

Safety of Lithium Battery for New Energy Vehicles: A Literature Review

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Abstract: An overview of the causes of lithium-ion battery fires, what types of extinguishing agents are used when a fire occurs, and how to effectively prevent fires from occurring. It describes in detail the potential factors required for lithium-ion battery fires and related real-world cases, the advantages and disadvantages of various extinguishing agents and whether they can be used in automobiles, and the lithium-ion battery safety systems that have been designed and how they work.

Keywords: Lithium battery fire; Causes of fires; Fire suppression; Fire prevention and control.

1. Introduction

Chemical power supplies have been developed for over two hundred years and in that time, chemical power supplies have evolved towards diversification and versatility. “Since 1990, when Sony invented the lithium battery”, it has been widely used in all aspects of people’s lives because of its high energy density, light weight, small size, and long service life. Later, lithium-ion batteries were used in cars, and it was expected that they could replace traditional energy sources. In 1992, Nissan began research into electric vehicles, perhaps for the first time in history, power cells were developed specifically for vehicles. In 1997, Nissan built the world’s first electric car using cylindrical lithium-ion batteries, called the Prairie Joy EV. Since then, lithium-ion battery vehicles have received a great deal of attention from various countries and a lot of money has been invested in research every year.

In 2021, 6.5 million electric vehicles were sold worldwide, while mainland China sold 3.2 million electric vehicles, accounting for half of global electric vehicle sales. And China has continued to offer a large number of incentives for new energy vehicles since 2016. “In order to take advantage of the fast-growing Chinese electric vehicle market seize the first opportunity, battery giants such as Samsung, LG and Panasonic are investment is accelerating and the battle for the market will intensify”

But to this day, electric vehicles are still not being promoted as much as they could be, because there are still many problems with lithium-ion electric vehicles that have not been solved. The safety of lithium-ion batteries is one of the most important challenges. Looking back, we can see that lithium-ion batteries have caused a lot of harm to people’s lives and property through explosions or fires. So what are the causes of lithium-ion battery fires? How can lithium-ion batteries be suppressed when there is a fire hazard? What can we do to prevent and control lithium-ion battery fires?

2. Causes of lithium-ion battery fires

2.1. Significance of lithium-ion battery fire incidents

Lithium batteries are widely used in electrical appliances, power and electricity because of their long service life, fast charging speed, ease of use and low negative impact on the

environment. In recent years, however, there have been a number of accidents involving lithium batteries that have caused damage to people through explosions or fires. Because of the continuous development of lithium batteries, the field of application of lithium batteries is also being effectively expanded. Therefore, the safety of lithium batteries during production, transport and storage is very important.

2.2. Analysis of the causes of lithium battery fires

“Lithium-ion batteries are a class of secondary batteries that are charged and discharged by the reciprocal movement of lithium ions between the positive and negative electrodes”. The short-circuiting of the positive and negative electrodes inside the lithium-ion battery leads to thermal disconnection. This leads to decomposition of the electrodes, electrolyte, evaporation and generation of electrolyte vapor and other combustible gases, once the heat accumulates in large quantities, it is very When heat builds up, combustion and even explosion can easily occur. The chart below summarizes the main causes and percentages of fires. Battery thermal runaway accounted for 52%, charging accounted for 18%, other accounted for 12%, mechanical damage accounted for 10%, and water immersion accounted for 8%.

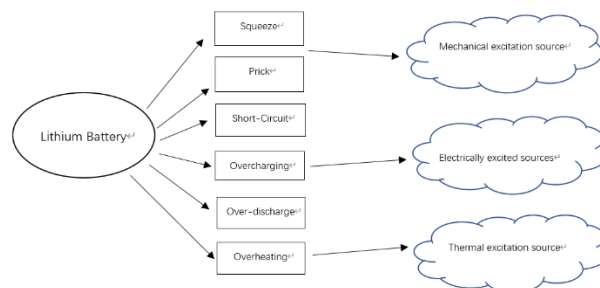


Figure 1. Main causes of fires

There are two fatal safety flaws in the structural design of the lithium batteries mainly used in China today. “Firstly, the use of lithium hexafluorophosphate as an electrolyte. Secondly, the main electrolytes used today are all flammable”. These design flaws cause lithium batteries to burn and explode if they are hit, short-circuited, exposed to water or used in high temperatures.

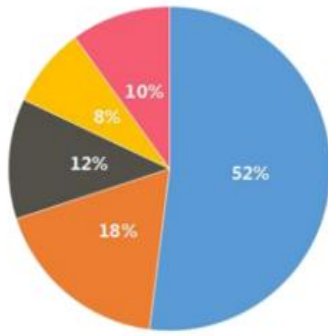


Figure 2. Percentage of causes of fire

2.3. Lithium-ion battery fire case

On 8 February 2017, a fire broke out in a chemistry workshop within a foreign-owned company in Tianjin, which resulted in the total destruction of the first-floor chemistry workshop and the lithium-ion batteries and related equipment stored in the workshop. There were no casualties in the fire. After investigation, it was finally confirmed that the cause of the fire was the lithium-ion batteries stacked in the temporary storage area of the waste batteries in the second-floor chemistry workshop. Due to the self-weight of the batteries, the strength of the strapping or external collision, the film separating the anode and cathode was broken, causing a short circuit inside the batteries and heat to gather rapidly. A chain reaction of combustion in the battery stack and eventually spread to a disaster. On average, there will be more than 6,000 lithium battery explosions in China each year until 2021.

3. Lithium battery fire suppression

3.1. Water mist Fire suppression

The most widely used extinguishing agent today is water. As the most basic extinguishing agent, water has the advantages of being non-toxic, harmless and easy to obtain, but it also has the disadvantages of being highly mobile, difficult to stay on burning materials, and not easy to volatilize water vapor in confined spaces. And “water generally conducts electricity”. And the water mist fire suppression system is “satisfy the minimum design working pressure conditions, 1 m from the nozzle on the plane, the coarsest part of the measured water mist water particle diameter $Dv0.99$ is not greater than 1000μ , can be generated by a variety of methods such as impact, pneumatic, high pressure and ultrasonic” [8-9]. In order to improve the fire extinguishing performance of the water mist fire suppression system, the sprayed water mist needs to have a fast speed and small diameter. In addition, the non-insulating nature of water is damaging to lithium batteries and takes longer to extinguish than some gaseous fire extinguishing systems, so extreme care must be taken when choosing to use it.

3.2. Dry powder extinguishing agents

Dry powder extinguishing agents are widely used in the field of fire extinguishing and have the advantages of low toxicity, wide range of sources and low cost, and in the process of fire extinguishing dry powder extinguishing agents have physical and chemical inhibition and can effectively play a role in preventing re-ignition. The main component of dry powder extinguishing agents is phosphate, and although it is basically non-toxic, a large number of particles inhaled into the human lungs can easily lead to asphyxiation if they

are in close proximity. And the sprayed powder is not easily cleaned up in electrical systems. At the same time, dry powder extinguishing agents are generally valid for five years, while China stipulates that the replacement cycle for dry powder extinguishing agents is one to two years. This rule also increases the cost of dry powder extinguishing agents. In addition, “dry powder extinguishing agents are easily rendered unusable after prolonged vibration or moisture, making them unsuitable for installation in vehicles”.

3.3. Aerosol extinguishing agents

“Aerosol extinguishing agent is PGA, belongs to the solid-based aerosol extinguishing agent, PGA technology through high-temperature pyrotechnics, the generation of solid particles aerosol, its characteristic of diffusion is extremely strong, can avoid the flow of obstacles, and can be drilled into the tiny voids, while having a large surface area of solid particles, increasing the efficiency of fire extinguishing” [11-12]. However, aerosol extinguishing agents are difficult to volatilize automatically and the metal oxides in the particles can easily cause short circuits in electrical equipment. Therefore, aerosol extinguishing agents are not suitable for use in lithium battery extinguishing systems for new energy vehicles.

3.4. Gas extinguishing agents

Carbon dioxide is a typical representative of gaseous extinguishing agents. Carbon dioxide is a colorless, odorless, and non-toxic gas at room temperature and does not support combustion itself. Carbon dioxide is usually stored in liquid form in a gas tank and is quickly vaporized after spraying to produce a large amount of carbon dioxide, which reduces the oxygen content in the burning area and achieves the fire extinguishing effect. The carbon dioxide will not damage the lithium battery, will not leave traces after spraying, and will not pollute the surrounding environment. All these features make it very suitable for new energy vehicle fires caused by lithium-ion battery fires.

Another widely used gaseous extinguishing agent is heptafluoropropane. Heptafluoropropane is colorless and odorless at room temperature and pressure. Heptafluoropropane suppresses lithium battery fires mainly by absorbing heat and reducing the concentration of oxygen. When Heptafluoropropane is sprayed on the flame area, it remains in liquid form and then absorbs a large amount of heat and rapidly vaporizes, reducing the temperature of the burning area and preventing the battery from re-igniting. Heptafluoropropane is a clean new fire extinguishing agent with low toxicity and low secondary pollution, which not only can effectively extinguish fires, but also releases residues that do not damage the ozone layer in the atmosphere. Heptafluoropropane also has excellent gas-phase electrical insulation and will not cause damage to other parts of the vehicle.

4. Lithium battery fire prevention and control

4.1. Current status of lithium-ion battery firefighting

Fires caused by lithium-ion batteries are quite different from ordinary fires. Lithium-ion batteries are an energy-containing substance with characteristics of intense combustion and rapid thermal spread. At the same time,

“lithium-ion batteries burn with the disadvantages of high toxicity, large smoke and dust, easy to re-ignite after extinguishing and difficult to extinguish” . Through the introduction of the existing fire suppression agents for lithium-ion battery fires and the analysis of their advantages and disadvantages, we would like to present some ideas for lithium-ion battery fire suppression systems. The first is the development of a new extinguishing agent specifically for lithium-ion battery fires. Secondly, to make full use of the advantages of existing extinguishing agents and to combine them in order to extinguish fires, prevent re-ignition and reduce the damage to lithium batteries, humans and nature. Thirdly, an in-depth study of the thermal runaway mechanism should be carried out to identify thermal runaway points at an early stage and to accurately spray the fire extinguishing agent to extinguish the fire before it has even formed.

Today, because of the lack of safety regulations for lithium-ion battery fire protection systems, lithium-ion battery fire protection systems are in a state of disposability. In January 2020, the average cost of our battery storage was RMB 2.549 yuan per kWh, but by March 2020, the average price of our battery storage dropped to RMB 1.643 yuan per kWh. As a result, experts predict that in the future, the market may adopt cheaper devices in the pursuit of profit, which will lead to a risk of product quality and safety, in which case the lithium-ion battery fire protection system will be more neglected.

On 1 August 2015, China's Ministry of Transport required that "pure electric buses and hybrid buses shall be equipped with a special automatic fire extinguishing device for the power lithium battery box" and on 15 November 2016, China's Ministry of Industry and Information Technology issued a notice requiring that "from 1 January 2017 onwards Before the introduction of the national safety standard for electric buses, all newly produced new energy buses will be temporarily implemented in accordance with the requirements of the Safety Technical Conditions for Electric Buses". The latest revision of the Technical Conditions for the Operation of Motor Vehicles stipulates that "purely electric buses and plug-in hybrid buses with a vehicle length greater than or equal to 6 meters shall be able to monitor the working status of the power lithium battery and provide an alarm when an abnormal situation is detected, and the exterior of the lithium battery box shall not catch fire and explode within 5 minutes after the alarm". The Ministry of Transport stipulates in the Classification and Rating of Operating Buses that "pure electric buses and hybrid buses shall be equipped with an automatic fire extinguishing device with alarm function in the lithium battery box".

4.2. Some existing fire protection systems for lithium-ion batteries

In response to a series of safety requirements put forward by the relevant national departments, many domestic and foreign new energy vehicle manufacturers, research institutes, research and development units have carried out a large number of fire monitoring and fire extinguishing solutions, device research and manufacture in respect of lithium batteries. The Figure 3 shows a simple diagram of the bus lithium battery fire prevention and control system.

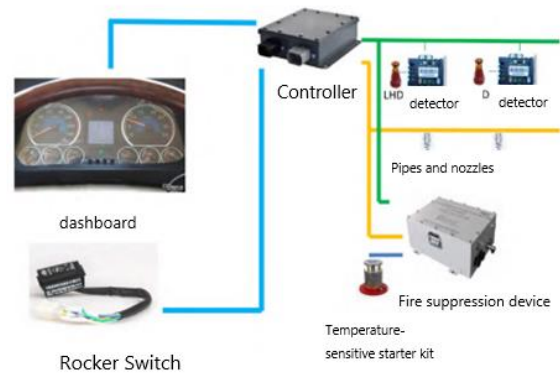


Figure 3. New energy bus lithium battery fire prevention and control system diagram

The fire detection system here uses a dual activation system, with fire detectors as the mainstay and temperature-sensitive mechanical activation components as the spokes. The sensors are designed with the three main aspects of "smoke, gas and temperature" in mind. The sensors will use smoke sensors, gas sensors and temperature sensors in a composite, multi-parameter determination, initially in four combinations of temperature, carbon monoxide, combustion characteristic gases and smoke. The detector will convert the input voltage into the voltage required by the carbon monoxide gas detector, temperature sensor, smoke sensor, main control chip, and communication circuit, use the main control chip for data acquisition, and finally calibrate the sampled values internally, integrate the carbon monoxide concentration, VOC concentration, smoke concentration, and temperature rise trend, determine whether there is a fire, and finally send a fire warning signal through the communication interface. The Figure 4 shown below is detector flow chart.

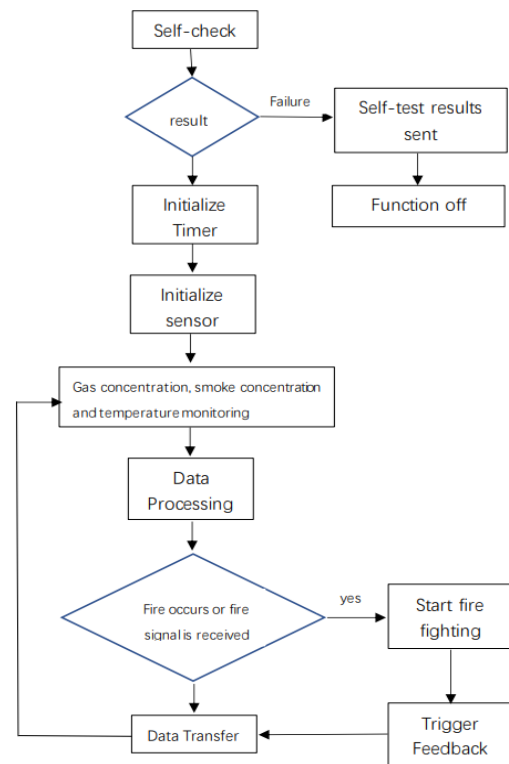


Figure 4. Detector flow chart

5. Conclusion

The safety of lithium-ion batteries is a very important issue today. With the development of society and technology, people pay more attention to the safety of their lives and property. In addition, the safety requirements for lithium-ion batteries in various countries are also becoming more and more stringent. Whether it is the enterprise or the state, will invest a lot of money to ensure the safety of lithium-ion battery storage, transportation and use, so in the lithium-ion battery explosion before the safety of prevention, the explosion occurred when the rapid extinguishing device, and the use of what fire extinguishing agent is most convenient and fast. These issues are the need for people to continue to explore and research.

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