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Analysis of Ni-Zn Batteries Performance for Hybrid Light-Vehicles Applications

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Outline of the presentation

- Introduction
- Ni-Zn batteries short-term characterization and comparison with lead-acid ones
- Ni-Zn batteries long-term characterization
- Ni-Zn batteries model for capacity estimation
- Conclusions

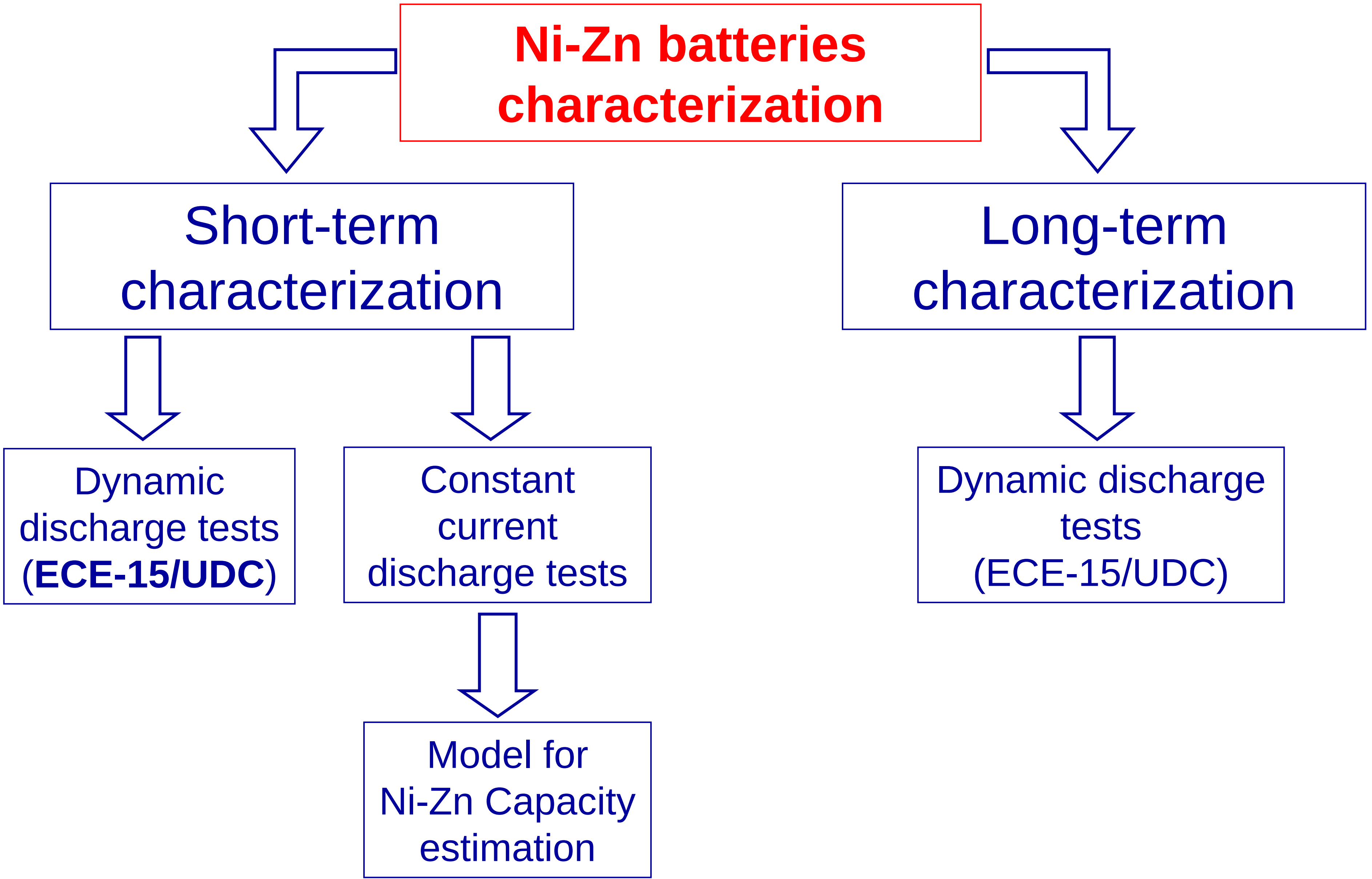
Introduction

Improvement of the performance of hybrid-electric vehicles

Progresses in the technology of the electrical energy storage

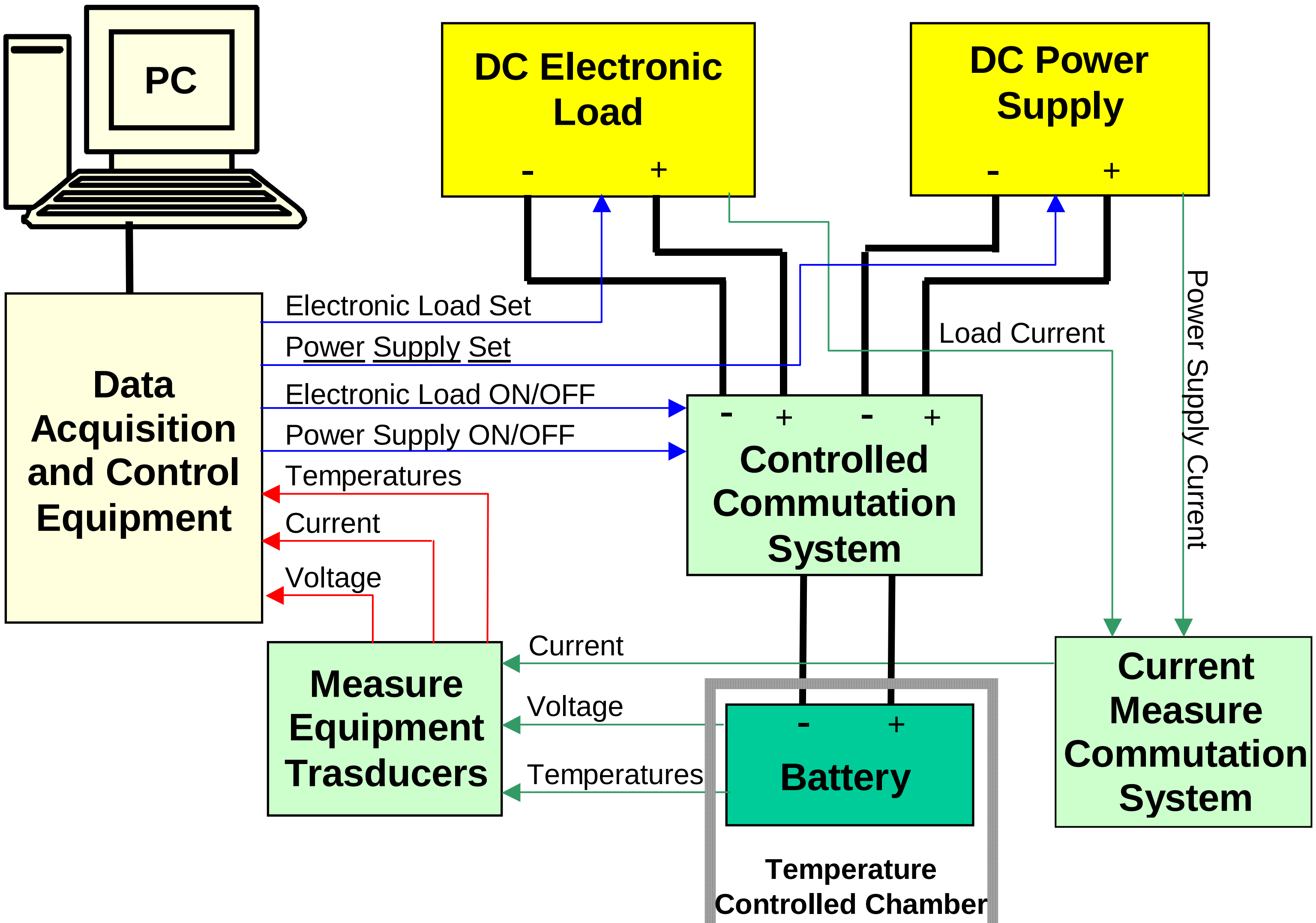
Within the *electrochemical systems for the electrical energy storage*, recent improvements in the reliability of *Ni-Zn* batteries make this technology one of the most promising for hybrid-electric vehicles applications.

Introduction *Cont.*



Introduction *Cont.*

PC-controlled bench



Ni-Zn batteries short-term characterization and comparison with lead-acid ones

Ni-Zn battery characteristics:

- Evercel; model: Ni-Zn 40-12;
    - **38.5** Ah at **C/20**;
    - **32.7** Ah at **C/1**;
    - **31.1** Ah at **3C;**
    - **20**°C;
- weight **7.88** kg.

Ni-Zn batteries short-term characterization and comparison with lead-acid ones *Cont.*

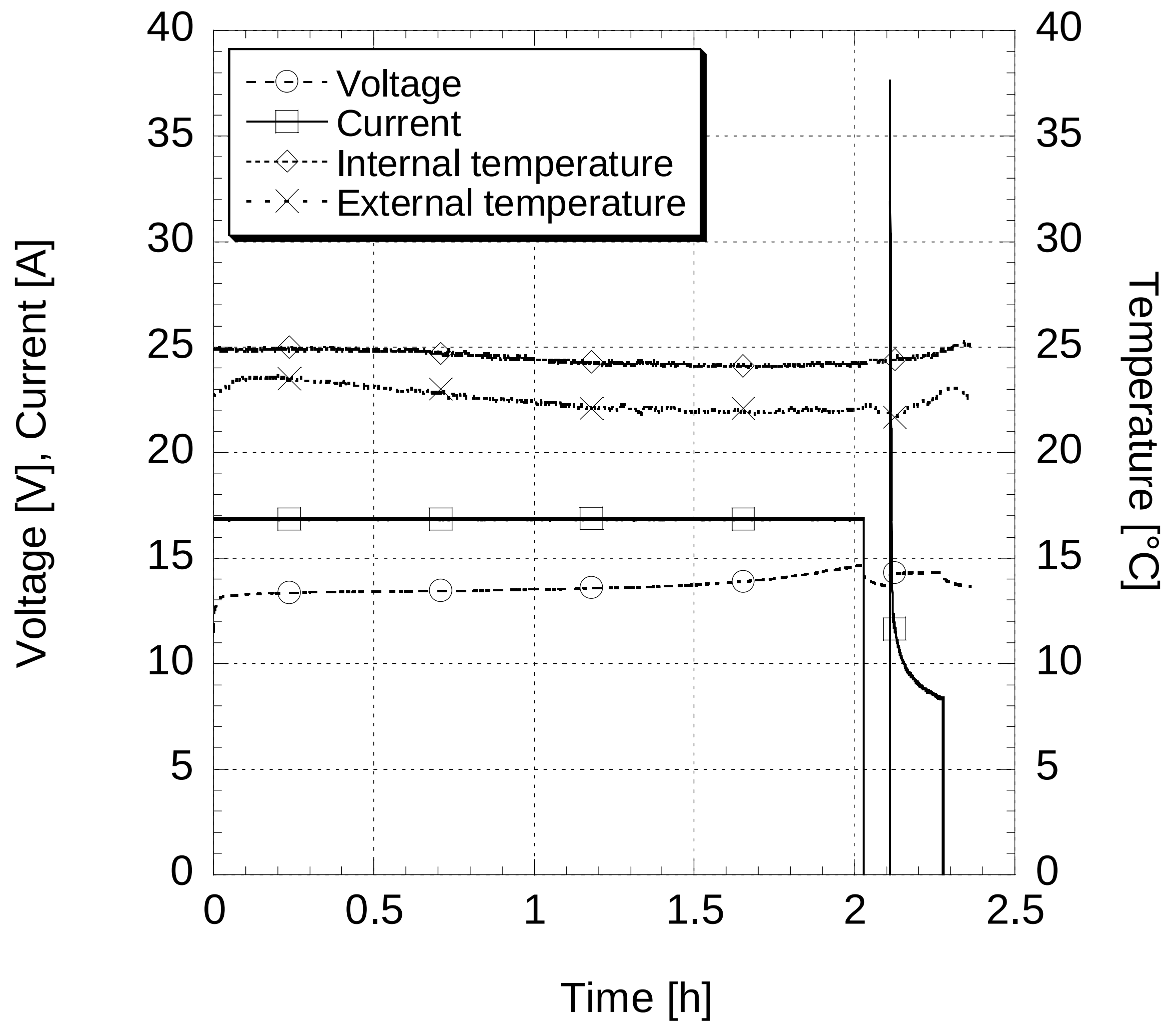
Lead-acid battery characteristics:

- Hawker; model: Genesis G12V26Ah10EP;
  - **26** Ah at **C/10**, **22.5** at **C/5;**
  - **20**°C;
- weight **10.1** kg.

Ni-Zn batteries short-term characterization and comparison with lead-acid ones *Cont.*

Ni-Zn Charge

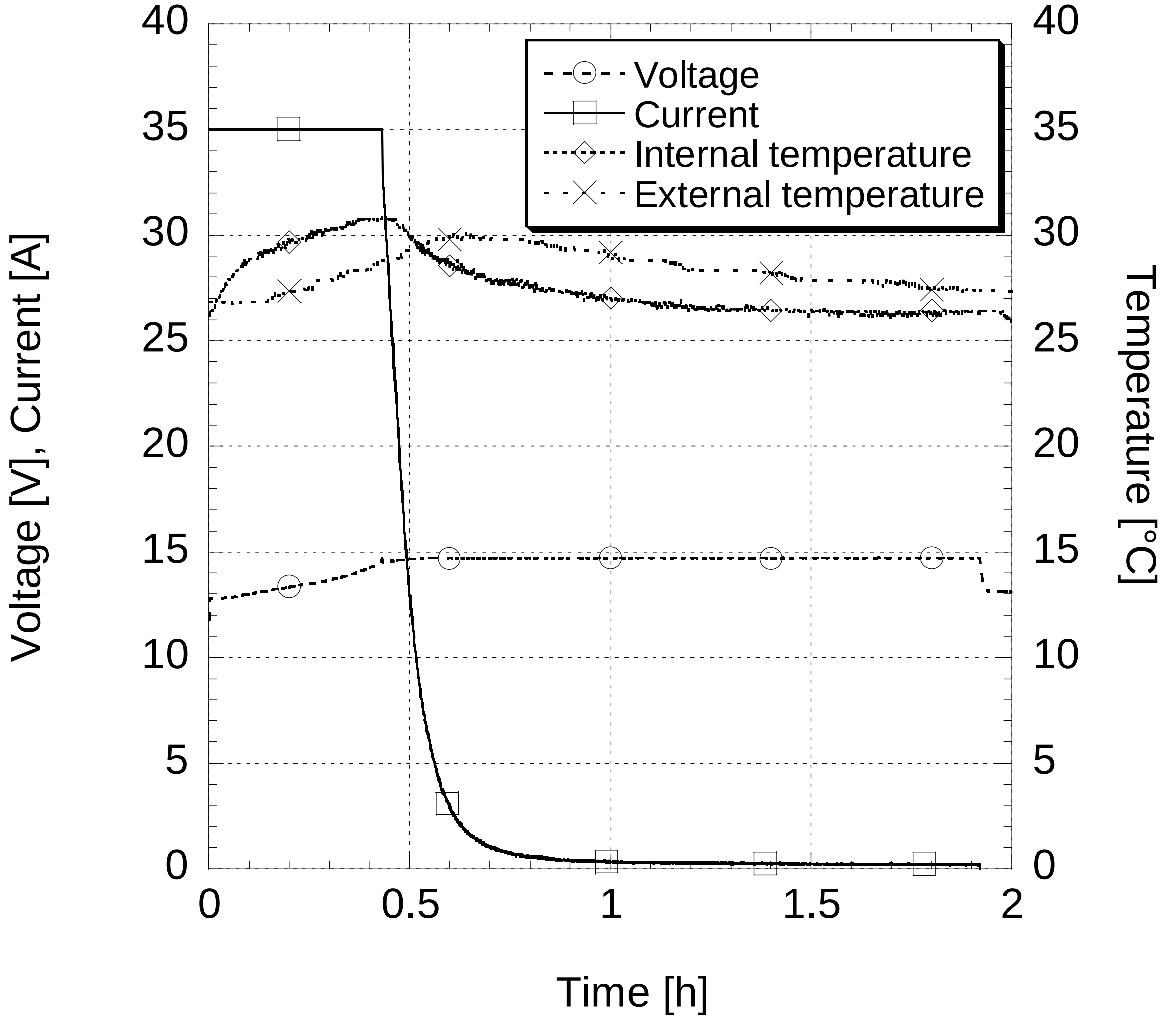
- phase 1: charge at constant current C/1.75, maximun voltage: 14.7 V;
- phase 2: stop for 5 minutes;
- phase 3: charge at constant voltage 14.35 V, minimum current C/4.



Ni-Zn batteries short-term characterization and comparison with lead-acid ones *Cont.*

Lead-acid Charge

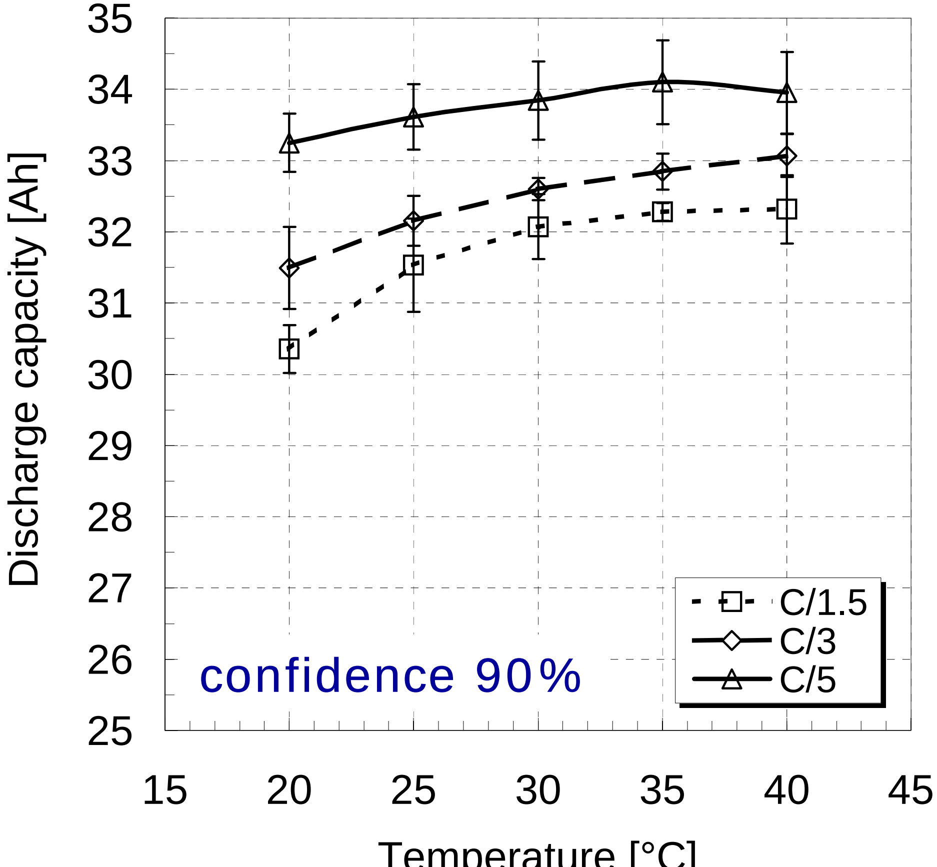
- phase 1: charge with constant current equal to 0.4×C/10 for a charging voltage less than 14.7 V (the duration of the phase 1 is T1);
- phase 2: charge with constant voltage equal to 14.7 V for time equal to T2 = 2h-T1.



Ni-Zn batteries short-term characterization and comparison with lead-acid ones *Cont.*

Ni-Zn discharges with constant current

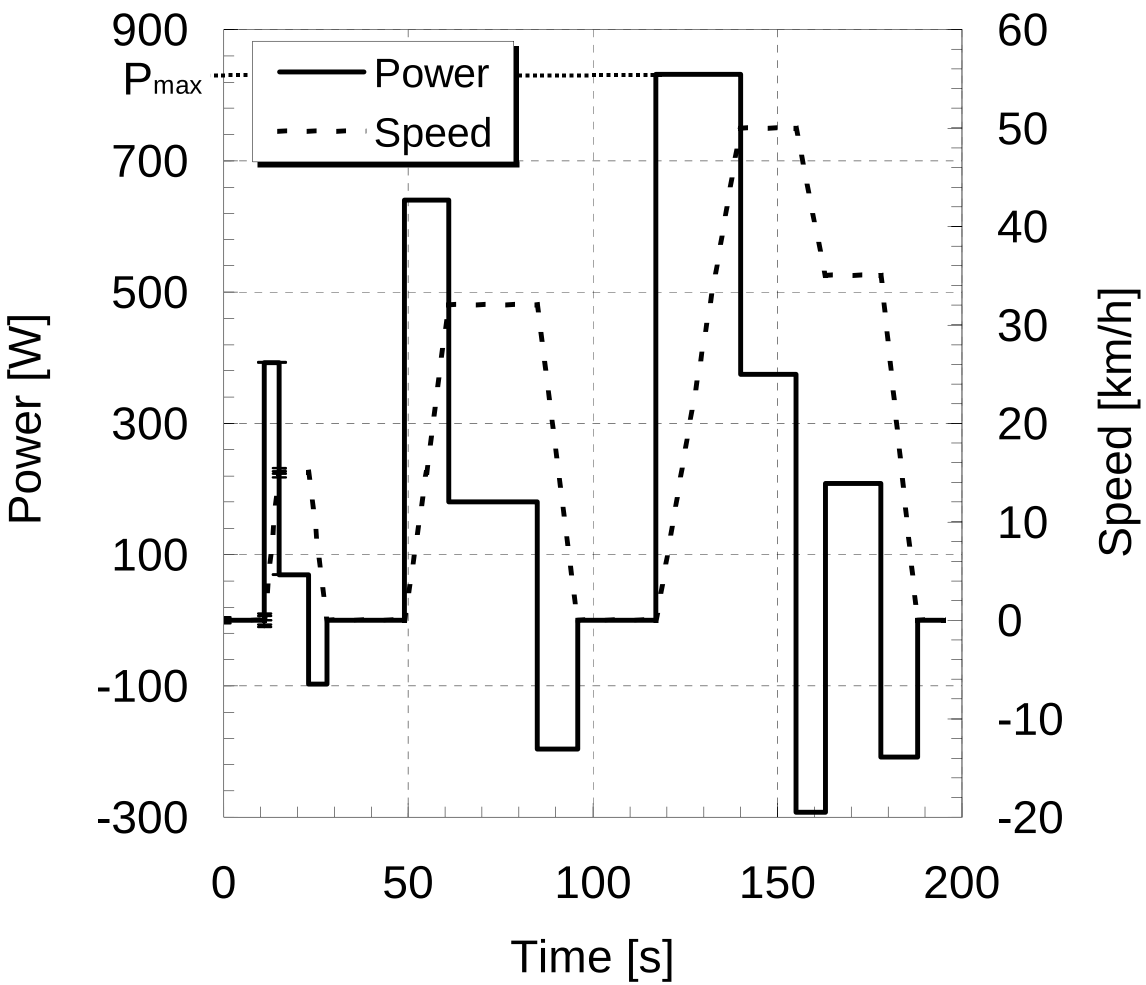
Ni-Zn battery performances as function of *discharge rate* and *temperature*.



The decrease of the capacity for temperatures above 30° is probably due to the Nickel electrodes that show a kind of unstable behavior above this temperature.

Ni-Zn batteries short-term characterization and comparison with lead-acid ones *Cont.*

Dynamic discharges based on the urban part of the **ECE-15** cycle: **ECE-15 / UDC**

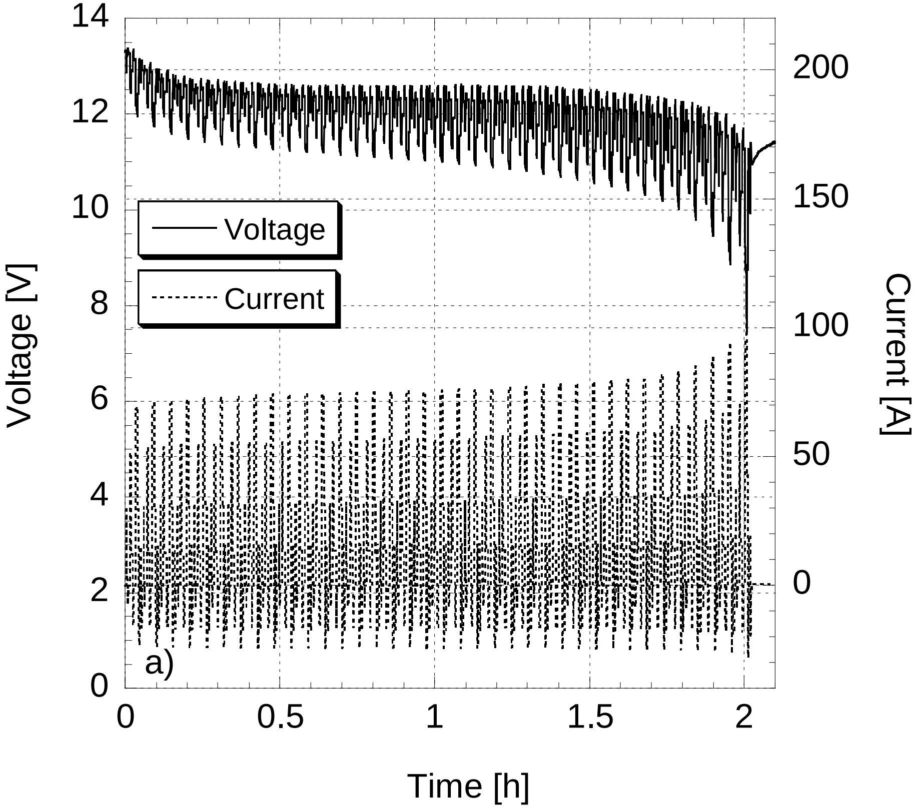


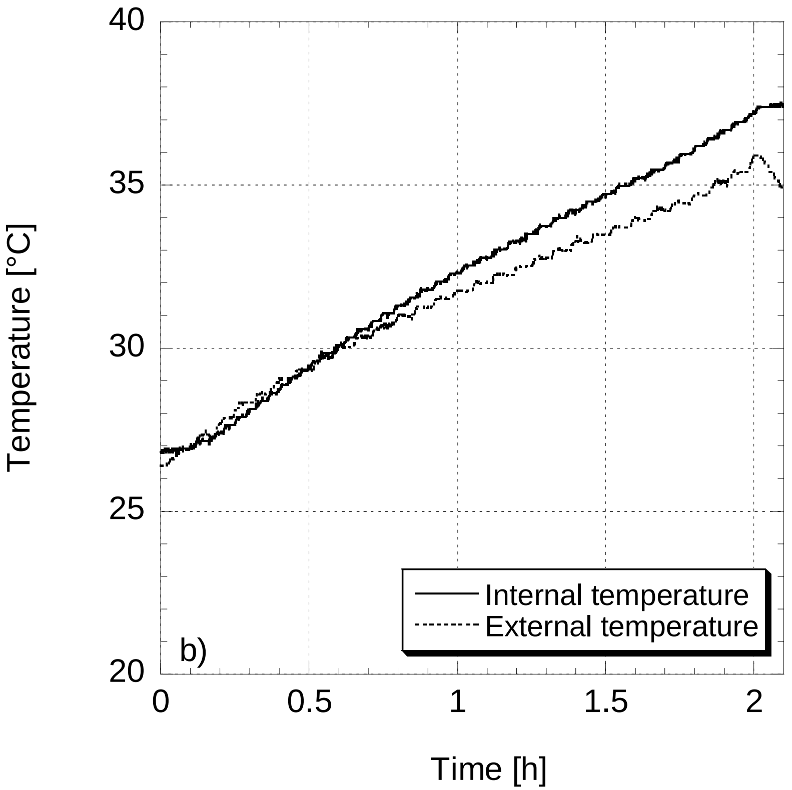
This type of tests is suitable for the simulation of the batteries performance when used on electrical vehicles and, in particular, when urban paths are of interest.

Ni-Zn batteries short-term characterization and comparison with lead-acid ones *Cont.*

Ni-Zn dynamic discharges based on the **ECE-15 / UDC** mini-cycle.

(Figure show recorded quantities for the Ni-Zn elements under test. The ambient temperature is of 25 °C)

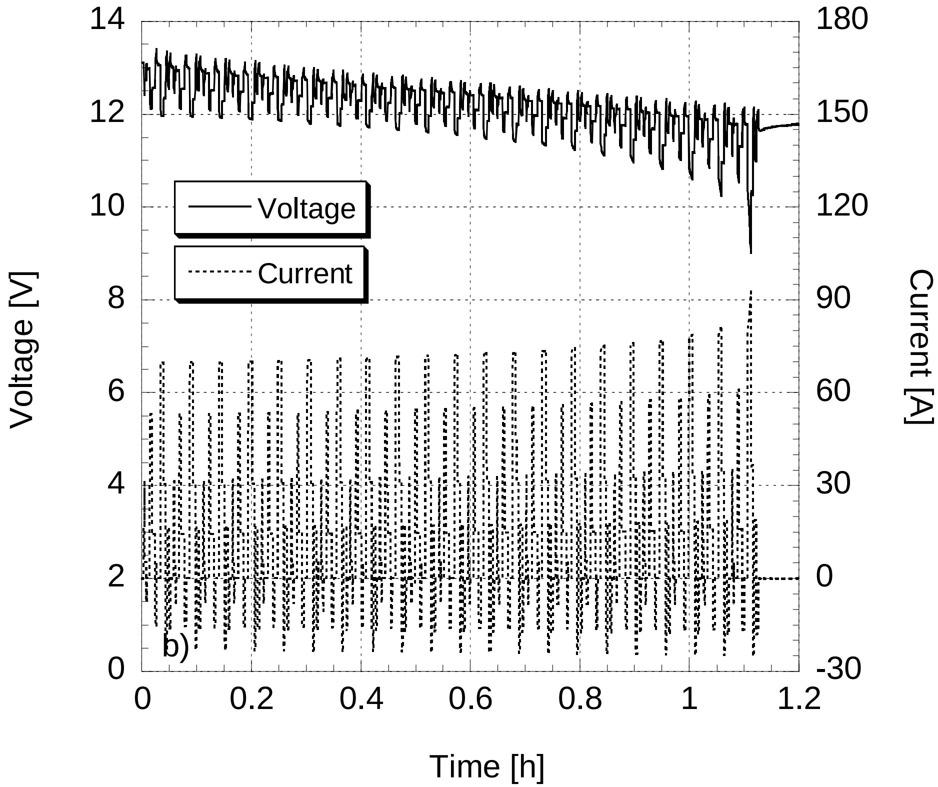


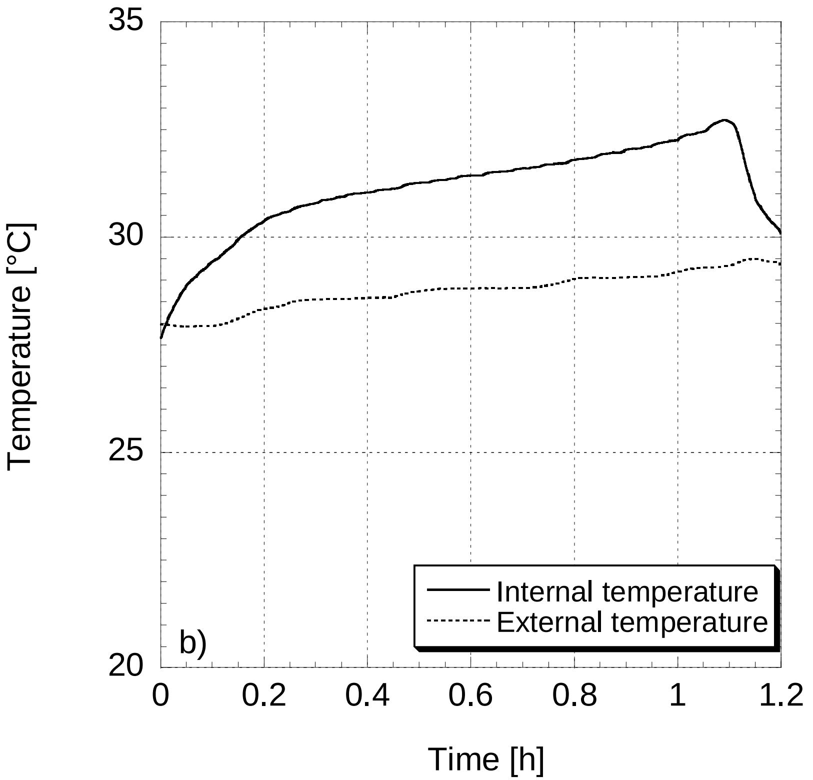


Ni-Zn batteries short-term characterization and comparison with lead-acid ones *Cont.*

Lead-acid dynamic discharges based on the **ECE-15 / UDC** mini-cycle for the lead-acid elements.

(Figure show recorded quantities for the lead acid elements under test. The ambient temperature is of 25 °C)





Ni-Zn batteries short-term characterization and comparison with lead-acid ones *Cont.*

Comparison between Ni-Zn and lead-acid performances.

	Ni-Zn specific energy [Wh/kg]	Lead-acid specific energy [Wh/kg]
C/5 constant current discharge	49.6	40.7
ECE-15/UDC dynamic discharge	27.9	20.3

Note: average values obtained from 6 elements for Ni-Zn batteries and 2 elements for lead-acid ones

Ni-Zn batteries long-term characterization

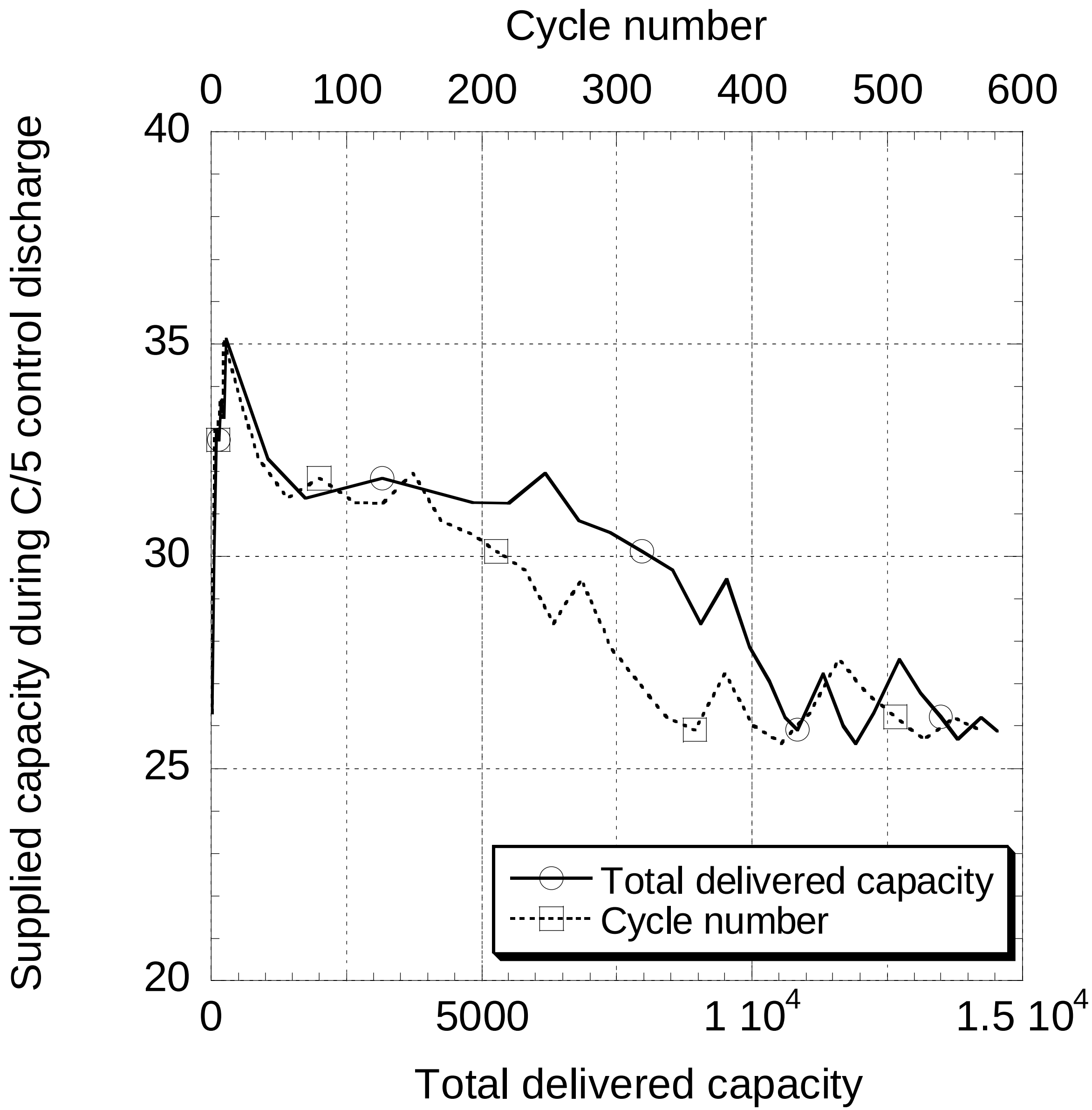
A long-term characterization has been performed considering the *on-board vehicle use* of the Ni-Zn batteries. Hence the urban part of the ECE-15 cycle has been adopted in order to reproduce the power absorption conditions met on a light electrical vehicle.

Long-term test sequences:

- ❑ **series of 20 charge – discharges macro cycles;**
- ❑ **C/5 control discharge to evaluate the effective battery capacity and, in turns, the battery end-of-life.**

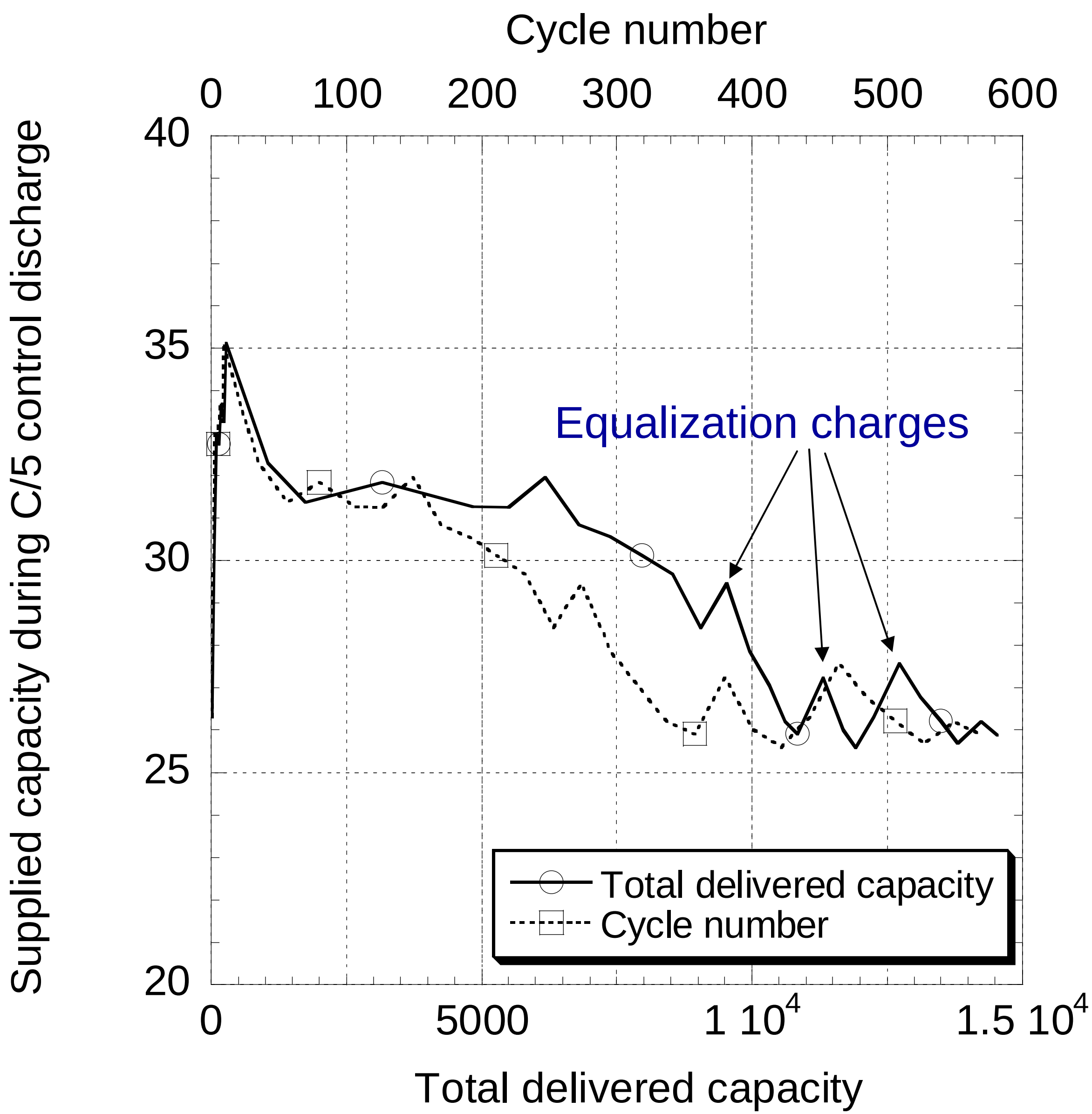
Ni-Zn batteries long-term characterization *Cont.*

Capacity of the Ni-Zn battery delivered during the control discharges as a function of the total delivered capacity



Ni-Zn batteries long-term characterization *Cont.*

Capacity of the Ni-Zn battery delivered during the control discharges as a function of the total delivered capacity



Ni-Zn batteries long-term characterization *Cont.*

The measured value of the battery capacity during C/5 control discharge, is compared with the rated battery capacity at C/5 discharge rate and, when a decrease of 20% the rated capacity is reached, the battery is considered at the end of its life.
Note the severity of such a criterion, since for hybrid vehicle applications the capacity needed for the vehicle to cover a standard one-day route is reasonably much lower than 80% the rated one.

The long term tests show a performances of the Ni-Zn batteries of *600 total cycles* with an approximately total delivered capacity of *15000 Ah*.

Ni-Zn model for capacity estimation

The proposed model for the Ni-Zn capacity estimation, is inspired by a previous one, presented in [1], which was conceived to predict the behavior of lead-acid batteries according to the following relation:

$$C(I,\theta) = \frac{Kc \cdot C_0^* \cdot \left(1 + \dfrac{\theta}{\theta_f}\right)^{\varepsilon}}{1 + (Kc - 1) \cdot \left(I / I^*\right)^{\delta}}$$

- θ is the electrolyte temperature;
- I is the battery current during a constant discharge profile;
- θ_f is the electrolyte solidification temperature;
- Kc, C_0*, ε, δ, I* are model parameters to be identified by means of tests described in [1].

[1] M. Ceraolo; G. Pede, “Techniques for estimating the residual range of an electric vehicle”, IEEE Transactions on Vehicular Technology, Volume: 50-1 , Jan 2001, page(s): 109 –115.

Ni-Zn model for capacity estimation *Cont.*

Such a model however, if applied to Ni-Zn batteries has been found to provide only a moderate agreement between experimental results and predicted ones.

Possible reasons:

1. capacity variation due to temperature and due to the discharge current are 'decoupled'. Assumption reasonable for lead-acid batteries (temperature coefficient);

2. Nickel electrodes show a kind of unstable behavior above 30°C

Ni-Zn model for capacity estimation *Cont.*

Proposed model:

$$C(I,\theta) = \frac{C_n \cdot \left[I_n / I + (\theta - \theta_n) \right]^{\varepsilon}}{(I/I^{*})^{\delta}}$$

- θ is the electrolyte temperature;
- I is the battery current during a constant discharge profile;
- C_n is the rated capacity at current I_n and temperature θ_n;
- ε, δ, I^* are model parameters to be identified by means of short-time tests.

Ni-Zn model for capacity estimation *Cont.*

Identification of the parameters ε, δ, I^*

An estimation of the three above parameters can be achieved by carrying out more than 3 measurements and by using them, together with a non-linear least squares method , to infer ε, δ and I^*.

The values of parameters ε, δ and I^* so determined are:

ε =0.0225

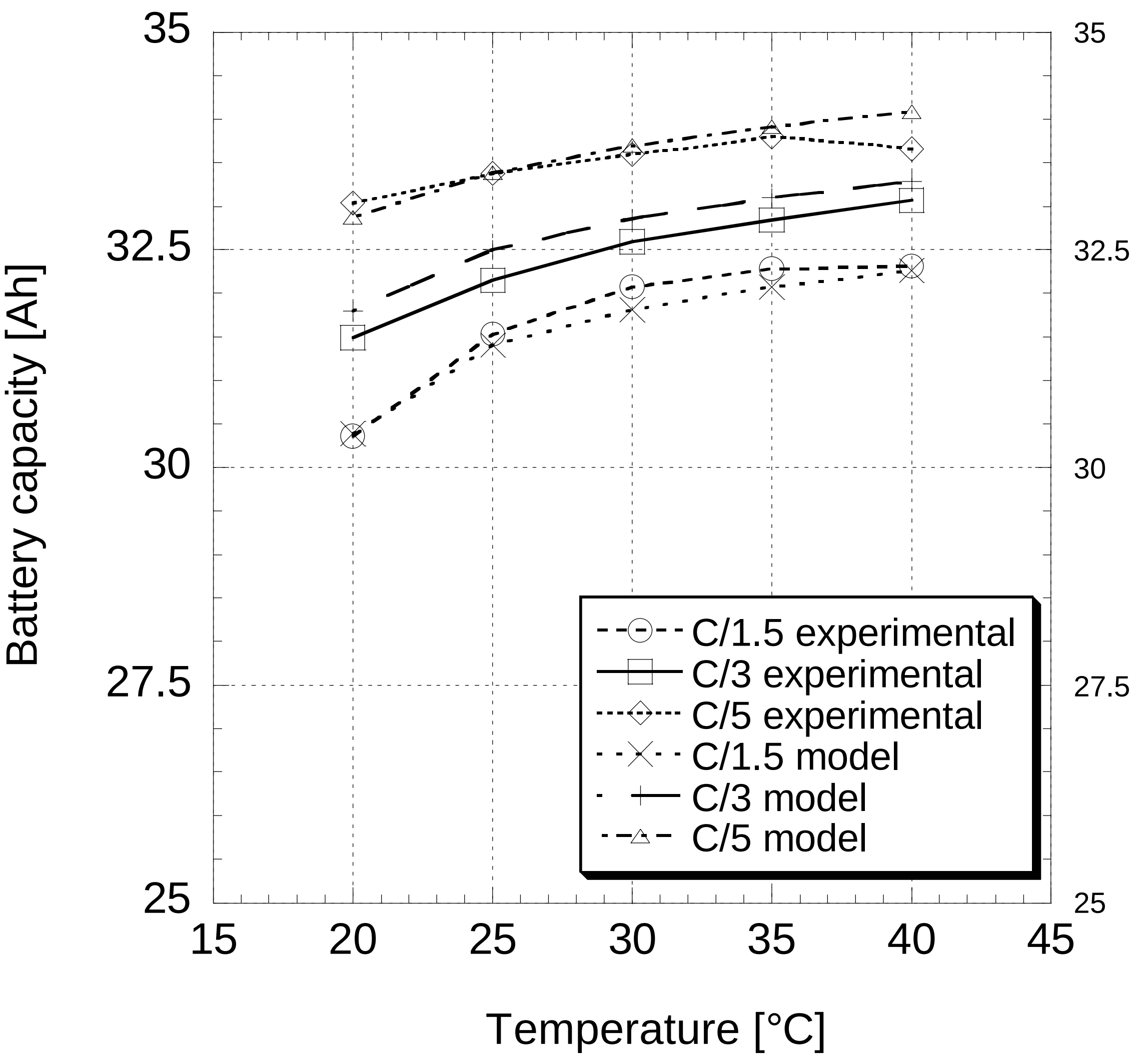
δ =0.0428

I^*=21.8 A

with a residual norm of 2.7%

Ni-Zn model for capacity estimation *Cont.*

Comparison between measurements and model predicted capacities at different temperatures and discharge rates.



Conclusions

The comparison between the two battery technologies under test has shown that the Ni-Zn one represents a promising solution for the hybrid/electrical vehicles application.

In particular the short term performance analysis shows the superior behavior of the Ni-Zn technology, as compared with the lead-acid one, when dynamic discharge profiles are considered. In addition, more homogeneous values of the supplied capacity as a function of the type of discharge, discharge rate and temperature, has been found for the Ni-Zn batteries.

Conclusions *Cont.*

Concerning the long-term performances, interesting values of total supplied capacity and total number of cycles are obtained for the Ni-Zn batteries under test. This result is particular interesting considering the type of selected discharges based on the ECE-15/UDC dynamic cycle.

An engineering model aimed at estimating the capacity supplied by the Ni-Zn batteries, as a function of the constant discharge current and temperature, has been proposed and compared, with sufficient agreement, with experimental results.