Mendrisio Operating Results using NiCd and ZEBRA Batteries


Abstract

In the framework of the ongoing EV introduction program in Mendrisio in the southern part of Switzerland 15 electric Peugeot 106 equipped with NiCd batteries and 5 electric Renault TWINGO equipped with ZEBRA batteries have covered 206870 km and 195750 km respectively. They have consumed from the mains electric energy of 53’372 kWh for the 106 and 45’414 kWh including cab heating for the TWINGO. This results in an average consumption for the Peugeot 106 and the Renault TWINGO of 25.8 kWh/100km and 23.2 kWh/100km respectively. These figures can be used for the operating cost calculation of electric vehicles of this class. The consumption of the vehicle with the “warm” ZEBRA battery was shown to be similar to that of the vehicle with the “cold” battery because of 100%Ah efficiency of the ZEBRA battery in combination with a well designed thermal management which is described in more detail. Future improvements will use thermal stored energy from the battery for passenger cab heating and better thermal isolation of the passenger compartment so that the seasonal effect will be reduced and the average consumption can be expected to be 20 kWh/100 km.

Keywords: battery, battery management, BEV, cost, data acquisition, energy consumption, passenger car, off peak, range, sodium-nickel-chloride, thermal management, vehicle performance, ZEV

1 Introduction

In 1994 the Swiss Federal Office of Energy (SFOE) launched a nationwide competition with the intention of selecting a commune as a test case for the introduction of lightweight electric vehicles (LEVs) as a pilot and demonstration (P+D) project. Applications were received from 34 communes, but in the final analysis the most convincing was that of the municipality of Mendrisio in canton Ticino near the border to Italy. This project was assured of strong political as well as economic support in the region and was based on a concept that was well developed, fully detailed and in the opinion of the SFOE quite realistic. The idea of a P+D project grew out of the need to test the impact of the introduction of lightweight electric vehicles in a geographically limited area. Mendrisio, a town of some 6,400 inhabitants at the southern tip of Switzerland, was chosen as the "pilot commune" thanks to the quality of the project it submitted as well as to the strength of the political and economic support behind it. Mendrisio is just seven kilometers from the border to Italy, about 18 kilometers from Lugano, Switzerland and 50 from Milan, Italy.

The large-scale fleet test was officially inaugurated on 23 June 1995 with the aim to accomplish three main objectives:

- Demonstration of the practical use of LEVs in everyday life,
- Testing and evaluation of measures aimed at promoting LEVs,
- Integration of LEVs in an environment-friendly mobility concept.
The first phase terminated on 30 June 2001. The numeral objective, to sell 350 LEVs, has been far exceeded. Altogether over the duration of the pilot project, 396 LEVs have been registered. Most of these vehicles are still in circulation today [1, 2].

Today, the soul of the VEL Project is maintained in a second phase, called VEL2, which was launched on the roots of its predecessor. This allows us to count nowadays on more than 10 years of experience in electric vehicle, namely on its technology and on its daily application.

The VEL project went in line with the strategy of MES-DEA for the development, production and marketing of components for electric vehicles. MES-DEA in Stabio is only 5 km distant from Mendrisio. An important step foreword in this strategy also was the acquisition of the ZEBRA battery technology in 1999 [3]. After the restart of production one year later an number of Renault TWINGO were converted to electric drive systems using MES-DEA components. Starting 2001 data from these vehicles are available as well.

There is the widely spread opinion that a “warm” battery like ZEBRA has higher energy consumption from the mains than “cold” batteries due to the thermal loss. It is the intention of this paper to evaluate real life data in order to check this and to establish reliable operating cost figures for electric cars.

2 Peugeot 106 Electric

2.1 Description of the vehicles used

Since 1996 Peugeot and Citroën (PSA Group) have been producing their respective electric vehicles: the 106 and the Saxo in the passenger car segment and the Partner and the Berlingo in the commercial segment. One can say that both Peugeot and Citroën Saxo have been the first OEMs to produce in large scale electric vehicles. This paper will focus on the passenger cars 106 Electric and Saxo Electric. Since they are both technically identical, for generalization purpose, we will refer only to the Peugeot 106 Electric (Figure 1) but mean, of course, both vehicles.

![Figure 1: Peugeot 106 Electric.](image-url)
Due to its battery and hence its performances, the Peugeot 106 Electric has become the “best-seller” of the VEL project with over 175 vehicles sold only in Canton Ticino. Some of these vehicles have been equipped with a data acquisition system (DAS) in order to monitor different information on performance and utilization patterns (see chapter 2.2).

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Peugeot 106 Electric</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of seats</td>
<td>4</td>
</tr>
<tr>
<td>Gross Vehicle Weight</td>
<td>1350 kg</td>
</tr>
<tr>
<td>Empty Vehicle Weight</td>
<td>1050 kg</td>
</tr>
<tr>
<td>Max speed</td>
<td>90 km/h</td>
</tr>
<tr>
<td>Acceleration from 0 to 50 km/h</td>
<td>8.5 s</td>
</tr>
<tr>
<td>Range on one charge at 80 km/h</td>
<td>80 km</td>
</tr>
<tr>
<td>Heating System</td>
<td>Webasto gasoline</td>
</tr>
<tr>
<td>Drive System</td>
<td>Leroy Somer DC motor, max power 20 kW</td>
</tr>
<tr>
<td>Battery</td>
<td>Saft NiCd STM 5 100 MRE (20 monoblocks for a total of 120V/117Ah = 14 kWh)</td>
</tr>
</tbody>
</table>

**Table 1: Peugeot 106 Electric Vehicle Data**

### 2.2 Data acquisition

15 Peugeot 106 Electric have been equipped with a DAS specifically studied and developed for this purpose. The acquisition was started in 1997 and lasted, for some vehicles, until 2003. Although some vehicles have dropped out of the acquisition program, we were able to collect 5682 valid daily measurements sets, which included among many others:

- Date and time
- Average speed
- Daily distance
- Energy consumption
- Energy recharged (from net or regenerative braking)
- Height difference
- Temperature

An important note has to be made for the energy consumption recorded. This value describes the energy consumption from the battery. In order to find the energy consumption from the net, during the data acquisition program the charger efficiency has been calculated. Over the years, a constant value of 76% has been found. This is also the correction factor used in this paper to convert the energy consumption from the battery into the energy consumption from the net.

### 2.3 Evaluation and results

The overall average consumption for the Peugeot 106 Electric is around 25.8 kWh/100km. It can be observed from figure 2 that for short distances the energy consumption does increase significantly. For long driving distance the consumption is even less than 20kWh/100km because the driving behavior is adapted to get the long range out of a 14 kWh battery. This corresponds to an average consumption of 18.4 kWh/100km from the grid as indicated in fig.2.

Fig. 3 shows the energy consumption over 2 years to be more or less constant. In other words, it is practically independent of the local temperature and doesn’t vary between winter and summer. This is
because the vehicle heating was not electric but with a Webasto gasoline heater and the vehicles were not equipped with winter tires. An influence on consumption due to adverse weather conditions (snow, heavy rain,...) is not observable, this is mainly due to the favorable geographic positioning of the Ticino region. Also, the large variation of the consumption should be noted, which indicates the large variation due to different drivers and different driving conditions (topography). For this reason every information about the electric vehicle range has to be related to well defined driving conditions and for a general evaluation only average values are relevant.

Figure 2: Consumption of Peugeot 106 Electric per way in kWh/100km
Figure 3: Energy Consumption of Peugeot 106 for a two year period; average 25.8 kWh/100km

3 Renault TWINGO with a ZEBRA Battery

3.1 Description of the vehicles

Since 2001 MES-DEA has started to convert conventional Renault TWINGOs into fully functional electric vehicles mainly for system testing of the components. This vehicle type was selected because it offers the combination of the several advantages like low weight, packaging space for the battery instead of the spare wheel (a vulcanization repair set is available), four seats plus luggage space and all this for a reasonable price. Fig. 4 shows the car and the data are summarized in table 2.

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Renault TWINGO Electric</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of seats</td>
<td>4</td>
</tr>
<tr>
<td>Gross Vehicle Weight</td>
<td>1230 kg</td>
</tr>
<tr>
<td>Empty Vehicle Weight</td>
<td>980 kg</td>
</tr>
<tr>
<td>Max speed</td>
<td>120 km/h</td>
</tr>
<tr>
<td>Acceleration from 0 to 50 km/h</td>
<td>5.5 s</td>
</tr>
<tr>
<td>Range on one charge at 80 km/h</td>
<td>120 km</td>
</tr>
<tr>
<td>Heating System</td>
<td>3 kW electric from the main Battery</td>
</tr>
<tr>
<td>Drive System</td>
<td>AC induction motor, max power 36 kW</td>
</tr>
<tr>
<td>Battery</td>
<td>ZEBRA Type Z5-278-ML3P-76 (278V/76Ah = 21.2 kWh)</td>
</tr>
</tbody>
</table>

Table 2: Electric Renault TWINGO Vehicle Data

15 vehicles of this type are currently in service and they are part of a program to bring 100 of these vehicles into the market in Ticino and Northern Italy.
3.2 Data acquisition

The TWINGOs could not be equipped with an automatic data acquisition system. Therefore the drivers filled in a logbook with date, km-counter, actual SOC and kWh-counter. It has taken care that all values were recorded at the same time so that they represent the actual status. The kWh-counter was connected to the 220 VAC input of the vehicles. Hence, the total amount of energy the vehicles received from the mains (which have to be paid by the user) is recorded. This included the energy charged into the main battery as well as into the 12V auxiliary battery for which a separate low power AC/DC converter was installed. It, of course, also included the energy that was consumed for keeping the ZEBRA battery on operation temperature. This guaranteed that the 12V battery is always fully charged for the operation of the main contactors to start the vehicle. This was an important improvement for the reliability of the vehicles.

The data collected allowed to calculate the total gross energy and the consumption per day used by the vehicles.

3.3 Evaluation and results

The data from the logbook are:

- \( d_i \) is the date (dd,mm,yyyy) as the actual day at which the data are recorded independent from the time of the day
- \( s_i \) is the km-counter (km) which gives the accumulated distance the vehicle has driven at the date \( d_i \)
- SOC is the “Status of Charge” in % of the battery capacity. This value is displayed on the dashboard and means the actual energy content of the main battery because it has no electrochemical self-discharge, the Ah-efficiency is 100% by nature.
- \( E_i \) is the kWh-counter (kWh) which gives the accumulated total energy that was consumed by the vehicle from the mains until the date \( d_i \)

These data were inserted into a spread sheet to calculate the output for figures 5 and 6 as follows:

- Energy consumption \( E \) in kWh/100km and per day or per period:
  \[
  E = (E_i - E_{i-1} - (SOC_i - SOC_{i-1}) \cdot E_B / \eta) / s_d \cdot 100 \text{ in kWh/100km}
  \]
  With \( E_B \) – rated energy of the battery, \( \eta \) – Charger efficiency and \( s_d = (s_i - s_{i-1}) / d \)
- Distance driven per day calculated from the distance driven between 2 data recordings divided by the number of days between 2 data recordings.

The overall average consumption for the electric Renault TWINGO is 23.2 kWh/100km. In figure 5 the energy consumption is plotted as a function of the distance driven per day. As in figure 2, the consumption is higher for short distances and decreases significantly for longer driving. The result is very similar to the Peugeot 106 but extended to the larger range of the TWINGO.
Figure 5: Consumption of electric Renault TWINGO per day in kWh/100km

Figure 6: Average Energy Consumption per Month during a period of 4 years with an overall average of 23.2 kWh/100km (4.3 km/kWh).
In figure 6 the energy consumption is plotted over the month of the year. The difference between summer with 20 kWh/100km and wintertime with 25 kWh/100km is evident. The reason is the additional energy consumption for passenger compartment heating during the cold season and the higher rolling resistance of the winter tires. The peak in August 2003 is due to a reduced usage of the vehicle during vacation time. For the future it is recommended to let the battery cool to ambient temperature if the vehicle is not used for a few weeks. During such a freeze/thaw cycle of the battery the status of charge is frozen so that there is no energy loss.

4 ZEBRA Battery Thermal Management

Figure 7 shows the ZEBRA battery system with its components. The cells are contained in a double walled thermal isolation box. The space between the walls is filled with isolation panels 25mm thick made out of foamed SiO$_2$ with a density of only 0.2 g/cm$^3$. Evacuated they permit a heat conductivity as low as 0.005W/mK. For a typical car battery this results in a remaining heat loss of approximately 90W, which corresponds to 2.16 kWh per 24h if the vehicle is not operated. But this thermal loss is not relevant if the vehicle is used because the normal efficiency loss of the battery is converted to heat. This heat is stored in the heat capacity of the cells (per cell 500 J/K) and is gradually used to compensate the thermal loss.

![Figure 7: ZEBRA Battery System with fan for cooling and resistive heater for heating](image)

The TWINGO battery is designed in such a way that for an average use of about 60 km/day the thermal loss is compensated by the heat produced by the electrical efficiency loss. The TWINGO has a typical range of 120 km so that for 60 km/day 50% of a full charge is used per day. The average energy efficiency for normal traffic driving is 80-85% so that approximately 10% out of 21 kWh = 2.1 kWh is available to compensate the thermal loss. As shown in figure 7, the battery has a built-in heating and cooling system, which is controlled by the “Battery Management Interface” (BMI) in such a way that the total temperature range of 270°C to 350°C is used for the operation in order to keep as much energy as possible inside the battery.
5 Conclusions

• Within the large variation of the practical energy consumption of electric cars the values for “cold” and “warm” batteries are equal.

• For an average driving distance of 40-60 km/day in Europe [4,5], the energy consumption of a city car like the Peugeot 106 or the Renault TWINGO is around 20 kWh/100km.

• Car heating in wintertime consumes about 5 kWh/100km in addition. Better thermal isolation of the passenger compartment in combination with improvements of the heating system using the advantages of the “warm” battery are possible and recommended.

• With the practical energy consumption of 20 kWh/100km as reported in this paper, an off peak power price of 0,1 €/kWh, a battery price of 240 €/kWh and a battery life of 1000 name-plate-cycles corresponding to 120’000 km there is a cross over in the energy cost for operation compared to an conventional car with a practical fuel consumption of 6 l/100km and a fuel price of 1 €/100km.

• For ZEBRA batteries a large volume production price of 109 €/kWh is reported [6]. The 240 €/kWh price is expected to be reached within the next 3 years due to development of non-EV applications of the ZEBRA electric energy storage technology.

References


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Mr Renato Manzoni was born in Paré, Italy, March 2, 1957. He got graduated as electronic engineer at Politecnico of Milano. He worked on development and installation of military and satellite imaginary systems. On 2001 he joint MES-DEA, following up the projects and redevelopment of the applications of ZEBRA batteries, as responsible of the customer service.

Martin Pulfer was born in March 15, 1957. He earn as MS in Chemical Engineering. He was engineer of development for industrial plastic-products and got chairman for security and “Environment protection” at the Federal munitions factory in Thun. Later he became leader of the chemical production before moving to the Swiss Federal Office of Energy. There M. Pulfer was leader of the national research program named “Rational use of energy in traffic. Since 2000 he is also chairman on reach of research- and P+D Program”.