Who Will Save the Electric Car?

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Background, Purpose and Hypothesis:

Despite increasing awareness of the dangers of global warming, we as a population continue to turn a blind eye to our environment every time we start our vehicles. Electric vehicles (EV's) offer a promising alternative; however, inadequate battery technology has been a huge roadblock. Without better batteries, EV's will never match the reliability, power, and convenience of conventional cars.

Many older model electric vehicles, such as GM's EV1, have used either lead-acid or Nickel Metal-Hydride (NiMH) batteries. However, lead-acid batteries are heavy, and perform poorly in cold weather, while NiMH batteries are expensive, and have a high self-discharge (Dell, 2001). Furthermore, many lithium-ion batteries contain graphite, which is an explosive hazard if the battery is overcharged (House, 2006). Clearly, older generation EV batteries leave some room for improvement.

Newer generation lithium-ion batteries have recently been developed that claim to be superior. Altair is supplying their NanoSafe battery for Phoenix Motors' EV's, and A123 is the supplier for the Commuter Cars Tango as well as GM's all-electric Volt concept car. Limited research exists that compares batteries specifically designed for electric vehicles. The few studies that do compare EV batteries are limited to a comparison of older generation batteries, or are studies done by the battery companies themselves.

The purpose of this experiment is to test two brand new EV lithium-ion battery innovations, one from Altairnano and one from A123, as well as lead acid and NiMH batteries. This experiment will compare these four different kinds of batteries to determine which battery discharges the slowest, recharges the fastest, and maintains consistent performance under cold weather conditions.

It is hypothesized that Altair's Nano-Safe battery and A123's lithium-ion battery will discharge more slowly and recharge more quickly, in comparison to the lead-acid and NiMH batteries. It is further hypothesized that lower temperatures will not impair the performance of the Altair or A123 batteries, but will have a marked effect on the lead-acid battery.

Procedure:

Tests were run on four different kinds of rechargeable batteries that had very similar capacity ratings and voltages in a similar range; these are listed in Table 1. Note that for the NiMH battery, testing was done on both 12 Ah and 30 Ah capacity batteries.

Table 1: Batteries Tested

	Altair	**A123**	**CYCLON**	**CTA**	**Powerizer**
Kind	Titanium Lithium-Ion	Lithium-Ion	Lead-Acid	Nickel Metal-Hydride	Nickel Metal-Hydride
Nominal Voltage	2.58	3.3	2	2.4	2.4
Rated Amp-hours	11	11.5	12	12	30

A great deal of preliminary testing (30 discharge tests and 42 charge cycles) was conducted over a eight-week period to determine the best charging regimes, the approximate discharge times, and the appropriate starting voltages for each battery. After completing this preliminary investigation, the experiment was designed.

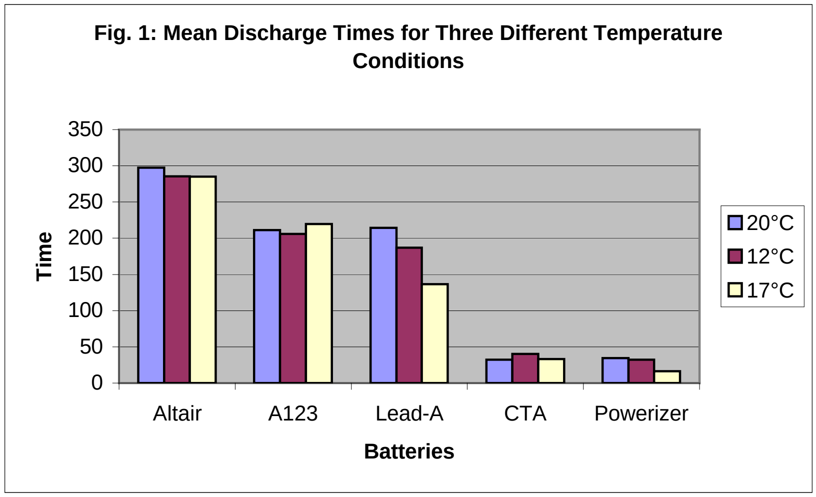
During the experiment, each battery was load-tested by connecting a resistor to the battery. The voltage was monitored regularly and recorded, approximately every 30 minutes. Voltage readings were determined by means of a digital multimeter. The resistor was removed from the battery when the cut-off voltage was reached. The cut-off voltage was calculated prior to discharging by multiplying 0.6 by the starting voltage.

The discharged battery was then charged using a dual power supply station. Batteries were charged at 25% greater voltage than their nominal voltage, until they reached their upper voltage range (approximately 10% higher than their nominal voltage). Resistors were attached to the charger so that the ideal charging voltage was attained and so that charge times between batteries could be accurately compared.

The load test was then repeated several times with resistive loads of 0.5, 1, 2, and 5.6 ohms. To examine the effects of cold temperatures on each battery's performance, the batteries were placed outside in –12°C weather conditions while they were being load-tested on a resistor. Batteries were also load tested in –17°C temperature conditions inside an industrial freezer. All testing was replicated a minimum of three times for discharging and five times for charging.

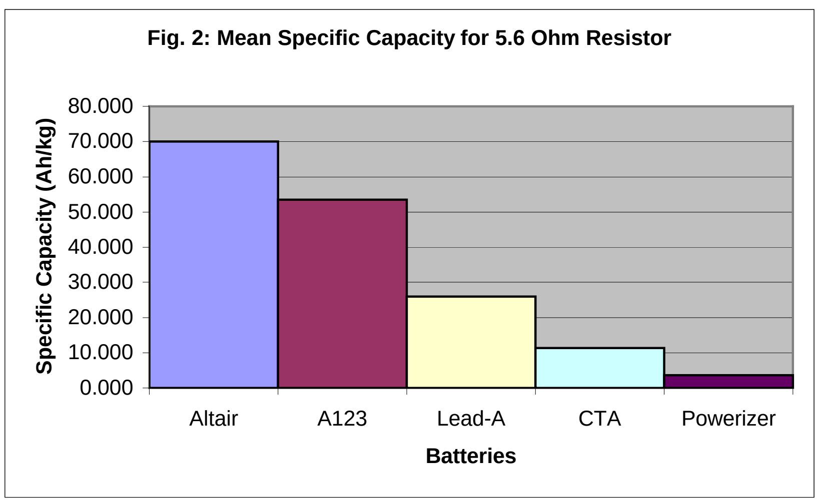
Results:

Mean discharge times were calculated for each resistor for all five batteries. Results revealed that the Altairnano battery took the longest time to discharge in comparison to the other tested batteries for all load conditions. Both NiMH batteries performed very poorly across all load conditions, especially considering the Powerizer battery had a rated capacity of approximately two and half times the other batteries! Perhaps industrial quality NiMH batteries would have produced better results.



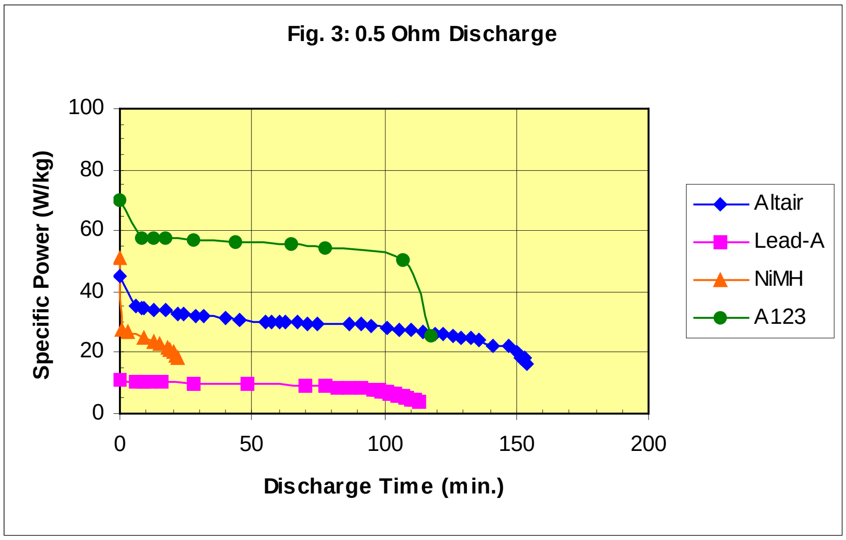
The discharge times for each battery (on a 1 ohm resistor) were then compared for three temperature conditions (Figure 1). No significant differences were found with changes in temperature for all batteries except the lead-acid battery. A t-test for this battery comparing the discharge times at –12°C and –17°C was significant.

The capacity output per unit weight (specific capacity) was calculated for each battery and for each load. When weight was factored in, as shown in Figure 2, the Altairnano battery continued to significantly outperform, and the difference in performance was magnified. In particular, the performance of the lead-acid battery deteriorated when weight was considered. Next, the energy output from each battery per unit volume was calculated (energy density). When volume was factored in, both Altair and A123 significantly outperformed the other batteries at all load levels. When a t-test



was performed on the energy density between the Altairnano and A123 batteries, it was found that the A123 had significantly higher energy density for two loads. The time to discharge was also divided by the cost of each battery to determine the capacity per dollar of cost. The lead-acid battery offered significantly better capacity/cost ratio than the other batteries. The Altair battery was a strong second place performer, and significantly outperformed the A123 battery on this measure.

Specific power, the power output per unit weight, was then plotted over time on a graph. It can be seen, in Figure 3, that the A123 delivers strong power, but the Altairnano battery gives longer-lasting power. Power density, the power output from a battery per unit volume, was also plotted over time. The power discharge pattern was very similar as that seen for specific power.



In terms of charging, the voltage of each battery bounced back significantly during the first 30 minutes after the resistor load was removed. Each battery self-charged to at least 70% of its upper charge level, and then added an additional 3-8% more charge during the first six minutes on the charger. Total charge times to reach upper voltage levels were then compared for all batteries. A significant difference in charge times was found, with both NiMH batteries charging faster than the rest. The two lithium-ion based batteries appeared to charge faster than the lead-acid battery. A t-test found that Altairnano charged significantly faster than A123.

Monitoring the batteries so frequently was a challenge, and sometimes the key cut-off voltage was missed, and the data could not be used. Therefore, a special testing circuit was built that triggered a buzzer when the cut-off voltage was reached. The data collected from this testing circuit was not used in the final analysis, as further adjustments to the circuit are needed before it can be used for future studies.

Conclusions and Applications:

It is apparent that the two newer-generation batteries are able to outperform the more traditional electric vehicle battery options across a wide range of variables. The only area where the NiMH demonstrated good performance was in the area of total charge time. The lead-acid battery offered good capacity per dollar of cost but sub-par performance when weight was factored in. The lead-acid battery was also the only battery that showed poorer performance in –17°C conditions. The Altairnano battery was clearly the best battery in terms of demonstrated amp-hours across all loads, and in terms of specific capacity. It also outperformed in total charge time. However, the A123 had the edge on energy density. The specific power discharge demonstrated the high power of the A123 battery, but the lasting power of the Altairnano battery.

Will the recent advances made in battery technology be sufficient to save the electric vehicle? Perhaps the A123, with its strong power, is best suited to a hybrid type vehicle where its shorter capacity can be offset by gasoline backup. Also, research has shown that graphite, which is used in A123's battery, may be more likely to overheat (House, 2006). Altairnano has replaced the graphite with nano-titanate, which they claim is safer. Further research should be done comparing the safety of these batteries in high temperature conditions. GM has announced that they plan to build their Chevy Volt using the A123 battery. Perhaps, in terms of an all-electric car, Altairnano's superior capacity and charge times may be a better option. It seems likely that the arrival of a reliable, powerful and convenient electric vehicle is just around the corner, thanks to the ever-improving world of battery technology.

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