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Exploration on Methods to Mitigate Thermal Runaway in Lithium Batteries

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Abstract. Lithium batteries are widely used in people's daily lives, such as in phones and cars. However, according to the report, this new technology has some safety issues. Consequently, the purpose of this article is to analyze the reason for the danger and how to conquer it. The data collected were from various resources, such as news, reports and cited references from others. After finding the information, the reason for the car explosion was figured out, and ways to solve the issue were also come up with. The majority of the issue is the external force or pressure causing the thermal runaway inside the batteries. Then, the substances in the battery react together and have a shortcut in the circuit. The consequence is that some gases are produced during the process and generate plenty of heat and finally cause an explosion. In order to tackle this issue, the article shows two practical solutions: one is using electronic sensors to monitor the values inside the battery, which can caution if some values are abnormal. Another way is to strengthen the materials inside the battery, such as the electrode, membrane and electrolyte. This article can improve the safety of lithium battery devices.

Keywords: Lithium battery, thermal runaway, electrode, electrolyte and membrane

1. Introduction

Lithium batteries are one of the most popular electronic batteries, with advantages such as high energy density, long cycle life, low self-discharging rate and environmental friendliness compared to traditional fossil fuels. The lithium battery has a range of advantages, including high energy density, no memory effect, long cycle life and low self-discharging, which make the lithium battery distinct from the global market. Nowadays, lithium batteries are widely used in mobile phones, electric vehicles, electric bicycles and other transportation [1]. Despite the merit aforementioned, there are some terrible problems, such as thermal runaway, that happen which easily cause fire or explosion in electric cars. This paper summarized the incidents from lithium batteries in recent two years. Table 1 below shows several incidents of lithium batteries from all over the world in recent time.

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Table 1. The incidents of lithium batteries in global [2]

Time	Location	Result	Reason for the incidents	Batteries' types
2025.6.4	Azuqueca de Henares, Spain	several explosions occurred at a lithium battery recycling plant	The lithium battery was hit and triggered the thermal runaway.	$LiCoO_2$
2025.5.6	Xuan cheng, China	car self-ignited, 4 deaths	something wrong in the circuit.	$LiFePO_4$
2024.10.30	Gyeonggi-do, South Korea	23 deaths and 8 injuries	shoddy production process and lack of management in factory	$LiMn_2O_4$
2025.3.24	Reims, France	4 deaths, 2 serious injuries and 26 minor injuries	wrong charge of lithium battery in building	$LiNiMnCoO_2$
2024.1.18	Zheng zhou, China	A car spontaneous combustion, 3 deaths	negative electrode lithium plating and cause short cut.	$LiNiCoAlO_2$

*The whole information was collected from the China News Network.

According to the table shown, the major reason leading to the accidents is thermal runaway. Therefore, this paper here will analyze the mechanism of thermal runaway and come up with several precautions to prevent the issue.

2. Lithium battery thermal runaway and prevention

The composition of the lithium battery. There are an anode and a cathode in both sides of batteries, a conducting electrolyte connects them and is able to transfer the electrons. There is a porous separator in the middle of the battery with the function to prevent the physical contact of electrodes but only allow ions to pass through. Thus, its structures and properties play an important role in battery performance, such as the life of the battery, the energy density and the power density [1]. Another part is the bath solution, which is full of the area in batteries and has a function to make the ions from the electrolyte move freely past the separator.

The development of the lithium batteries. In initially, the concepts of lithium batteries came from Japan. At that time, the anode was Li and the cathode was CFx, and the reaction equation was Li+(CF)n==LiF+C. The major challenge in this material was making the reaction reversible even when lower fluoride levels were used. In 1972, the cathode was replaced by TiS2 and the output voltage could reach 2.4V and the lithium ions are reversible. However, the material of TiS_2 was very expensive and reacts very actively with water. In 1980, the TiS_2 was replaced by $LiCoO_2$ while the voltage came to 4.4V [2]. In 1990, the second generation of lithium batteries was developed. The Bellcore labs used $LiMn_2O_4$ as a new cathode and produced Mn_2O_4 and Li when charging while the anode was replaced from the original Li to C. Now, there are also a range of substances able to be used in cathodes, like $LiFePO_4$, LPD and LMD, while Si can also be used in anodes to increase the energy density of batteries. The development of lithium batteries can improve the capacity and charging velocity of batteries, but the thermal runaway problem has not been solved before.

2.1. Lithium battery thermal runaway mechanism

The lithium battery thermal runaway is the process in which intense chemical reactions occur inside the battery, creating a large amount of heat and leading to a sharp rise in temperature. In this process,

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the positive and negative electrode materials and electrolyte inside undergo a series of irreversible side reactions, and form a thermal runaway chain reaction [3].

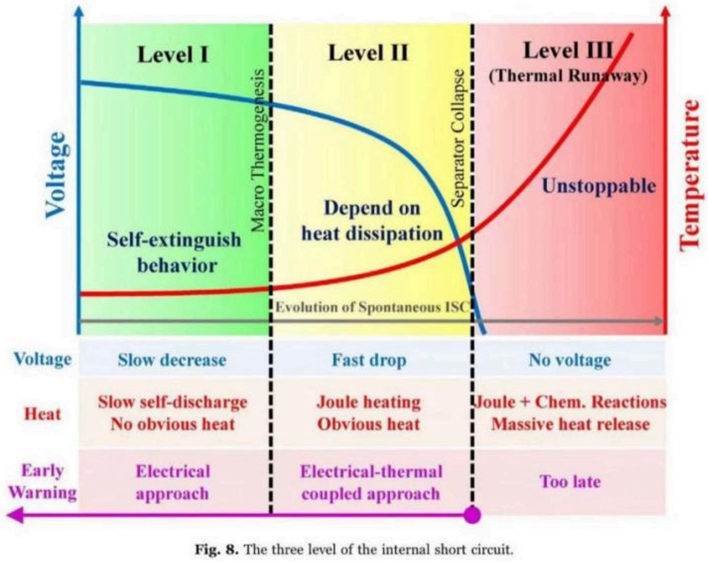

Figure 1. The main process of thermal runaway [3]

Figure 1 shows the temperature of the battery varies with the different processes of thermal runaway. The time from level 2 to level 3 shows the rapid increase in temperature caused by thermal runaway. The common temperature in the working lithium battery is lower than 60 degrees, which is the period level 1 (Figure 1). In this interval, the electronic devices can work safely. However, there are some factors that may lead the process after time 1. One is the load of the battery. When the load of the battery is further above the maximum load that the battery can bear, it may generate a lot of heat and increase the reaction rate. The external force is also a factor that causes many cases of electric vehicle fire incidents. The membrane is a material that cannot undergo high pressure; the high pressure brought by the huge external force may break the membrane and the substance from the positive and negative electrodes may react together, and the temperature may increase. There is an SEI solid electric interface in the anode initially, which is a product after the reaction between carbon and electrolyte, which has a function to protect the anode of the battery. However, the membrane is very weak and may break when undergoing the pressure. The consequence is that the solution will react with the anode and have an internal short circuit. Moreover, the anode will reduce due to reacting with the solution and the binder, which connects the shell and anode, will also join the reaction. Polymers are widely used as binder, which may melt or burn under high temperatures [4].

Another factor is an external issue in lithium batteries called lithium plating on the anode. Which means there is some lithium growth on the surface of the anode after the device is used for a long time. When the lithium plating is long enough, it may break the middle membrane and the substance from the cathode and anode will react with each other. As the cathode is in contact with the anode, there is a short circuit appearing in the battery, generating a lot of heat.

2.2. Prevention for the thermal runaway

There are two methods for this issue: one is using a sensor and providing a warning in time if there is some data exception. Another approach is to enhance the batteries' pressure resistance by

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replacing the materials, thereby reducing the probability of thermal runaway.

2.2.1. Sensors

As thermal runaway increases the temperature, the temperature sensor is necessary; the thermistors can be added in the circuit. If the temperature exceeds the threshold (heating up by more than 5 degrees per minute) or shows an abnormal sudden increase, it may indicate thermal runaway. The gas and pressure sensors are also important. Some special gases are emitted when thermal runaway happens, such as carbon monoxide, hydrogen and alkane [5]. The sensor can serve warning signals if there is a sudden increase in the concentration of gases on the list this paper mentioned before. As the gases are emitted, the pressure in the space increases. Therefore, the pressure sensor will also provide warnings. The voltage and current sensors have been able to find the abnormal value in the circuit. Before the thermal runaway happened, there may have been a sudden drop in voltage or a spike in current in current. These sensors are better to use together to prevent a single sensor from possibly reporting an error. By combining multiple dimensional data such as temperature, gas, and pressure the monitoring accuracy may be proven.

There is an example for this approach. The dedicated fire-extinguishing device for lithium battery energy storage cabinets developed by Shanghai Yican adopts perfluorohexanone fire-extinguishing technology, combined with a multi-level temperature-gas composite detection system. It can accurately identify abnormalities in the early stage of thermal runaway and quickly release fire-extinguishing agents. This device is capable of blocking the thermal runaway chain reaction, preventing electrolyte deflagration and fire spread. Its fire-extinguishing efficiency is more than 60% higher than traditional methods, and it has been widely used in energy storage power stations and other scenarios [6].

2.2.2. Replacing materials

Using alternative materials for the electrolyte, membrane, cathode, and anode, first, the electrolytes can change. The electrolytes typically use organic carbonate compounds as solvents, which are highly reactive and easy to burn up. The positive electrode materials are strong oxidizing compounds, while the negative electrode materials are strong reducing compounds in charging states. In conditions such as overcharging, overheating, and short circuits, the strong oxidizing positive electrode materials are usually unstable and prone to releasing oxygen. Moreover, the carbonates are easy to react with oxygen and release a large amount of heat and gas. The generated heat will further accelerate the decomposition of the positive electrode, producing more oxygen and promoting more exothermic reactions [7]. At the same time, the metallic lithium has a strong negative reduction, which will immediately burn up when in contact with oxygen and ignite the electrolyte, and separator, thus causing thermal runaway of the battery, leading to battery combustion and explosion. Improving the purity of organic solvents in electrolytes: the presence of trace impurities has a significant impact on battery performance.

Improving the purity of organic solvents in electrolytes can ensure a higher oxidation potential of the organic solvents in the electrolyte and reduce the decomposition of $LiPF6$. It can also slow down the dissolution of the SEI membrane and prevent gas expansion. The purity of the solvent directly affects its oxidation potential, thereby further affecting the stability of the electrolyte [8].

As for membranes, the lithium battery separators mainly have three categories, which are PP/PE/PP multi-layer composite micro-porous membranes, PP or PE single-layer micro-porous membranes, and coated membranes. The widely used separators are mainly polypropylene micro-

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porous membranes, which have stable chemical structures, excellent mechanical strength, and good electrical-chemical stability.

However, the purity of the membrane is also important. There are some inevitable impurities, such as metal and burrs, inside the battery, although the production process of batteries is very complex. The impurities inside the battery will be amplified and cause serious issues. Such as leading to an increase in electrical conductivity and temperature. The heat generated may eventually cause thermal runaway of the battery [9].

Moreover, the higher the mechanical strength of the separator in the vertical direction, the lower the probability of a shortcut in circuits in the battery. The smaller the thermal shrinkage rate of the separator, the better the safety performance of the battery. The micro-pore closing function of the separator is another method to improve the safety of power batteries. In addition, the ceramic separators can also improve battery safety. There is an example to mitigate the thermal runaway by using an alternative membrane. A research team from Tsinghua University has made key progress in lithium-ion battery separators and has effectively mitigated the problem of thermal runaway. The technology means dual-continuous separator technology. Professor He Xiangming's team has developed a bi-continuous separator (Bi-Sep). It achieves a nanoporous structure and ultra-high tensile properties. This separator can simultaneously stop internal short circuits and chemical crosstalk between electrodes in a high-temperature environment of 60℃, significantly improving battery safety. Compared with traditional separators, its unique structure can withstand higher temperatures and avoid chain reactions caused by thermal runaway [10].

We can reduce the thermal runaway by controlling the lithium plating on the anode. The essence of this issue is the speed of lithium ions that enter the anode; in excess, the capability of the anode, or the structure of the anode is destroyed, and the SEI membrane is broken [11]. To solve this issue, the capability of the anode can be enlarged in order to provide more space for lithium ions and prevent plating. The thickness of the membrane can decide the probability of plates breaking the membrane and causing a shortcut. Some film-forming additives, such as Fluoroethylene Carbonate can be added into the electrolyte, which can spur the anode to form a stable SEL film, reducing the lithium's direct reaction with the electrolyte. Using thin electrodes and porous current collectors is able to shorten the diffusion path of lithium ions.

There is also a method to reduce the amount of lithium plating. The present invention discloses a method for reducing lithium plating of lithium batteries, including the following steps: (1) Electrolyte pre-treatment: Introduce nitrogen gas into the electrolyte with pressure 0.8-1.2 MPa; (2) Charge the lithium battery at 1.3-1.45℃ current at 35-55℃ to a voltage of 4.2-4.25V, let it stand for 24-36h, and then discharge it at 0.05-0.1 ℃ current to 2.1-2.8V, and stop the discharge. The advantage is that by pretreating the electrolyte and introducing nitrogen gas into the electrolyte, when the current for lithium plating is used for charging, lithium will be precipitated on the surface of the anode. The precipitated lithium reacts with the nitrogen to form an SEI film and reduce the occurrence of the lithium plating phenomenon [12]. There is an example in the Samsung company. Due to the insufficient thickness of the membrane in the Note7, the abnormal deposition of metallic lithium on the negative electrode surface during charging easily pierced the separator, resulting in an internal short circuit and releasing a large amount of heat, which eventually triggered an explosion. This incident prompted Samsung to improve the battery design and adopt a thicker separator to reduce the risk of short circuits.

These are two methods for solving the thermal runaway. Some companies and universities have proved the feasibility. The next stage is to utilize the technology in new products of lithium-ion

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batteries in different devices. The importance is the good connection between the new altered battery and the devices, such as the size and distribution of the circuit.

3. Conclusion

As lithium batteries have many advantages, they have been widely used in public. However, the thermal runaway is the most serious problem that needs to be tackled. This problem may cause the damage of electric devices and even get them to catch fire or explode, which poses a safety threat to the public. In order to solve this problem, this study searched for information about the composition of lithium batteries and the mechanism and reason for thermal runaways. Then this paper proposes two solutions: one is using sensors to detect the error data and warning, which is practical in theory and easy to complete. Another method is to find alternative materials or structures for the electrolyte, membrane and anode, which need further research to assure safety in multiple factors. However, the thermal runaway is the problem that has been addressed in recent years. The sequence is that there is not much successful research and experimentation to mitigate or reduce the problem. The strategies outlined in this study remained largely theoretical, with insufficient empirical validation. There are also some issues that need to be considered, such as the size of the sensor, the accuracy of the detection and the cost of altered and purified materials. In the future, the direction of research may be concentrated on the tests on the detection accuracy of a series of sensors added to lithium batteries, as well as tests on the practical application of new materials.

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