



SURFACE VEHICLE INFORMATION REPORT

J3325™

MAR2025

Issued

2025-03

Battery Pack Venting

RATIONALE

Battery packs used in mobility applications require pressure equalization of the airspace within the pack to ambient barometric pressure conditions in a dynamic environment as well as emergency venting of cell vent gases that are released during cell failure to prevent explosion events. This SAE Information Report provides guidance on how to select and integrate vents for pressure equalization and emergency venting as part of holistic battery pack safety concepts.

FOREWORD

Battery pack vents play an important role in holistic battery pack safety concepts. Pressure equalization vents enable equalization between the battery pack interior and the ambient atmospheric pressure. Burst disc functionality, enabling emergency degassing under thermal runaway conditions, can also be integrated. As battery cell chemistries and battery pack designs evolve and diversify, the selection of appropriate vent design and their pack integration based on the individual pack's requirements become more and more important. To support engineers in this task, this SAE Information Report will provide guidance. The main questions that will guide appropriate selection are:

- What is the maximum pressure difference between the battery pack interior and environment that can be allowed to prevent the deformation of battery pack housing components and loss of sealing forces?
- At which overpressure shall emergency degassing be initiated?
- How much vent gas must be guided outside the pack - and how fast - to prevent massive overpressure buildup inside the pack?

As vents are part of the rechargeable electric energy storage system (RESS) safety concept, this report also provides background information on the most important physical and chemical effects and processes that define their functional requirements. As the final design of the venting concept also depends on other safety measures implemented in the RESS, the report also highlights current solutions in a non-comprehensive manner.

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SAE WEB ADDRESS:

Full document details: SAE J3325_202503

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1. SCOPE

The scope of this information report is battery packs containing lithium-ion battery cells with liquid electrolyte, focusing on automotive applications like passenger cars and trucks. Considering different operating conditions as well as durability and safety requirements, some of its contents might provide guidance for other applications. The same applies to battery cell chemistries not covered in this report (e.g., sodium-ion or solid-state battery cells).

2. REFERENCES

2.1 Applicable Publications

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AS568 Aerospace Size Standard for O-Rings

AS4716 Gland Design, O-Ring and Other Seals

SAE J1715/2 Battery Terminology

SAE J2464 Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System (RESS) Safety and Abuse Testing

SAE J2929 Safety Standard for Electric and Hybrid Vehicle Propulsion Battery Systems Utilizing Lithium-based Rechargeable Cells

SAE J3073 Battery Thermal Management

2.1.2 IEC Publications

Available from IEC Central Office, 3, rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland, Tel: +41 22 919 02 11, www.iec.ch.

IEC 60529 Degrees of protection provided by enclosures (IP Code)

2.1.3 ISO Publications

Available from International Organization for Standardization, ISO Central Secretariat, 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, Tel: +41 22 749 01 11, www.iso.org.

ISO 3601 Fluid power systems - O-rings

ISO 12405 Electrically propelled road vehicles - Test specification for lithium-ion traction battery packs and systems

ISO 20653 Road vehicles - Degrees of protection (IP-Code) - Protection of electrical equipment against foreign objects, water and access

2.1.4 NHTSA Publications

Available from National Highway Traffic Safety Administration, 1200 New Jersey Avenue, SE, Washington, DC 20590, Tel: 1-888-327-4236, <https://www.nhtsa.gov/>.

FMVSS 305 Federal Motor Vehicle Safety Standard No. 305 - Electric-Powered Vehicles: Electrolyte Spillage and Electrical Shock Protection

2.1.5 UL Publications

Available from UL, 333 Pfingsten Road, Northbrook, IL 60062-2096, Tel: 847-272-8800, www.ul.com.

UL 94 Tests for Flammability of Plastic Materials for Parts in Devices and Appliances

UL 2596 Test Method for Thermal and Mechanical Performance of Battery Enclosure Materials

2.1.6 United Nations Publications

Available from United Nations Economic Commission for Europe, Palais des Nations, CH-1211, Geneva 10, Switzerland, Tel: +41-0-22-917-12-34, www.unece.org.

UNECE R100 Uniform provisions concerning the approval of vehicles with regard to specific requirements for the electric power train

2.1.7 GB Publications

Available from 106# Zhongmao Building, Sungang, Beizhan Road, Luohu, Shenzhen, China, Tel. +86-755-2583-1330, <https://www.gbstandards.org>.

GB 38031 Electric Vehicle Traction Battery Safety Requirement

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J1715 Hybrid Electric Vehicle (HEV) and Electric Vehicle (EV) Terminology

SAE J1739 Potential Failure Mode and Effects Analysis (FMEA), including Design FMEA, Supplemental FMEA-MSR, and Process FMEA

SAE J2990 Hybrid and EV First and Second Responder Recommended Practice

2.2.2 ISO Publications

Available from International Organization for Standardization, ISO Central Secretariat, 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, Tel: +41 22 749 01 11, www.iso.org.

ISO 1629 Rubber and latices - nomenclature

3. DEFINITIONS

Definitions are in accordance with SAE J1715/2 and SAE J2929.

3.1 BATTERY CELL RUPTURE

Loss of mechanical integrity of the cell housing, resulting in release of contents. The kinetic energy of released material is not sufficient to cause physical damage external to the battery system.

3.2 BATTERY ENCLOSURE

The physical housing surrounding the battery cells and modules; may additionally surround the thermal management system, battery management system, battery monitoring system (BMS), and sensors for battery health and performance optimization.

NOTE: ISO 12405 states that for removable (swappable) battery systems the BMS is inside the battery enclosure.

3.3 BATTERY PACK/RECHARGEABLE ELECTRIC ENERGY STORAGE SYSTEM (RESS PACK)

A battery assembly that consists of one or several modules.

3.4 BATTERY SYSTEM COMPONENTS

Components contained within a hybrid electric vehicle or electric vehicle traction energy storage system.

3.5 ELECTRIC ARCING

Phenomenon where an electric current flows through a gas-filled gap, creating a plasma channel that can reach very high temperatures and cause damage to the surrounding materials.

3.6 EXPLOSION

Very fast release of energy sufficient to cause pressure waves and/or projectiles that may cause considerable structural and/or bodily damage.

3.7 FILM

Layer of material with a typical thickness in the nanometer to micrometer range.

NOTE: Covers (semi-permeable) membranes (porous films) as well as foils (non-porous films).

3.8 FIRE OR FLAME

The emission of flames from a battery (approximately more than 1 second). Sparks are not flames.

3.9 FLAME ARRESTOR

A device located at the outlet of a venting system designed to prevent an external spark or flame from propagating into or out of the battery.

NOTE: The original definition only covered the direction into the pack. For this document, it has been extended to cover outward flow as well.

3.10 FLAMMABLE/FLAMMABILITY LIMIT

Flammable limits apply generally to vapors and are defined as the concentration range in which a flammable substance can produce a fire or explosion when an ignition source (such as a spark or open flame) is present. The concentration is generally expressed as percent fuel by volume.

3.11 GASSING

The evolution of gas from electrolysis or other chemical decomposition processes in a battery.

NOTE: In addition, the term shall also cover vapors and gases resulting from a phase transition of a liquid.

3.12 LOWER FLAMMABLE/FLAMMABILITY LIMIT

The minimum concentration of a combustible substance that is capable of propagating a flame in a homogeneous mixture of the combustible and a gaseous oxidizer under the specified conditions. Below the lower flammable limit (LFL), the mixture of substance and air lacks sufficient fuel (substance) to burn.

3.13 MULTIFUNCTIONAL VENTS

Pressure equalization vents with additional functions (e.g., burst disc and/or flame arrestor functionality).

3.14 OPERATING CONDITIONS

Conditions under which a battery is being used including, but not limited to, voltage, current, temperature, humidity, elevation, and/or duty cycle.

3.15 OVER CHARGE

Continued charging of a fully charged battery.

3.16 OVER DISCHARGE

The continuation of discharging after reaching the cutoff voltage.

3.17 PRESSURE EQUALIZATION VENT

A device to allow equalization of the battery's internal pressure with the external pressure.

NOTE: Some batteries may also use this vent to allow moisture and gas byproducts to escape.

3.18 PRESSURE RELIEF VALVE

A valve that will open when the pressure inside the RESS exceeds a specified value and will close when the pressure drops below a specified value.

NOTE: The gas flow is from a battery to the external environment. The term also covers valves that do not automatically close but can be closed by other means.

3.19 RUPTURE DISK/DISC (VENTING)

A non-reclosing pressure relief safety device to release excessive internal pressure and gases in a controlled way from the battery.

3.20 STATE OF CHARGE (SoC)

State of charge (SoC) is the level of representation of the level of charge of a battery relative to its referenced capacity through time. SoC is often expressed as a percentage based on a reference point as determined by the manufacturer (for example, 0% = empty charge, 100% = full charge).

3.21 THERMAL PROPAGATION

The sequential occurrence of thermal runaway within a battery system triggered by the thermal runaway of a cell in that battery system.

3.22 THERMAL RUNAWAY

An uncontrolled increase of battery temperature caused by exothermic reactions inside the battery.

3.23 UPPER FLAMMABLE/FLAMMABILITY LIMIT

The maximum concentration of a combustible substance that is capable of propagating a flame in a homogeneous mixture of the combustible and a gaseous oxidizer under the specified conditions. Above the upper flammable limit (UFL), the mixture of substance and air is too rich in fuel (deficient in oxygen) to burn.

3.24 VENTING

The release of excessive internal pressure from an RESS cell, module, or pack in a manner intended by design to preclude rupture or explosion.

4. ABBREVIATIONS

LFP	lithium iron phosphate
NMC	lithium nickel manganese cobalt oxide
RESS	rechargeable energy storage system
SoC	state of charge

5. BACKGROUND INFORMATION

The following sections will provide background information needed as a basis for vent design and pack integration.

5.1 Pressure Equalization

In a closed system, the air mass inside is constant, so any rise in temperature or change of the ambient (outside) pressure must be equalized by a gas exchange between the pack interior and the environment. To enable the reliable and safe operation of an RESS, pressure differences between the pack interior and the environment must be compensated to prevent deformation of the battery pack enclosure, which could lead to cracks or reduced pressure on sealings, allowing liquid and solid contamination to get into the pack, potentially leading to a malfunction of battery system components. This is achieved through the use of vents, which enable pressure equalization under standard operating conditions as well as in edge cases. These only seldom occur but pose special challenges to the component's function. The maximum acceptable pressure difference between pack interior and ambient conditions depends on the RESS design, like the housing's stiffness and required sealing forces.

5.2 Thermal Runaway

If the rate of heat generation in a battery cell is higher than the heat that is dissipated from the cell, self-heating occurs, which might further accelerate internal exothermic reactions. Thermal runaway implies that the self-heating rate accelerates in an uncontrolled manner.

In a thermal runaway event, internal cell reactions produce gassing. The cell housing can withstand a certain pressure depending on the choice of material and safety vent design (pouch versus hard case). If the gas pressure inside the cell exceeds the pressure defined by the manufacturer, the cell housing opens and gas, particles, and usually also electrolyte escape. A defined vent design is important to avoid cell case explosion.

The characteristics of a thermal runaway event depend on different parameters. For example:

- Battery cell materials (anode, cathode, separator, electrolyte) and their thermal stability
- Battery cell size and format (cylindrical, pouch, prismatic)
- Battery cell SoC
- Thermal runaway initiation method
- Battery cell history (crash, aging, and cycling)
- Boundary conditions (e.g., relating to heat dissipation)
- Availability of oxygen external to the cell

As thermal runaway events can never be completely prevented, measures must be taken to reduce the negative impacts of those events. To achieve this, vents with multiple functions play an important role.

5.2.1 Thermal Runaway Basics

5.2.1.1 Thermal Runaway Initiation

In general, battery thermal management systems, as described in SAE J3073, are designed to prevent the temperature inside the battery cell, generated under normal charge and discharge operation, from reaching a thermal runaway condition. However, abnormal or abuse conditions can result in self-heating rates that exceed the thermal management system cooling capacity. Abnormal or abuse conditions include mechanical stress such as impact, vibration, crushing, excessive cell clamping pressure, external heating, electrical malfunctions like overcharging and short circuits, or flooding events. Contamination or other defects inside the cells resulting from cell production can also result in internal short circuits or dendrite growth, which can result in increased internal cell heating. Additionally, defects in the RESS, such as improper welds or external short circuits, can also result in excessive heating that can cause thermal runaway.

The different initiation methods will lead to different severity of a thermal runaway event. For example, overcharging leads to conditions with SoC above 100%, and the excess energy stored in the battery cell will be released in the thermal runaway event, typically making it more severe.

Thermal runaway will most often not be initiated in cells with low SoC, historically below 30%, but this threshold may be lower for newer high energy density cells.

5.2.1.2 Phases of Thermal Runaway Events

Lithium-ion cells operate typically at temperatures below 50 °C, as internal temperatures increase beyond the normal operating window can initiate exothermic reactions. However, after initiation as described in 5.2.1.1, the first phase of exothermic reactions inside the cell often does not lead to a rapid increase in temperature. It typically starts with reactions at the solid electrolyte interface (SEI) or reactions with plated lithium on the anode. As cell temperature increases, both gas-generating chemical reactions and vaporization of electrolyte inside the cell may generate overpressure inside the cell and cause a first venting event before the thermal runaway. For prismatic and cylindrical cells, the safety vents open at several bars, and these formats have defined areas through which the venting will occur. This is not the case in pouch cells, where the weakest circumferential sealing area will open and release the vent gases, typically at significantly lower pressures.

Initial reactions between electrolyte and anode could typically be followed by separator melting (e.g., starting at approximately 135 °C for separators made from polyethylene). The introduction of ceramic separator layers can enhance thermal stability. Separator damage leads to internal shorts, rapidly increasing internal temperatures, which is followed by decomposition and reactions between the cathode and electrolyte. For some chemistries, cathode decomposition typically releases oxygen, which can react with the organic electrolyte. This second phase can lead to a fast buildup of gas and pressure inside the cell, and when released from the cell, a large number of particles from cell material can be ejected as well. As the released gases start to burn, even more heat is generated.