High Voltage Cathode Battery Development

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Abstract

As with any power source, the pressure to provide more energy in a smaller package is just as real in thermal batteries. Improvements in insulation materials and additives have greatly influenced the state of the art. However, greater gains will need to come from a fundamental transformation in the basic electrochemistry used. Since CFD Research Company's roll out of the High Voltage Cathode EaglePicher has been moving toward using the material in batteries. This paper presents the results of the battery development effort to produce two production ready designs using the High Voltage Cathode with the associated electrolyte. These results include inertial activation tests as well as discharge into power loads at temperature extremes.

Keywords

Thermal Batteries: high voltage cathode; power load; HVC

Introduction

For many years, molten salt batteries have mainly been developed and manufactured around lithium or lithium alloy anodes with iron disulfide or cobalt disulfide cathodes. While these systems were great improvements to the state of the art when they came about, increased demands for even more power in smaller packages has found them wanting. The ever-increasing prevalence of programs requiring power loads, as opposed to resistive or current loads, can be especially difficult as electrochemical discharge reduces voltage which, in turn, increases the current demand to sustain the same power. Taken another way: in aggressively sized batteries space is valuable and has to be used judiciously.

One of the best solutions to this vicious loop is to be able to increase the voltage in each cell. The resulting space saved from the reduced number of cells can be used to increase the electrochemical capacity. CFD Research Corporation's High Voltage Cathode (HVC) provides one such solution [1] with a baseline of 2.6 volts per cell is a significant improvement over the 1.85 volts of FeS_2 cell. The height of the cell stacks in a battery can be reduced by 30% thereby increasing the capacity which gives the batteries a longer operating life. Successful single cell tests with current loads are a great start. Power loads in batteries tested at temperature extremes is the next logical step.

Starting Out

It was generally accepted that this Li (Alloy)/HVC couple would not to be an interchangeable replacement for the Li(Alloy)/Iron Disulfide system. Results would need to be interpreted in the light of a potential new paradigm.

As this was also the first time the HVC and associated electrolyte were blended at EaglePicher instead of CFD Research Corporation, the development goals also included demonstrating manufacturability by producing batch sizes capable of supporting low rate initial production (LRIP) battery production and demonstrating flow and fill capability for all materials on automated presses at EaglePicher.

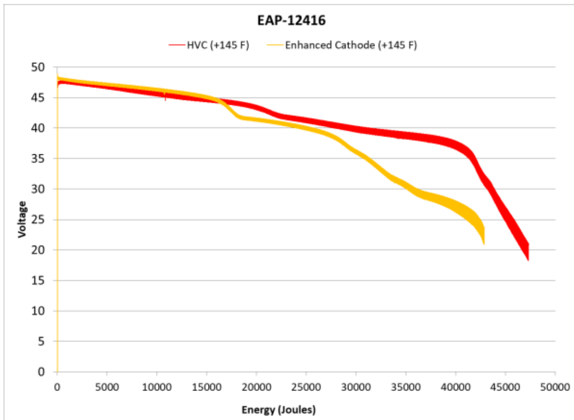

Figure 1: EAP-12416 high temperature tests of HVC compared to the Enhanced Cathode.

Design Approach

EaglePicher sought to develop two batteries, the electric igniter activated EAP-12416 and the inertial igniter activated SAP-12417. The EAP-12416 uses EaglePicher's EP-250-1 electric igniter where the SAP-12417 utilizes the EP-1205 inertial igniter to provide battery activation upon application of a prescribed shock pulse. In either case, the igniter fires through a center hole directly igniting the heat pellets.

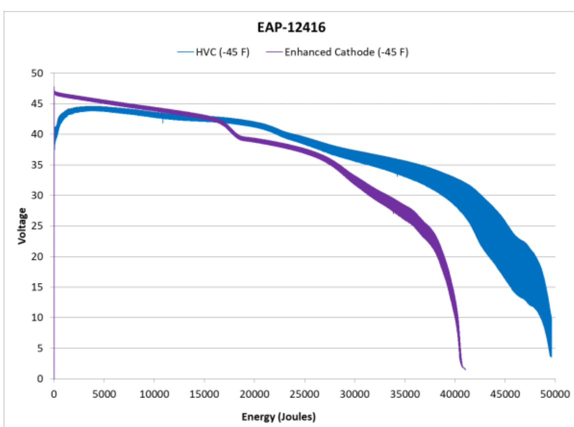

Figure 2: EAP-12416 low temperature tests of HVC compared to the Enhanced Cathode.

Both batteries are identically sized with additional volume allowed outside the SAP-12417 header to accommodate the length of the inertial igniter. Although tested to different load profiles, these batteries require

essentially the same electrochemical capacity. While both loads are power loads they differ slightly in the application. The EAP-12416 is tested with power pulses at a 50% duty cycle applied on top of a power base load. The load for the SAP-12417 is several increasing constant power loads.

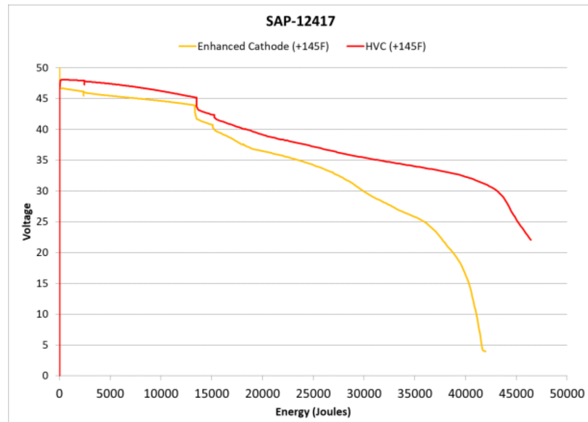

Figure 3: SAP-12417 high temperature tests of HVC compared to the Enhanced Cathode.

Initial development included a parallel path for both batteries that utilized EaglePicher's enhanced Iron Disulfide cathode with additives [2]. Eventually, this alternate design was no longer pursued in favor of the HVC designs that exhibited much better performance by supporting the required load with a higher voltage for a longer duration.

Having similar performance lifetimes, the same insulation arrangements were used on both batteries. This was also facilitated by both batteries as well as both electro-chemistries using the same cell size.

Development

Performance testing of each prototype occurred after sufficient temperature conditioning at the temperature extremes of -45°F to +145°F. Two high voltage-stable electrolytes have been developed and demonstrated by CFD Research: a high rate, all-lithium salt electrolyte, and a lower melting electrolyte to extend operating life and improve rise times for batteries using high voltage cathode materials. Both of these electrolyte formulations were tested. However, the all-lithium formulation was found to provide the best results. Alternately, the design advantages of the lower melting electrolyte were not found to be necessary to meet the desired lifetime in the required size.

After a few initial test iterations of the SAP-12417 in an electrically activated configuration the remaining tests used the inertial igniter and were activated on the shock tower at EaglePicher. No adverse performance was observed with this advancement.

Results

At the end of the development cycle the High Voltage Cathode electrochemistry was the only path to provide the required power within the required volume. As can be seen in the voltage versus discharge energy plots (see Figures 1-4), initial voltage plots for both the High Voltage and Enhanced cathodes are nearly identical. The difference, however, is at around 20,000 Joules of discharge the HVC design maintains greater voltage. This is a direct result of the space savings of the high voltage

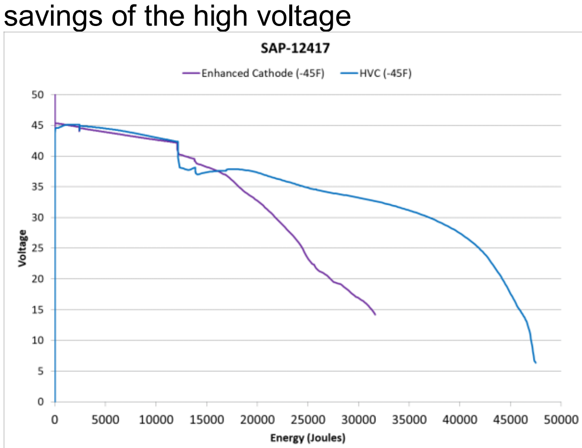

Figure 4: SAP-12417 low temperature tests of HVC compared to the Enhanced Cathode.

cathode translated into additional electrochemical capacity.

Peak volts per cell aligned very well against the single cell results previously published. The EAP-12416 demonstrated an increase of over 30% in peak volts per cell.

EAP-12416		
Cathode	**Temp**	**Volts/Cell**
HVC	+145°F	2.66
HVC	-45°F	2.53
Enhanced	+145°F	1.96
Enhanced	-45°F	1.91

Similarly, the SAP-12417 showed slightly better increases of 33%-44% at the low and high temperatures, respectively.

SAP-12417		
Cathode	**Temp**	**Volts/Cell**
HVC	+145°F	2.67
HVC	-45°F	2.51
Enhanced	+145°F	1.85
Enhanced	-45°F	1.89

Safety

In advance of the S9310 test regimen high temperature open circuit tests were performed on both designs in fixtures indicative of a tactical next assembly. The voltages of both units peaked and then gently rolled off without experiencing cell to cell shorting seen in thermal runaway events with complete voltage decay occurring in just over an hour (reference Figures 5 and 6). Maximum case temperature of both designs remained below 150 °C. This type of uneventful roll off is not typical of thermal batteries in general and especially not the case in aggressively sized batteries like the EAP-12416 and SAP-12417, but has been experienced with the High Voltage Cathode.

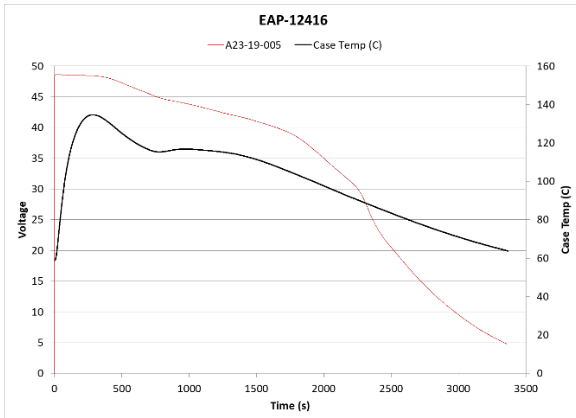

Figure 5: EAP-12416 tested open circuit with case temperature.

Next Steps

At the time of this writing both the EAP-12416 and the SAP-12417 are undergoing a sequence of non-operating and operating environmental tests.

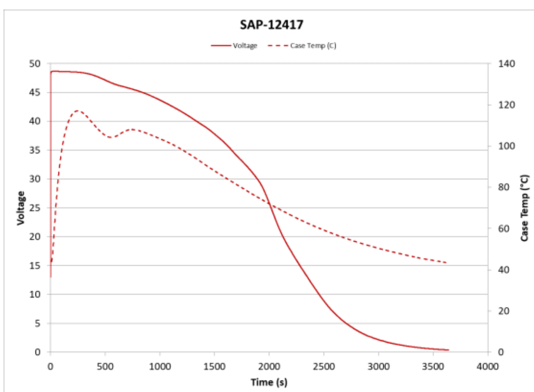

Figure 6: SAP-12417 tested open circuit with case temperature.

Also, the authors intend to revisit some of the initial larger battery HVC experiments incorporating the discoveries from the current effort.

Currently, plans are being made to construct a full rate production scale facility to produce the High Voltage Cathode and the corresponding electrolyte at EaglePicher.

Conclusion

CFD Research Corporation's High Voltage Cathode is demonstrating the capability to be a solution to greater energy densities in thermal batteries. Greater voltage per cell yields an opportunity for smaller batteries, greater energy densities or, perhaps, some combination of the two.

Acknowledgements

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References

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