Gore Battery Venting Technology
White Paper

ADVANCED VENTING TECHNOLOGIES FOR LITHIUM-ION BATTERY ENCLOSURES

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Background

Thermal runaway of lithium-ion battery cells remains a prevalent issue in the energy storage industry. Thermal runaway can be caused by physical damage, overcharging, manufacturing defects, or other reasons. During thermal runaway, a lithium-ion battery cell is unable to contain all of the heat generated internally. As the temperature of the battery rises, large quantities of gas are produced when components within the cell decompose. To mitigate the potential for explosion, larger lithium-ion battery modules are typically equipped with module evacuation vents which open when the internal pressure reaches a threshold value. This effectively reduces the pressure inside the battery enclosure.

Two common applications for larger lithium-ion battery packs are electric vehicle (EV) batteries, which can store 100 kWh of energy or more in a single large battery pack, and residential battery energy storage systems (BESS), which typically store 10-20 kWh of energy across several modules when fully charged.

Historically, EV battery packs have employed NMC (nickel manganese cobalt) battery cells, which release gas at a much higher rate during thermal runaway compared to alternative LFP (lithium iron phosphate) battery cells. Module evacuation vents on the market today are typically sized for the more extreme case of NMC cells. This “one size fits all” approach makes those evacuation vents suitable for NMC battery packs but oversized for LFP battery packs used in a majority of residential BESS and many electric vehicles.

For example, a typical EV battery pack evacuation vent designed for NMC chemistry is often 50 to 60 mm in diameter, extending 10-15 mm from the wall of the enclosure, and is capable of releasing >100 L/s of gas at 200 mbar differential pressure. While such a device is also capable of handling a more moderate 5-10 L/s gas generation rate of an LFP battery cell of similar size, it is substantially overdesigned for that task.

Product Development

W. L. Gore & Associates, Inc. (Gore), a leader in electronics and automotive venting products for more than 45 years, is developing a small, low-profile evacuation vent solution intended for residential battery energy storage system modules and EV battery packs employing LFP chemistries.

Gore’s patent-pending evacuation vent, currently under development, separates from the enclosure when internal pressures exceed a critical threshold (nominally 200 mbar), exposing an evacuation port and allowing thermal runaway gases to escape from the battery pack. The proprietary vent activation mechanism is not dependent on adhesive properties, which is advantageous in maintaining a consistent activation pressure across a broad range of operating temperatures for the full lifespan of the deployed battery system. The evacuation vent design can include a breathable layer for pressure equalization during normal battery pack operation or potentially an impermeable layer, depending on the specific requirements of the battery pack.

In initial testing, a vent prototype (27 mm diameter, 0.75 mm height, “Gore Vent A”) was installed onto a test fixture, conditioned at one of three temperatures (-40°C, ambient, or 80°C) for one hour in a climate chamber, and subsequently exposed to a pressure ramp at one of two ramp rates (~0.08 bar/s or ~1.0 bar/s). The average activation pressure is shown in Figure 1 as a function of temperature. The dashed line indicates the 200 mbar target activation pressure for the part.

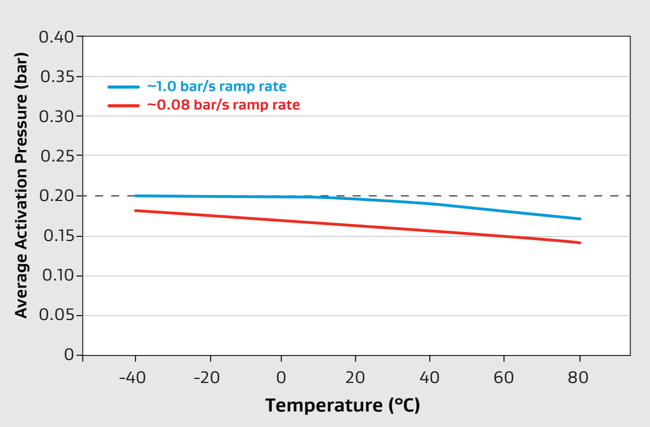

Figure 1: Climate chamber activation pressure test results for Gore Vent A

Reusable Thermal Runaway Enclosure Design

To evaluate the performance of the thermal runaway evacuation vent in a residential BESS module installation, Gore partnered with Jensen Hughes (Baltimore, MD) for testing. Jensen Hughes is a global leader in safety, security and risk-based engineering and consulting. With over 40 years of fire testing experience, the Research, Development, Testing, and Evaluation (RDT&E) team at Jensen Hughes defines industry best practices in custom engineered fire safety product testing.

With input from Gore, Jensen Hughes designed and constructed a reusable steel enclosure to serve as a surrogate for a 5 kWh residential energy storage system module. The enclosure had internal dimensions of 143 mm x 422.7 mm x 347.7 mm (5.63” x 16.64” x 13.69”), with 12.7 mm (0.5”) thick walls. The representative residential enclosure was designed to house a 2 x 8 arrangement of 105 Ah LFP prismatic cells with 3.2 mm thick (0.125”) millboard insulation between adjacent cells. It included a layer of insulation on the interior of the enclosure to prevent the possibility of electrical arcing to the exterior. Cell locations not populated with an active prismatic cell during testing could be filled by steel plates or left open to increase enclosure free air volume.

Based on the desired test configuration, the free air volume within the module enclosure is variable from approximately 5 L to 19 L. The fully loaded test configuration is depicted in Figure 2 with the cover removed and one active cell at the upper right. The free air volume of the enclosure in this configuration was approximately 5 L. By removing various steel plates and insulation, the free air volume could be increased to a maximum value of approximately 19 L, as shown in Figure 3, with one active cell at the upper right and a restraining block immediately below it. For all tests, the active cell was constrained using threaded rods and spacer cells. This simulated the restrictions present in energy storage systems to limit cell swelling during a failure event.

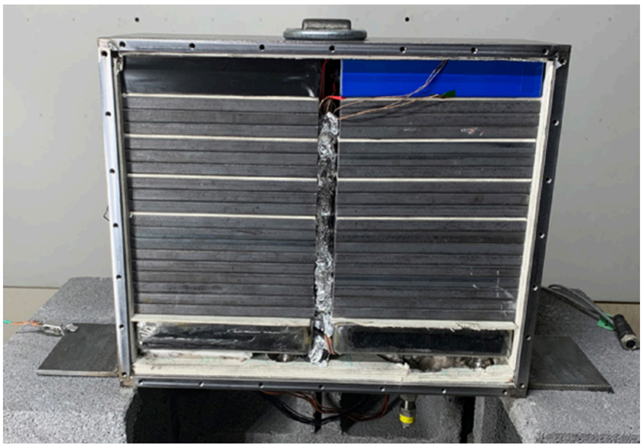

Figure 2: The fully loaded enclosure with the cover removed

Figure 3: The minimally loaded enclosure with the cover removed

The versatile enclosure design included three 101.6 mm (4") diameter circular openings with modular cover plates, as shown in Figure 4 and Figure 5. During the thermal runaway testing, each opening was covered by a plate containing a GORE Vent, a solid plate, or a failsafe plate containing a commercially available 1.0 bar pressure relief valve (Swagelok SS-RL3M4-F4). This configuration allowed the GORE Vent to be installed on any one of the three locations for the test. Due to the modular design of the cover plates, alternative GORE Vents of different sizes could easily be tested by exchanging the plate, enabling rapid product iteration cycles and parallel product development efforts utilizing the same test apparatus.

The enclosure was instrumented with thermocouples and pressure transducers according to the schematic shown in Figure 6. Co-located pressure and temperature measurements were collected at five locations near the enclosure boundary and include measurements local to the GORE Vent, near the failing cell, and along the midline of the module. Test measurements were collected using a NI cDAQ data acquisition system with pressure measurements captured at a rate of 3000 Hz. Initial leakage tests were conducted with three solid cover plates installed on the enclosure to confirm the enclosure was air-tight when pressurized to 1 bar with compressed air.

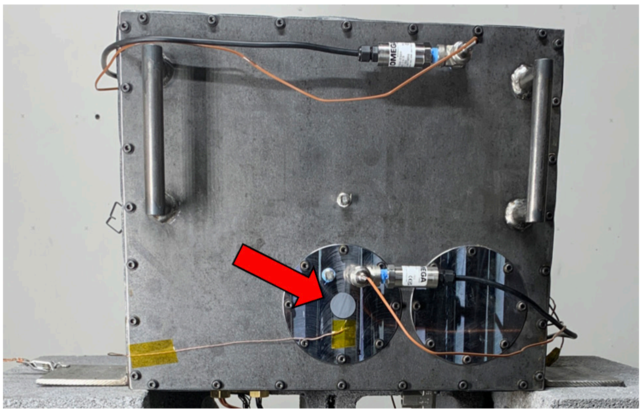

Figure 4: The enclosure with front panel installed, including two cover plates; the GORE Vent is indicated by red arrow.

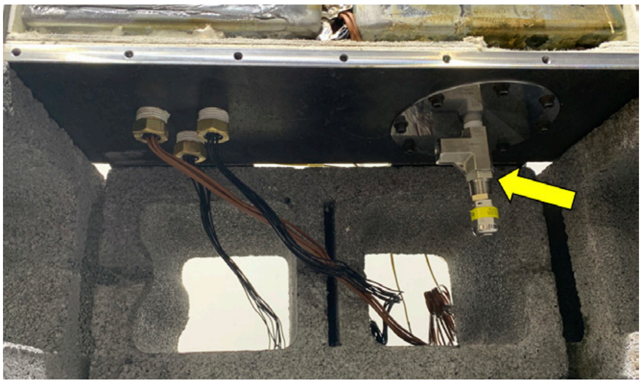

Figure 5: Bottom of the enclosure, showing one cover plate with a pressure relief valve installed, indicated by the yellow arrow

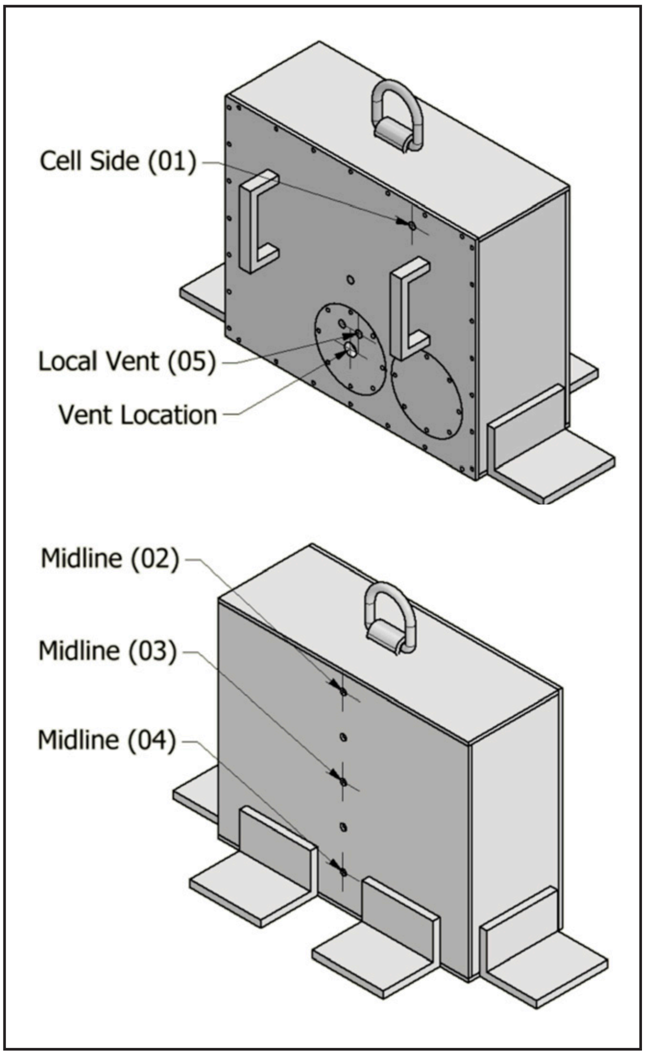

Figure 6: Schematic showing instrumentation of the enclosure

Single-Cell Characterization Tests

Prior to conducting thermal runaway tests in the enclosure, characterization tests were performed on the 105 Ah prismatic LFP cells to determine critical failure temperatures and quantify the volume of gas produced during thermal runaway. The details of these tests can be found in the Appendix. Each battery cell (shown below in Figure 7) included a burst disc for cell-level overpressure protection. The P/N LF105 cells were manufactured by EVE Energy Co., Ltd in Hubei Province, China.

Figure 7: A 105 Ah prismatic LFP cell used for testing (P/N LF105 from EVE Energy Co., Ltd)

Enclosure Thermal Runaway Tests

Following the initial single-cell characterization tests, two thermal runaway tests were conducted inside the representative module enclosure. For each test, one active 105 Ah prismatic LFP cell was heated at 5°C/min (in accordance with UL9540A) to induce thermal runaway. Parameters for the two tests are shown in Table 1 below, with the primary difference being the free air volume present in the enclosure for each test.

Test Parameter	Thermal Runaway Test #1	Thermal Runaway Test #2
Battery cell heating in accordance with	UL9540A	
Number of active 105 Ah LFP prismatic cells	1	
State of charge of the active cell	100%	
Number of cell locations populated with steel plates	15	1
Approximate free air volume inside the enclosure	5 L	19 L
GORE Vent in use	GORE Vent A	
GORE Vent location (per Figure 4)	Front middle	
Diameter of hole covered by the GORE Vent	16 mm	

Table 1: Thermal Runaway Test Parameters

In both tests, the GORE Vent activated shortly after the burst disc on the prismatic cell failed. In Thermal Runaway Test #1, failure of the cell-level burst disc caused the pressure inside the enclosure to increase by 195 mbar in 140 ms, triggering the activation of the GORE module vent. Representative pressure data is shown in Figure 8. The pressure profile was nonlinear, but the average pressure rise rate over the initial 140ms was 1.4 bar/s.

In Thermal Runaway Test #2, failure of the cell-level burst disc initiated an enclosure internal pressure rise to 210 mbar in 54 ms, activating the GORE Vent prior to the enclosure internal pressure reaching a maximum value of 220 mbar. Representative data is shown in Figure 9. In this case, the pressure profile was essentially linear, with a ramp rate of 3.9 bar/s. For both tests, the temperature of the plate where the vent was installed did not vary from ambient conditions prior to vent activation.

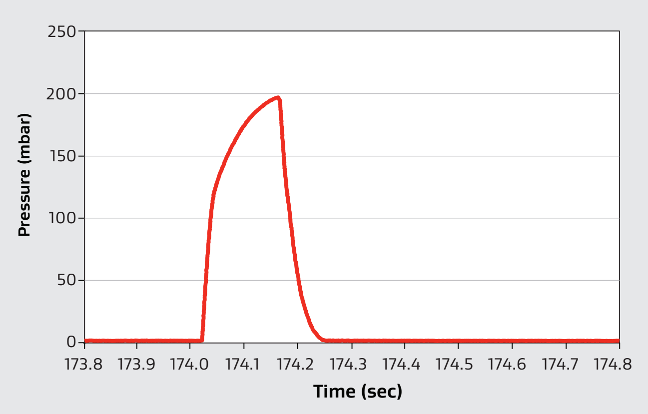

Figure 8: Pressure inside the enclosure due to failure of the burst disc, Thermal Runaway Test #1

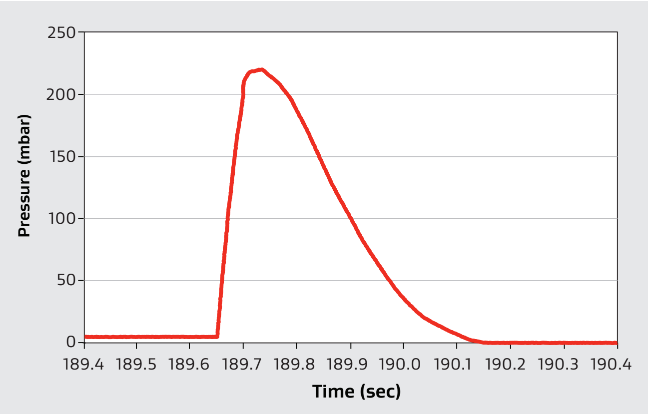

Figure 9: Pressure inside the enclosure due to failure of the burst disc, Thermal Runaway Test #2

Figures 10 and 11 contain high-speed video frame images of the vent as pressure increased in the enclosure during Thermal Runaway Test #1, immediately prior to activation of the vent and shortly after the vent activated, exposing the opening for thermal runaway gases to escape the enclosure.

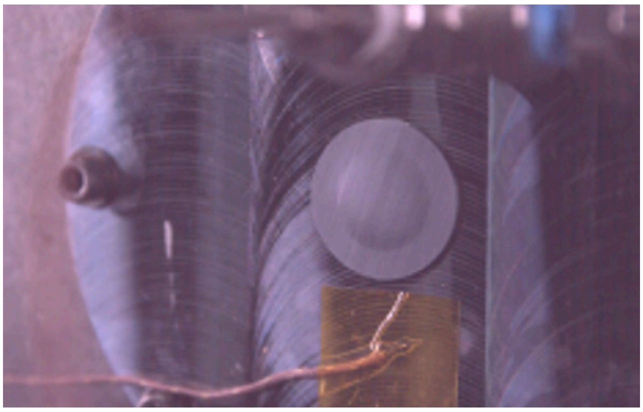

Figure 10: Gore Vent immediately prior to activation, Thermal Runaway Test #1

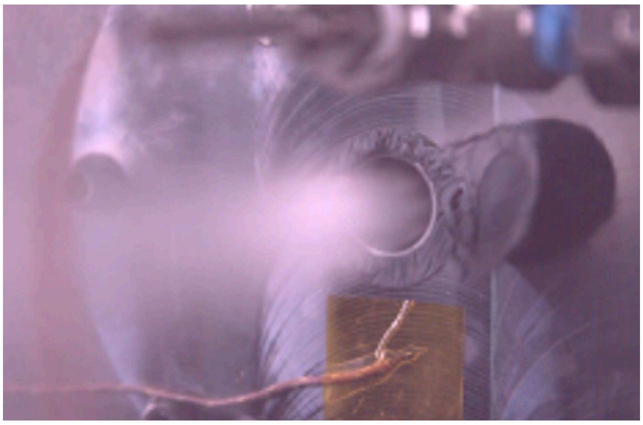

Figure 11: The cover plate after activation of GORE Vent, Thermal Runaway Test #1

Figure 12 contains the average activation pressures from climate chamber testing (as shown in Figure 1) and includes two black dots which represent the vent activation pressures for the two thermal runaway tests. As can be seen from this data, there is good agreement between climate chamber testing with compressed air and real-world thermal runaway testing, particularly given how fast the ramp rate was for Thermal Runaway Test #2 compared to the ramp rates used during climate chamber testing.

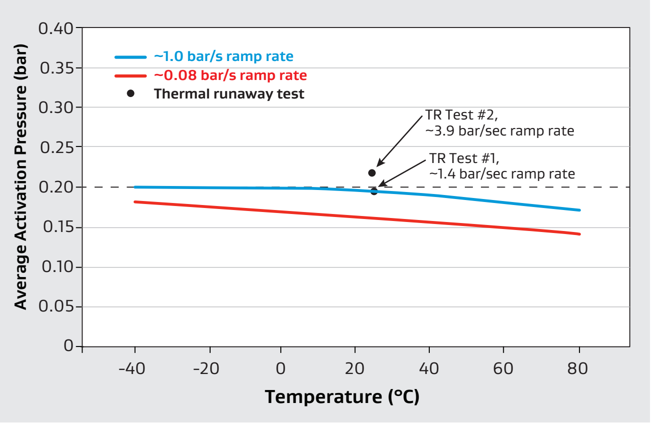

Figure 12: Comparison of climate chamber activation pressure and thermal runaway test results

Conclusions

Gore is currently developing a low-profile dual function evacuation vent for use in LFP battery packs for the residential BESS and automotive markets. Vent activation pressures from climate chamber pressure testing across the temperature range -40 - 80°C were consistent with vent activation pressures from ambient temperature thermal runaway tests.

In partnership with Jensen Hughes, Gore has also developed a reusable enclosure for thermal runaway evacuation vent testing.

Customers who are interested in integrating Gore's developmental dual function evacuation vent into their enclosure design or evaluating its performance with specific application parameters such as cell type, cell location, free air volume, and vent location should contact Gore to discuss their application and to request R&D samples.

Acknowledgments

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Appendix

Prior to testing, battery cells were charged to 100% state of charge. The open circuit voltage and mass of each cell was documented prior to instrumenting the cell with thermocouples and thin film heaters.

Thermal runaway was initiated in two separate cells under ambient conditions in accordance with UL9540A to determine the critical cell temperatures at which venting and thermal runaway were observed. The tested cells vented at temperatures of 216°C and 211°C, respectively, prior to entering thermal runaway when their external temperatures reached 277°C and 280°C.

Next, two additional cells were separately put into thermal runaway in accordance with UL9540A inside a pressure vessel, calibrated to 39 L of free air volume and shown in Figure 13, to assess gas production during thermal runaway. External cell temperatures at the start of thermal runaway were near 280°C, which aligned well with the results from the previous ambient thermal runaway tests. Total gas volume generated during the entire thermal runaway event was 56.5 L and 61.1 L, respectively.

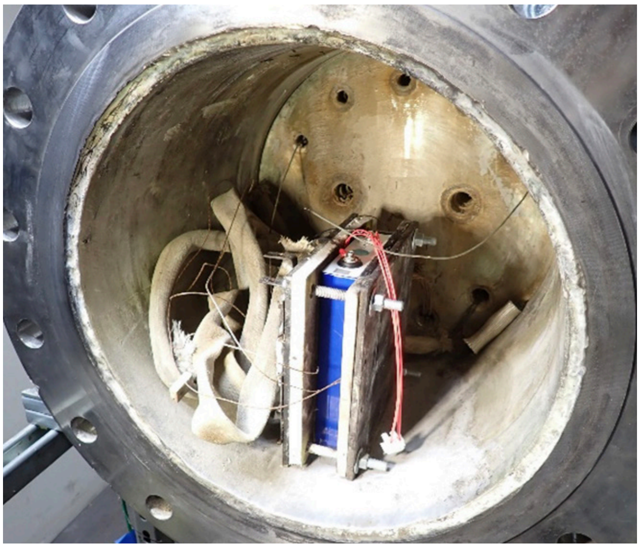

Figure 13: Pressure vessel used for cell characterization

Gas production was not constant throughout the duration of each thermal runaway event. Figure 14 shows a plot of the volume of gas generated by the cells inside the pressure vessel as a function of time. The thermal runaway events proceeded in two distinct stages:

- Cell venting began at ~2600 seconds for both cells when the burst disc on the cell ruptured and approximately 2.9 - 4.1 L of gas was released into the chamber in ~0.5 seconds. An artifactual gas volume spike was observed in the recorded data, as the event occurred so rapidly that the Ideal Gas Law assumption of uniform temperature was not valid. Following this initial event, components within the cell continued to generate gas at a low rate for about 10 minutes.
- Thermal runaway began at ~3100-3300 seconds when a much larger volume of gas was produced (53.6 L in 110 seconds and 57.2 L in 87.8 seconds). This second stage evolved more slowly than the first stage, facilitating more mixing and a uniform temperature; as such, no artificial gas volume spike is observed in the plot.

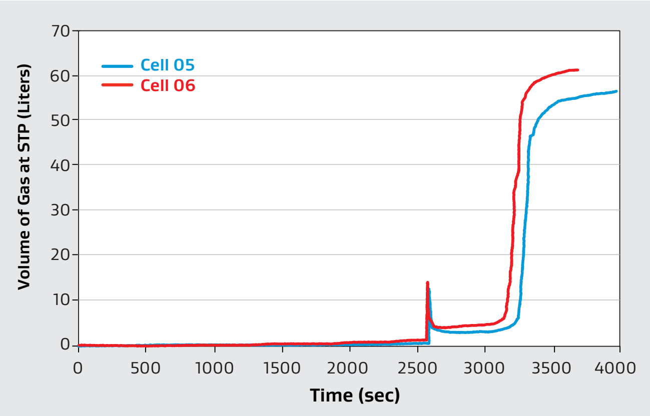

Figure 14: Thermal runaway gas production of two EVE LF105 battery cells

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