3300mAh Zinc-Air Batteries for Portable Consumer Products

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Background

Electric Fuel Ltd. is the world leader in the development and commercial application of zinc-air fuel cell technology to primary and refuelable power solutions. During the 1990's the company developed large-scale zinc-air systems for electric vehicles such as postal vans and transit buses, and for high-power torpedoes. Since 1996 Electric Fuel has been developing primary zinc-air batteries for portable applications including handheld consumer electronic devices such as cellular telephones.

Electric Fuel's Instant Power™ z inc-air technology is a high-energy, high-power fuel cell technology that is safe and environmentally benign. The underlying electrochemistry has been around for more than 100 years, whereas Electric Fuel's current technology is the result of 11 years' development. The company has over 40 patents, and 50 more are pending.

Commercial products introduced since 1999 include primary replacement batteries for popular models of cellular telephones, and portable chargers for cellphones and personal digital assistants (PDA's). All are based on the company's 3300 mAh zinc-air cell.

This paper discusses details of the cell and battery construction, applications and performance.

The 3300 mAh Zinc-Air Cell

As shown in Figure 1, Electric Fuel's patented cell is constructed from two roughly rectangular metal case components, an oxygen reduction cathode, or air cathode, and a zinc gel anode. Table 1 lists the cell reactions in simplified form:

At the anode:	$Zn + 2\ OH^- \Rightarrow ZnO + H_2O + 2e$
At the cathode:	$\frac{1}{2}O_2 + H_2O + 2e \Rightarrow 2\ OH^-$
Overall reaction:	$2Zn + O_2 \Rightarrow 2ZnO$

Table 1. Cell Reactions

Each 3300 mAh cell weighs 15.5 grams on average, and has a total volume of about 5 cc. Specific energy is 240 Wh/kg, and energy density is about 700 Wh/l. Nominal, or open circuit voltage, is 1.4 V per cell.

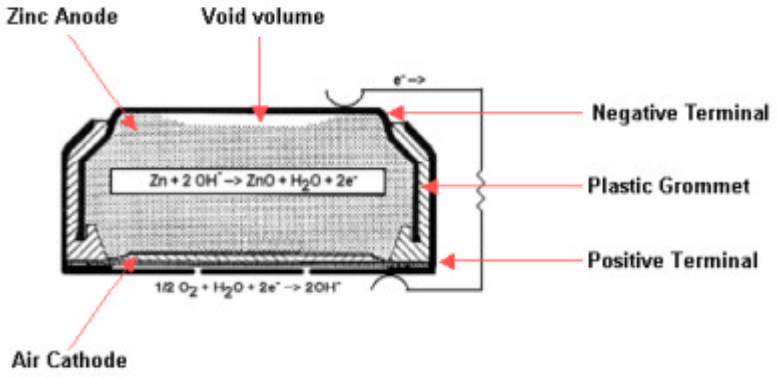

Figure 1. Schematic of zinc-air cell

As can be seen from the photograph in Figure 2, the prismatic metal cell casing is perforated on the cathode side to allow air access to the cathode. Cells are fabricated on automated equipment capable of producing more than one million cells per month.

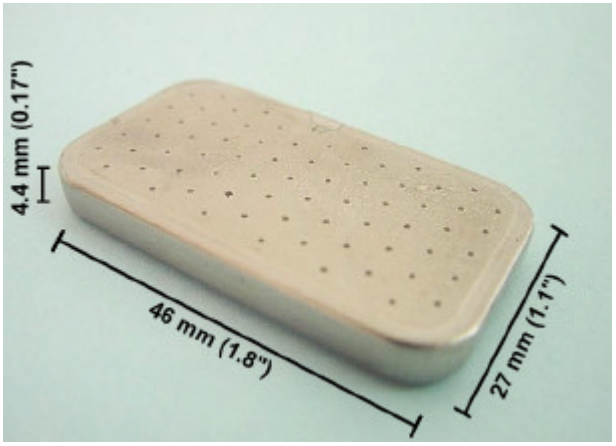

Figure 2. Photograph and dimensions of 3300 mAh zinc-air cell

Cell performance has been optimized to allow attainment of not less than the rated capacity of 3300 mAh under expected discharge conditions. Figures 3 and 4 show typical cell voltages under a variety of discharge regimes.

In Figure 3 it is possible to see the effect of current density on voltage. With an active area of 10 cm^2, current of 0.5 A translates to 50 mA/cm^2. It can be seen that at a constant current density of 50 mA/cm^2, a cell will nominally reach a cutoff voltage of 0.9 V at the point of 100% depth of discharge, i.e., 3300 mAh. This current density corresponds to a typical current required for analog cellphone usage.

Figure 4 shows voltages measured in a GSM-mode discharge, which generally draws high current pulses of 0.55 milliseconds duration followed by lower baseline current for 4.05 milliseconds. The GSM mode simulated by the discharge represented in Figure 4 is a particularly extreme one, with pulses of 2.0A and a baseline current of 0.2 A.

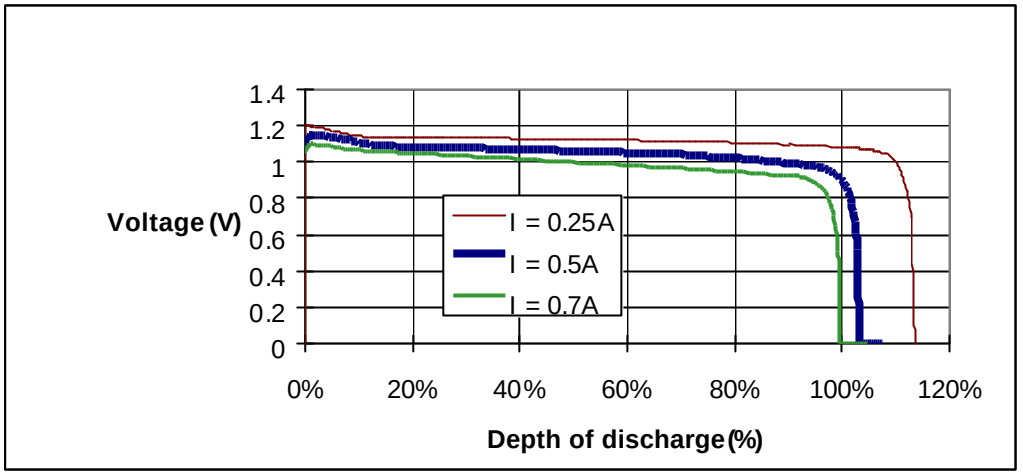

Figure 3. Cell voltages during constant-current discharge, as a function of depth of discharge, for three different current values.

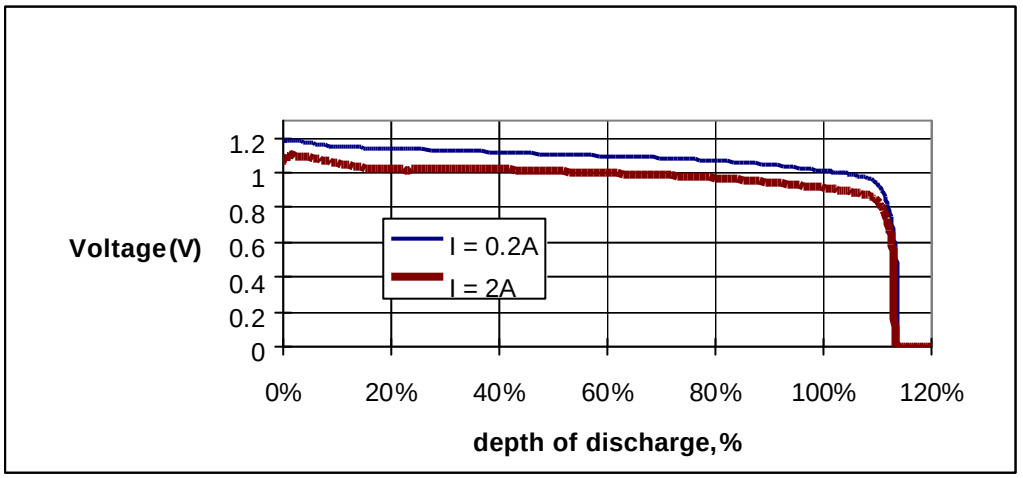

Figure 4. Cell voltages during GSM discharge, as a function of depth of discharge, 0.2A / 2A GSM regime

One of the key difficulties faced by zinc-air developers is the loss of capacity associated with environmental conditions such as low temperature. Figure 5 is a graph of delivered capacity of the Electric Fuel 3300 mAh cell, as a function of ambient temperature during discharge. The graphs shows that when discharged below 5°C there is a slight drop-off in capacity, becoming noticeable at temperatures below 0°C. Reasonable capacity is still available down to -10°C. After being returned to room temperature, the cell recovers fairly rapidly. There are no lasting effects from storage in low temperatures.

At the other extreme, discharge at elevated temperatures up to 65°C has no adverse effects on capacity.

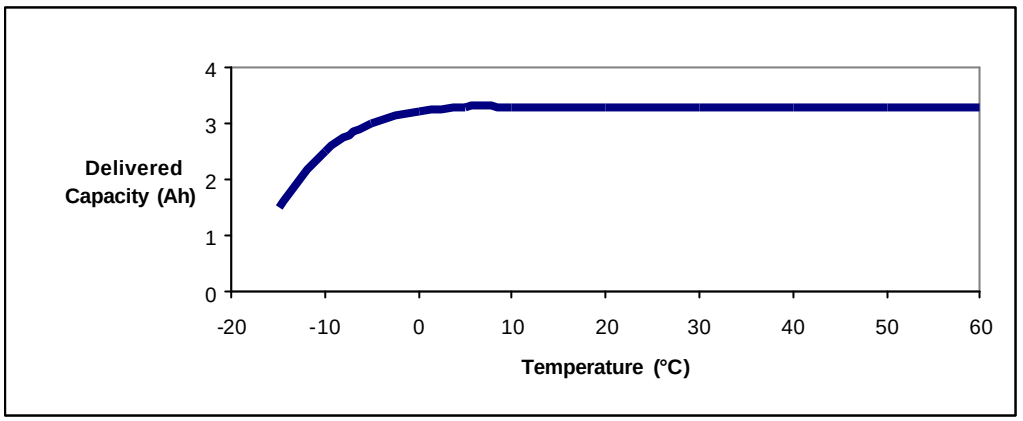

Figure 5. Cell capacity as a function of ambient temperature

Instant Power Batteries

Electric Fuel has introduced its line of Instant Power™ brand batteries commercially, configured at first as disposable replacement batteries for cellular telephones, and, more recently, also as portable chargers for rechargeable cellphones, personal digital assistants (PDAs) and other portable consumer products.

All of the products to date are built using the company's 3300 mAh, 1.4V zinc-air cell. The cells are assembled in series to provide the required voltage. Generally, four cells are used to provide voltage sufficient for emulating a 3.6V lithium-ion battery; some models, designed to replace nickel-metal hydride batteries, are comprised of five, or even six, cells, in order to obtain a higher total voltage. The cells are assembled in injection-molded plastic cases which contain holes to allow air access to the cells.

A sampling of commercially available batteries is shown in Figure 6.

Figure 6. Instant Power™ Batteries for (from left) Motorola, Nokia, Samsung and Ericsson cellular telephones

The Instant Power batteries are optimized for cellular operation, especially for digital modes such as GSM which require pulses of up to 2 A.

The batteries deliver at least 3300 mAh in all of these modes, delivering 3 to 5 times the talk and standby time of most rechargeable batteries which are supplied as original equipment with the cellphones. Figure 7 shows a comparison of GSM-mode talk times between and Instant Power battery, two types of lithium-ion original equipment batteries, and a set of 4 AA-size alkaline batteries.

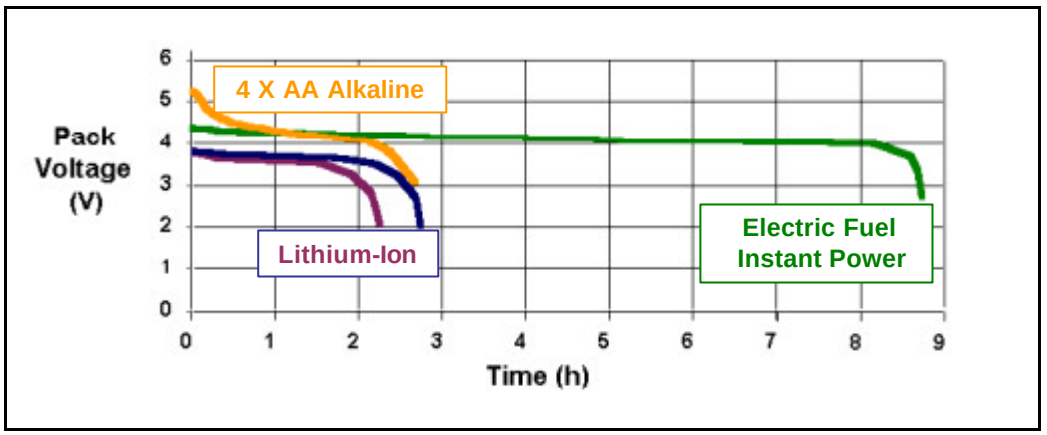

Figure 7. Comparison of GSM-mode talk time

The batteries have a shelf life of 2 years in their original packaging, and active life of about a month after being removed from the packaging. Consumers benefit from a battery that is already charged when they purchase it, and which is ready to use right out of the package without any charging required. The end user cost of the battery translates to about 1 cent per minute of digital talk time, which is typically a small fraction of the per-minute cost of using the phone.

Instant Power Chargers

Electric Fuel recently introduced a line of portable chargers for cellular telephones and PDA's. The power source for the chargers is a small battery pack assembled from four 3300 mAh cells. The zinc-air batteries are used as chargers for the device's rechargeable battery, and can support simultaneous charging and operation. Taking into account the relative inefficiency of the power electronics and of the rechargeable battery itself, users can expect to get 3 charges of a typical 700-900 mAh rechargeable battery.

The Instant Power charger is designed so that the same battery can be used with all cellphones and PDA's which employ 3.6V lithium-ion rechargeable cells. The battery is also sold separately as an Instant Power Cartridge refill. The charging interface and power electronics are contained in a SmartCord™ charge adapter. Each SmartCord model is suitable for use with a wide range of products from a given manufacturer.

Figure 9. Instant Power Charger shown charging cellphone (left); Instant Power cartridge (right)

A top level specification of the Instant Power Cartridge is shown in Table 2.

Rated Capacity:	3300	mAh
Voltage		
– Open circuit	5.6	V
– Continuous GSM (2.0A/0.2A)	>4.0	V
– Continuous 0.5A	>4.4	V
Maximum Current		
– Continuous	0.7	A
– Pulse (1 sec)	2.0	A

Table 2. Instant Power Cartridge specification

The versatile Instant Power Charger can be used by consumers in a number of ways:

- for extending talk and use time
- for portable charging on the go
- as emergency backup when the device's rechargeable battery runs down

Conclusion

Electric Fuel is developing additional applications for its 3300 mAh zinc-air cells. These will include batteries and chargers for high-end internet-enabled cellphones, and the so-called 3G, or 3rd-generation cellphones, as well as other handheld electronic devices such as two-way radios and digital cameras. Camcorder and notebook computer applications are also being designed, and will most likely be implemented with larger cells, possibly in the 10 Ah range.