



Cell overcharge testing inside sodium metal halide battery



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HIGHLIGHTS

- Cell overcharge test conducted on E620 battery at operating temperature and full charge capacity.
- Cell voltage and local temperatures measured during testing.
- Battery endured cell overcharge safely and successfully performed discharge and charge cycling afterward.

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ABSTRACT

Testing was conducted to measure electrical performance and safety of the General Electric Durathon™ E620 battery module (600 V class 20 kWh) during cell overcharge. Data gathered from this test was consistent with SAE *Electric Vehicle Battery Abuse Testing* specification J2464 [1]. After cell overcharge failure and 24 A current flow for additional 60 minutes, battery was then discharged at 7.5 KW average power to 12% state of charge (SOC) and recharged back to 100% SOC. This overcharging test was performed on two cells. No hydrogen chloride (HCl) gas was detected during front cell (B1) test, and small amount (6.2 ppm peak) was measured outside the battery after center cell (F13) overcharge. An additional overcharge test was performed per *UL Standard 1973 – Batteries for Use in Light Electric Rail (LER) Applications and Stationary Applications* [2]. With the battery at 11% SOC and 280 °C float temperature, an individual cell near the front (D1) was deliberately imbalanced by charging it to 62% SOC. The battery was then recharged to 100% SOC. In all three tests, the battery cell pack was stable and individual cell failure did not propagate to other cells. Battery discharge performance, charge performance, and electrical isolation were normal after all three tests.

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1. Introduction

If not designed, constructed, or operated properly, any battery can become quite hot due to internal component failure. Unfortunately, a sodium–sulfur (NaS) battery fire has occurred, due to an internal electrical short circuit [3]. Published finding was that manufacturing defect in a cell caused release of molten material (e.g., cathode electrolyte or anode sodium), which then caused electrical shorting across neighboring cells. This internal electrical current produced significant heating, which cascaded similar failures to all cells in the battery. Design upgrades to this battery, which were subsequently implemented, include internal fusing to interrupt abnormal current flow and anti-fire insulation boards between battery modules in the racking.

A similar thermal runaway failure occurred inside a lithium ion battery used in the Boeing 787 airplane [4]. Conclusions included recommendation that certification testing should have been done at the most extreme service conditions and upon the final battery design.

Goal of this testing was to measure General Electric Durathon™ E620 sodium-metal halide battery performance and external enclosure temperatures after a single cell was failed due to overcharge.

Equation (1) shows the net chemical reaction during battery charging. Equations (2)–(4) show the reactions in the cathode compartment, which contains the nickel (Ni) and salt (NaCl) materials in the uncharged state. The first step is nickel ionization, where two electrons flow out of the cathode to a higher voltage as shown in Equation (2), which causes energy consumption in the external electrical circuit. Similarly, the salt is ionized as shown in Equation (3). The nickel and chlorine ions combine to form nickel

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chloride as shown in Equation (4). The sodium ion moves from the cathode compartment into the anode compartment, because the beta alumina solid electrolyte (BASE) that separates the compartments conducts sodium ions. Lastly, the sodium ion combines with the 2 electrons to form liquid sodium in the anode compartment as shown in Equation (5). These reactions occur in the reverse direction during battery discharging, and the two electrons move to a lower voltage state, thus producing energy on the external electrical circuit.



Data gathered from this test was consistent with *Electric Vehicle Battery Abuse Testing* specification J2464 section 4.4.3.2 by Society of Automotive Engineers (SAE) [1] and *Batteries for Use in Light Electric Rail (LER) Applications and Stationary Applications*, Underwriters Laboratory (UL) Standard 1973 section 17 – Imbalanced Charging Test [2]. The over-charge test creates a well-known failure condition in the E620 sodium–nickel–chloride cell. Fig. 1 shows the E620 battery module with and without battery management system (BMS) attached. This chemistry and battery design provide many safety features under the overcharge condition:

- 1) Sodium–nickel–chloride chemistry does not have free sulfur (like the NaS battery), which boils at 444 °C and greatly increases internal cell pressure. The small quantity of sulfur in the E620 battery is bonded with nickel (NiS) and does not pressurize the cell at high temperatures.
- 2) When the BASE breaks in a NaS battery, the resulting polysulfides are very corrosive and can corrode the cell case, which can cause a breach. Lack of free sulfur in the sodium–nickel–chloride chemistry eliminates this failure mode.
- 3) When the BASE breaks in the E620 battery, the sodium (Na) reacts with the sodium alumina tetrachloride liquid electrolyte (NaAlCl_4) to form benign salt (NaCl) and aluminum (Al), which are non-reactive and do not increase cell pressure as temperature rises. Fig. 2 shows the cell construction. The aluminum formation results in a low electrical resistance in the failed cell, which allows it to pass current with minimal heating and thus helps avoid cascading failure. Under overcharge conditions the

liquid electrolyte will decompose to NaCl and AlCl_3 as shown in Equation (6). If the cell case is ruptured and this liquid electrolyte is also exposed to water vapor, the AlCl_3 will react with moisture to form HCl and an aluminum oxy-chloride (AlOCl) as shown in Equation (7).



- 4) The liquid electrolyte provides additional cell protection up to 20% overcharge, because sodium (Na) can be taken from the liquid electrolyte instead of the BASE, which would weaken its mechanical structure.
- 5) Another safety feature in all E620 cells is the anode compartment is evacuated during cell assembly. Removing the air reduces internal cell pressure during an overcharge event, because this gas is not compressed inside the anode compartment (See Fig. 2).
- 6) Lastly, in the event cathode or anode material did leak outside of the cell, a sump compartment beneath the cells captures any liquid and helps prevent lateral movement that could result in electrical shorting in neighboring cells.

These safety points are supported in an independent study by David Trickett [5,pagev], which included the following conclusions about cell failures and overcharge:

“1. Cell failures have been shown to have non-catastrophic results ...”

9. When cells are exposed to high enough temperatures to compromise their containment function, the EH&S hazards imposed from the resulting failure appear to be small. ...

13. Cells fail safely when overdischarged.”

Because the E620 battery also uses sodium-metal halide chemistry, it is often referred to as being in the “Zebra” battery family.

2. Materials & procedure

2.1. Materials

Table 1 lists the components and equipment needed to run this test. Test was run on a standard E620 battery with wire pairs added to 3 cells and thermocouples (T/C's) around these cells. Cells were the standard 1-shim build and have 46 A-hr nameplate capacity at

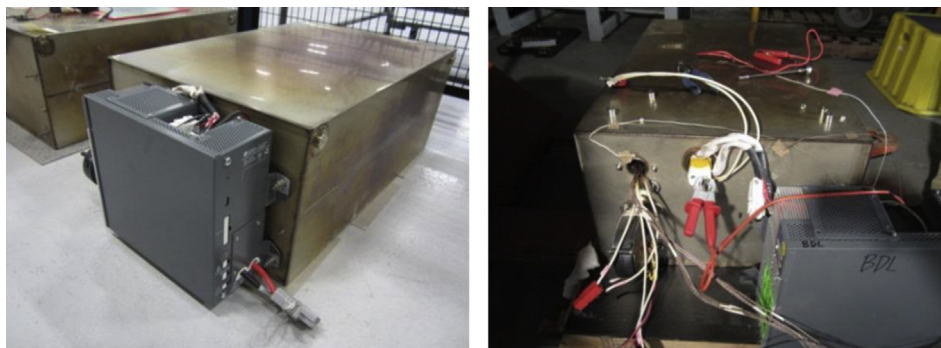


Fig. 1. Battery module with BMS (left) and without BMS (right).

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