IMFSE Master's Thesis: Suppression of Li-ion Battery Fires

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Popular Science Summary

Lithium-ion batteries (LIB) are widely used nowadays as a green energy carrier and play an important role in reducing global carbon emissions. However, the inherent thermal runaway remains a main problem affecting the fire safety of LIB in their field applications, particularly on electric vehicles (EV) and battery energy storage systems (BESS). The thermal runaway phenomenon is commonly caused by electrical, mechanical or thermal abuses as well as the battery's internal short-circuit, which lead to a rapid temperature increment within the batteries resulting in fire, smoke and explosion. The LIB fires are difficult to be extinguished due to its self-sustained nature and the possibility of re-ignition.

This thesis presents a systematic and thorough literature review of fixed fire suppression systems and extinguishing agents for lithium-ion battery fires. The review covered various relevant publications from the earliest research in 2013 to the latest in Mar 2023. The research experiments were classified based on different LIB configurations, from small-scale experiments (batteries in cells and modules) to large-scale experiments (batteries in EV packs and BESS racks). More than twenty (20) extinguishing agents ranging from water-based, gas-based, powder-based and combined agents were tested in these research with two (2) typical dispersion modes (total flooding and direct injection).

In the total flooding dispersion mode, the extinguishing agents could not reach the battery cells and the seat of the fire due to the hindrance by the battery module/pack boxes or rack cabinets. In the direct injection dispersion mode, the extinguishing agents reached the exposed battery cells or modules and the seat of the fire, which could suppress the fire and cool the LIBs more effectively than in the total flooding dispersion mode.

Among different extinguishing agents, water-based agents have a better cooling effect of mitigating thermal runaway, particularly water mist with additives. Gas-based and very fine powder-based agents have a quicker flame extinguishment capability but are less effective in cooling. A water-based suppression system was recommended as a backup if the gas-based or very fine powder-based suppression system is adopted as a primary means of LIB fire suppression.

The thesis recommends carrying out further research of the novel extinguishing agents that have been tested in the small-scale experiments onto the large-scale experiments to verify their effectiveness before an actual filed application. Direct injection mode is also worthwhile to be explored and verified in large-scale rack experiments. Last but not least, future research is necessary to optimize the carrying capacity of appropriate extinguishing agents and maximize their effectiveness onboard electric vehicles, as well as special consideration of extreme operating temperatures of extinguishing agents due to different climate conditions when electric vehicles travel on roads.