Advanced, Cooling Liquid Immersion Fire Suppression Technology for Expandable Battery Energy Storage System (BESS)

Exclusive Dielectric Liquid Immersion Designed for Effective Fire Suppression

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Introduction

Use of renewable battery energy is an important means to improve energy self-sufficiency, reduce expense of electricity, and ensure stable power supply. Lithium-ion batteries are "being deployed at a massive scale to improve the resilience of our national electrical grid". (Barowly, p.3). Battery energy storage systems (BESS) are an important part of maintaining clean energy, however, high safety requirements are imposed on BESS.

The United States Department of Energy's (DOE) Energy Storage Strategic Plan describes thermal runaway as the primary safety concern for lithium-ion batteries, describing it as once thermal runaway occurs, it has the components for combustion or possibly explosion. The report also mentions that the DOE is still seeking a universal effective fire suppression for Lithium-ion fires, or a method of application to suppress a thermal runaway fire.

"Thermal runaway is defined as a phenomenon in which the lithium-ion cell enters an uncontrollable, self-heating state" (Barowly, p.6), which accelerates the release of heat inside a cell, due to a series of exothermic reactions, and manifests as an exponential, uncontrollable, increase in cell temperature. Thermal runaway is one of the primary risks related to lithium-ion batteries, and could result in the ejection of gas, shrapnel particulates, extremely high temperatures, smoke, or fire. (UL Research Institutes).

System cooling is important for maintaining the battery at a safe operating temperature. However, thermal runaway propagation should not be contingent on coolant circulation due to redundancy in fans or pumps, or even in the power plan.

> **"Module designs should include barriers (e.g., air gaps, dielectric liquids, aerogels, and phase change media) between cells to provide passive protection against thermal runaway propagation. A typical arrangement has thermal barriers between cells and a cooling plate below them."**
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> DOE Energy Storage Strategic Plan, April 2024 (p.30).

Etica's ESS and BESS Systems may be the answer to the universal solution, incorporating a patented cooling circulation system and its battery cooling device.

Etica's battery cooling device includes a cooling tank, a guide plate and an overflow channel. The cooling tank has a liquid inlet opening and an accommodating space. The liquid inlet opening is located above the accommodating space, allowing cooling liquid to flow into the accommodating space through the liquid inlet opening.

The guide plate is located in the cooling tank, and one side of the guide plate is adjacent to the battery module. The bottom end of the guide plate is separated from the bottom of the cooling tank by a distance to allow the cooling liquid to flow to the other side of the guide plate side.

The overflow channel is arranged on the outer wall of the cooling tank and below the cooling tank. The overflow channel has a flow guide opening and a liquid outlet opening. The flow guide opening is located on one side of the cooling tank, and the liquid outlet opening is located below the cooling tank. This can prevent the coolant pipeline from bursting and at the same time increase the cooling water circulation flow. (See Figure 1.)

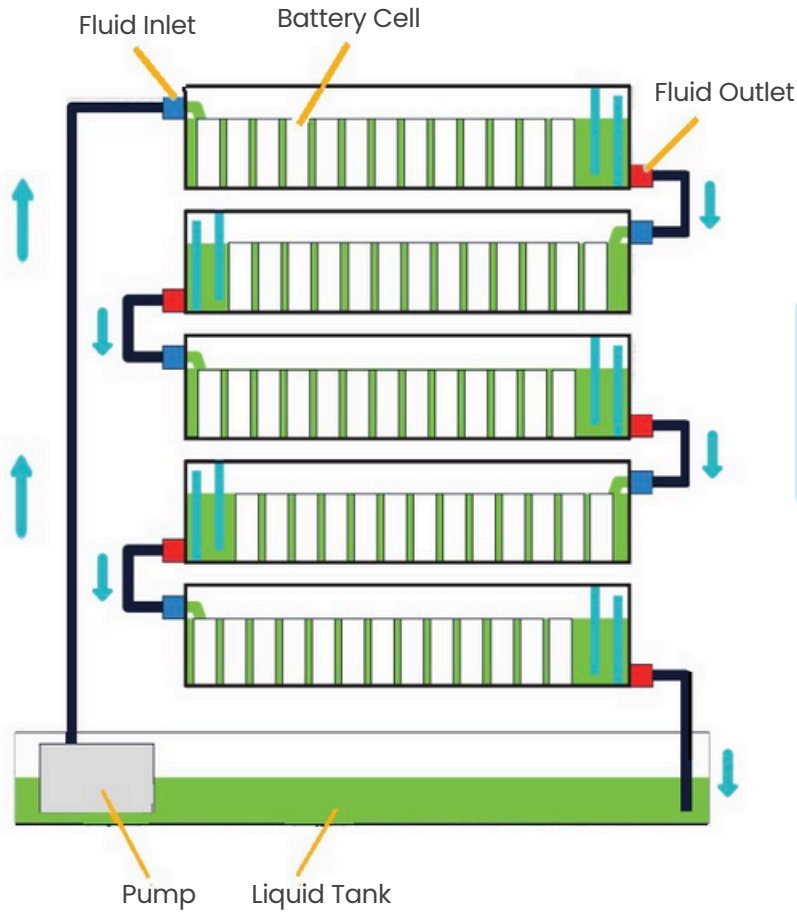


Figure 1.
Etica's Patented Immersion Cooling System to Avoid Thermal Runaway Propagation

Background

When heat generated within a battery cell exceeds heat dissipated to that cell's surroundings, thermal runaway often begins. This increased heat propagates chemical reactions which can release thermal energy, and at high enough temperatures, the cell's separator can distort or melt, leading to an internal short circuit.

Once rapid thermal energy is generated from an internal short circuit, thermal runaway occurs. If internal cell temperatures continue to rise, the rate of the chemical reactions increase, and a feedback loop is created -- the rise in temperature in a single cell transfers heat to other cells, potentially propagating the process throughout a battery pack. (Barowly, p.6).

Once thermal runaway occurs, excessive heat transfer must be dissipated quickly to prevent damage or propagation to adjacent cells. There are three ways to transfer heat: conduction (occurs in solids or fluids at rest); convection (occurs in liquids or gases in motion); radiation, (takes place with no material carrier). Encyclopedia Britannica, Inc. (2024). Etica's immersion cooling system encompasses these key principles of heat transfer.

First, by means of conduction, heat is transferred non-conductive dielectric oils. The material properties of dielectric oils are chosen for their ability to absorb and carry away heat without reacting chemically with the battery or degrading under high temperatures; they have lower thermal conductivity compared to metals, and are sufficient for dissipating heat from the cell surface. These oils provide electrical insulation, which is critical for preventing short circuits or electrical arcing between the battery cells. As the battery cell surface overheats, the heat is conducted from the cell's surface to the surrounding dielectric oil.

Direct immersion in dielectric oil absorbs and transports the heat generated in a runaway cell, preventing adjacent cells from reachingunsafe temperatures. Etica's design includes a gap between adjacent cells, which serves two purposes:

1. Allows free flow of dielectric, enhancing the thermal dissipation rate
2. Creates a buffer zone, limiting direct thermal conduction

Secondly, convection occurs via heat transfer within the dielectric oil. Natural convection occurs as the oil approaches the overheating cell, absorbing heat; the temperature of the oil temperature rises, reducing its density. A buoyancy effect occurs, causing the warmer, lighter oil to rise, while cooler, denser oil from the reservoir or surrounding area flows in to replace it. The system employs forced circulation of dielectric oil (forced convection) to enhance convective heat transfer.

The heated oil is moved away from the cell toward a larger reservoir of cooler oil, which enhances the cooling rate and ensures a stable temperature around the cells. This process prevents the buildup of thermal gradients in the system and helps maintain uniform cooling across all cells.

Thermal management of multiple cells is possible. If one cell enters thermal runaway, the immersion cooling system dissipates the excess heat quickly into the circulating oil and out to the reservoir, keeping surrounding cells at a stable, safe temperature and preventing cascading events.

Finally, indirect radiation occurs through the heat dissipation at the reservoir of cooler oil. The circulating oil transfers heat to a larger external reservoir, which acts as a heat sink. where the oil has a larger area exposed to cooling mechanisms (e.g., air-cooled fans, liquid cooling systems, external heat exchangers), helping to dissipate the heat accumulated from the battery cells. A 2022 review in the Journal of Power Sources found that immersion cooling, which provides direct dielectric fluid (such as transformer oil) contact with all cell

surfaces, to be one of the most promising approaches for suppressing thermal runaway in some situations. Immersion cooling rejects high heat, thereby improving safety. C. Roe et al., Journal of Power Sources, 525 (2022).

The DOE plan compares fire suppression methods including traditional fire suppression agents, such as water-based agents, gaseous clean agents and aerosolized powders. (See Table 1.) Immersion cooling in a dielectric liquid (as opposed to submersion after an incident) is described as “one area of considerable interest” in stopping the thermal runaway process. DOE Energy Storage Strategic Plan, April 2024 (p.34).

Liquid has better thermal conductivity compared to air cooling and phase change material, making liquid cooling systems more suitable for cooling lithium-ion batteries and large batteries used in engineering and commercial applications. Liquid cooling also is used most by major electric car manufacturers. Zhou et al., Materials Advances, 4 (2023).

Oil is commonly used in a direct liquid cooling battery thermal management system, because is not electrically conductive, not easily combustible, and due to its high thermal conductivity coefficient, it allows heat to be transferred directly from the battery to the oil. Zhou et al., Materials Advances, 4 (2023).

Compared to natural cooling, immersion cooling can reduce the maximum temperature of the battery during discharge significantly. Cooling and stabilizing temperature performance of transformer oil has been proven to be superior to that of silicone oil. The cooling performance of liquid-immersed battery thermal management system and its influencing factors were studied by Zhou et al., and the results showed that the liquid immersion cooling scheme with full immersion height has the best thermal management performance.

The use of dielectric immersion cooling is an emerging alternative to battery thermal management systems. This approach's advantage is achieving of extremely high rates of heat transfer through the direct contact of the cells with the immersion fluid, especially in 2-phase fluid systems. Additionally, use of many of these immersion fluids reduces the risk and effects of thermal runaway by acting as fire suppressants. C. Roe et al., Journal of Power Sources, 525 (2022)

Table 1. Fire Suppression Effectiveness and Safety Comparison: Water, Gaseous Agents, Aerosol, Immersion

Fire Suppression Method	Application	Limitations & Results
Water-based Includes foams typically used for fires in combustibles and hydrocarbon and alcohol-based liquid fuels material	1. Direct application 2. Direct injection of water into each module 3. Flowing water	**Direct Application** • to the source of the fire in a very dense rack of modules • conductive quality of water short circuits • extends the damage **Direct Injection** • large scale damage to the ESS when inadvertently discharged **Flowing Water** • challenges in preventing further equipment or environmental damage
Gaseous-Clean Agents e.g., Novec 1230 and FM200, common in the protection of sensitive electronics and act by either cooling or displacing oxygen	Act by either cooling or displacing oxygen	• Challenges in the suppression of ESS fires include limited effectiveness due to the extreme heat generated during the thermal runaway process, as well as the duration of the incident • Limited effectiveness due to the extreme heat generated during the thermal runaway process, as well as the duration of the incident • Concentration of the agent for long enough to extinguish flame - elimination of visible flame does not stop the thermal runaway process and the continued production of flammable gas now creates an explosion risk as the gases are allowed to build in the sealed enclosure
Aerosol Agents	Discharge into the enclosure or room to disrupt the chemical chain reaction and extinguish flames	• Ineffective for lithium battery fires (limitations in cooling and the need for sealed environment to maintain agent concentration) • Need to prevent the build-up of flammable gases with rapid exhausting

Immersion*	Battery is submerged into a non-conductive dielectric fluid, making direct contact with the cell	• Immersion fluids can increase heat transfer by up to 10,000 times (compared to air)
		  ◦ single-phase direct contact immersion cooling offers up to 1,000 times improvements in heat transfer over air cooled systems
		  ◦ achieved performance increased in 2-phase systems, through latent heat of evaporation of the liquid-to-gas phase transition and the resulting turbulent 2-phase fluid flow
		
		• Heat dissipation rate of the power battery is improved

Source: DOE Energy Storage Strategic Plan, April 2024, (p.34).

*Sources: C. Roe et al., JPS, 525 (2022) p.30.
Wu Weichen, Zhou Zhiyan Cooling circulation system and battery cooling device thereof. Patent No. TWM646757U
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Proposed Solution

Etica's heat transfer process prevents thermal runaway propagation. The gap between the cells ensures efficient heat removal through convection and conduction, minimizing the chance of heat propagating to adjacent cells the system, and acts as an additional thermal buffer. The continuous flow of cooled dielectric oil limits the temperature rise in neighboring cells.

Etica's immersion cooling ESS/BESS employs an advanced thermal fluid technology, which fills the lithium-ion battery modules, effectively isolating each cell, preventing thermal runaway propagation. (See Figure 2.)

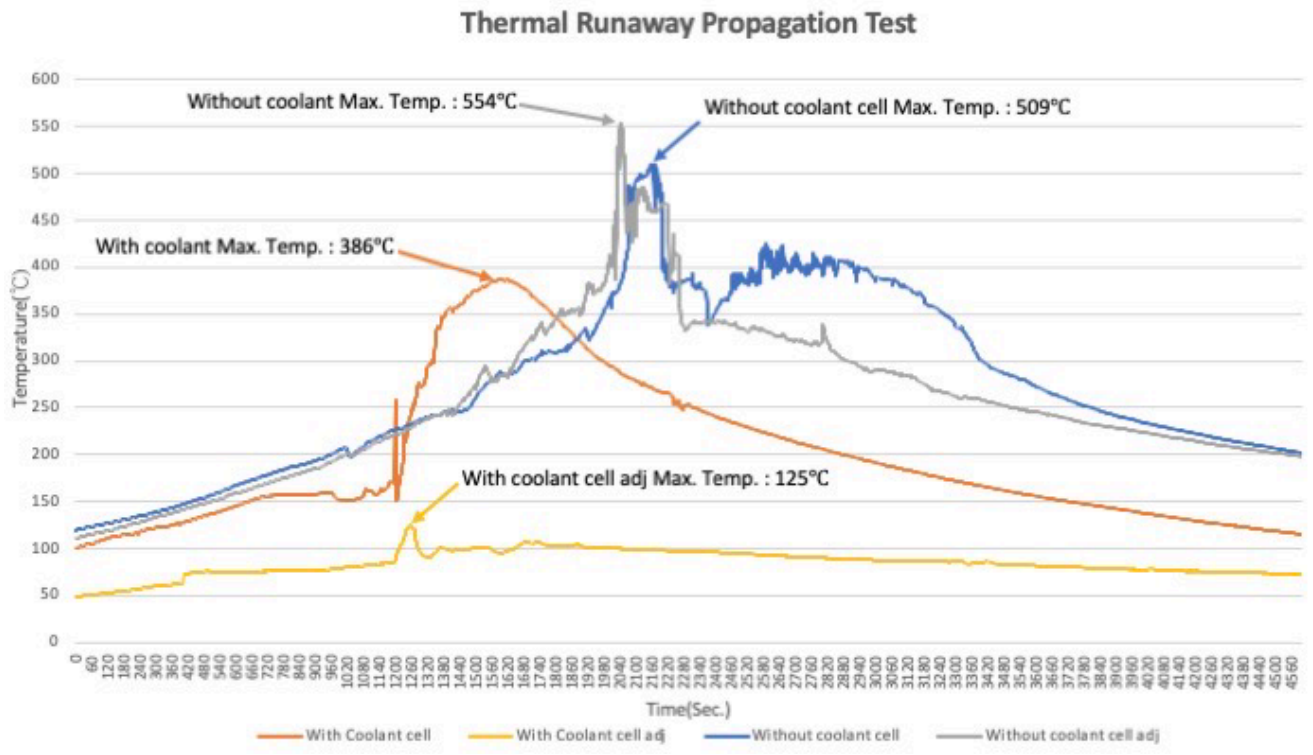


Figure 2. Battery Immersion Cooling System Eliminating Thermal Runaway Propagation Over Time

By immersing battery cells in a proprietary coolant, Etica's cooling system employs a sophisticated active thermal management system, which enables efficient heat transfer by directly contacting the cells. This approach ensures optimal battery cell temperatures for maximum performance and longevity.

The Battery Management System (BMS) independently monitors cell-level conditions, such as temperature, and triggers cooling when necessary. When the BMS detects temperature variations, it activates the pump to circulate the coolant through the system. This dynamic response rapidly dissipates heat during peak operations or thermal events. By integrating the BMS with the cooling system, Etica's immersion cooling maintains a stable thermal environment, reducing the risk of thermal runaway and optimizing overall system efficiency.

Etica’s patented cooling circulation system and battery cooling device thermally manages fire suppression by providing flowing liquid with direct contact to the battery cells, effectively eliminating the propagation of the neighboring cells, and thereby stopping a chain reaction of thermal runaway. The power battery cooling device employs a radiating pipe, a cooling chamber, a refrigerating device, and a temporary storage chamber, arranged in a protective shell of the power battery.

Conclusion

Immersion cooling is the current state-of-the-art in the cooling of lithium-ion batteries. Removing heat and leveling out temperature distributions in single cells and packs are key considerations to preventing thermal runaway propagation. Submerging the battery in a dielectric fluid through immersion cooling potentially may increase the rate of heat transfer by 10,000 times relative to passive air cooling. High heat rejection capability also improves safety by suppressing thermal runaway.

The United States Department of Energy describes module designs including barriers such as dielectric liquids between cells as providing passive protection against thermal runaway propagation, and goes on to report that immersion cooling in a dielectric liquid is described as an “area of considerable interest” in stopping the thermal runaway process.

Etica’s patented cooling circulation system and its battery cooling device is an answer to the universal solution of stopping the thermal runaway propagation.

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