technological processes.

5.2. Chrysler

SAFT has been working with Chrysler for five years. In March 1993 a TE van, equipped with a Ni–Cd SAFT battery of 180 V/200 Ah reached Los Angeles after a marathon 2803 mile trip. This modern gold rush had started 9 days before in Detroit. The recharging of the batteries was made with a mobile rapid recharge station developed by NORVIK. The journey needed 55 rapid recharges. The total faradaic efficiency was 94% and the energy efficiency 71%. The average mileage per charge was 51 with a maximum of 72. The commercial speed was 55 mph. More than 4.4 *C*/1 Ah had been discharged per 24 h.

5.3. Tours minibus

As mentioned in Section 4.4, the city of Tours has used two minibuses (4.5 ton, 20 passengers) for 5 years now. The batteries have been discharged 1000 times. This represents approximately 1000 000 km as the daily journey is around 96 km. This is the longest demonstration that has ever been carried out on EV batteries.

6. Summary of the main characteristics

The main characteristics are presented in Table 1.

7. Remarks concerning the memory effect

Many things have been said concerning the memory effect. The scope of this paper is not to give a breakdown of this subject but it is necessary to briefly mention it as the STM module has no memory effect.

The reasons that the memory effect does not exist with the STM are as follows.

On the cathode

(a) The nickel hydroxide efficiency has been improved, thus it is close to that of the cadmium one. So, the charging factor (1.2) used during normal recharge is sufficient to compensate for the imbalance which could appear during partial rapid recharge.

(b) If the cycling is such that at each cycle the same partial discharge occurs, the slow change of β-NiOOH into γ-NiOOH has no real effect on the performance of the battery because the cutoff voltage of the vehicle is around 1 V_{pc}, which is far below the voltage depression caused by the 'γ' second plateau.

(c) The ageing of the nickel hydroxide is eliminated by the use of a proprietary ternary complex.

On the anode

(d) The plastic-bonded electrode does not contain active iron, so there is absolutely no poisoning of the nickel electrode.

(e) This electrode also does not have a nickel structure so the decrease of capacity due to the slow elaboration of the inert Ni_5Cd_{21} alloy is completely avoided.

(f) The plastic-bonded electrode reduces the ageing of the cadmium material to a very low level.

8. Conclusions

The new SAFT nickel–cadmium technology using sintered positive electrodes and plastic-bonded negative electrodes produces an excellent balance between energy efficiency, energy density, power life and cost. With 54 Wh/kg today and 63 Wh/kg in 1996, the SAFT STM module is the only possible industrial battery available for EVs which have a need for a range of more than 100 km.

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