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Material Characteristics and Equalized Charging Control of New Lithium Cell for Battery Electric Vehicle

Yaya Wang* and Juanjuan Wang
Xi’an Traffic Enginering Institute, Meibei Xi Lu, Binhe New District, Xi'an District, Shaanxi Province, xi’an 710300, China.
*Corresponding Author.

Abstract:

The purpose is to enable the lithium cell to realize rapid charging, and solve the battery safety problems caused by functional materials in the process of charging and power consumption, so that the lithium cell can be widely used in battery electric vehicles (BEV) to meet the needs of consumers. First, based on the intelligent material performance and working principle of the new lithium battery, the influence of different material processing on the performance of lithium cell is analyzed. Next, an equalized charging control system based on fuzzy control is created. Finally, according to different electrolytes, the thermal performance of new lithium cell of BEV and the performance of lithium cell are tested under equalized control. With the increase of temperature, the mass fraction loss of new lithium cell with silicon dioxide as the electrolyte is greater than that with fluoropolyimide as the electrolyte. Lithium cells with different electrolytes of silica dioxide and fluoropolyimide have good thermal stability. In the process of charging without equalized control, different single cells of BEV's new lithium cell cannot be fully charged simultaneously. If continuous charging is conducted, the battery will be overloaded and then damaged. If the charging is stopped, the battery will be used for a short time in the process of recycling. When the equalized charging control system based on fuzzy control is used for equalized charging control, five single batteries in the lithium cell are filled successively around 900s. Therefore, the equalized charging control system based on fuzzy control can make the single charge state of lithium cell consistent, and there is basically no overcharge, which can protect the service time of BEV’s new lithium cell. This exploration has certain research significance for the thermal properties of electrolyte materials of BEV’s new lithium cell and the equalized charging of lithium cell.

***Keywords**: Functional materials; intelligent materials; material processing; material testing.*

I. INTRODUCTION

The rapid progress of the new energy vehicle industry has intensified the global demand for lithium cells, resulting in a sharp rise in the price of lithium cells and a severe supply shortage, and the price of battery electric vehicles (BEV) has also risen with the tide. The price of lithium cell electric bicycles is generally hundreds to 1000 yuan higher than that of electric bicycles with valve-regulated lead-acid (VRLA) batteries, so it is difficult to be recognized by consumers in the market [1, 2]. Lithium cell is light and environment-friendly and will not cause environmental pollution after being abandoned. Once the application technology is mature and the market sales volume increases, the price of lithium cell electric bicycles will be reduced. If a new battery with low cost and high service life can be created, it can really be mass-produced and commercial, which can perfectly solve these two problems, and the price of BEV can also be reduced [3-5]. The power performance of the lithium cell electric bicycle is similar to that of the VRLA battery. It can run 30 ~ 45 kilometers according to the battery capacity after being charged for 6 ~ 8 hours. Its weight is only about 1 / 5 of that of the VRLA battery. Lithium cell electric bicycles' biggest advantage is their long service life [6]. At present, lithium cells are generally guaranteed for two years and VRLA batteries for one year. Lithium cells are much less resistant to fluctuations in charge and discharge than VRLA batteries. It is one of the reasons for the failure to use lithium cells in the current high-power vehicles effectively, resulting in the decline of durability [7-9]. The safety of lithium cells still needs to be improved. At present, the hidden dangers of lithium cell fire, combustion and even explosion cannot be completely eliminated [10]. The collision of vehicles may cause the positive and negative materials of the battery to break through the diaphragm, and the ultra-high current at the moment when the energy is quickly recharged to the battery during braking will lead to short circuit, temperature rise, combustion and even explosion of the battery. In addition, the electrolyte of lithium battery is the organic electrolyte, which is easier to catch fire and burn after contacting with air [11, 12].

Foreign researchers have developed a new technology to use mask waste to produce supercapacitor batteries successfully. The battery shell is made of drug blister packaging. This research achievement can simultaneously solve the two major problems of waste mask recycling and battery supply shortage, and the new battery's energy density is close to that of an ordinary lithium cell [13]. The manufacturing materials of new batteries mainly include graphene, masks, drug packaging and other medical wastes [14]. The researchers believed that the charging speed can be increased by 10 times by using nickel niobate as the anode of lithium-ion batteries [15]. Scientists held that it could improve the charging speed, reduce the risk of anode material damage, and improve the battery's service life [16]. There are many problems in the equalized charging of existing batteries. Chen Jianqing proposed the lithium cell equalized method of single charging. It is based on energy transfer to balance the voltage between batteries [17]. Sun Qianlai et al. built a battery charging balance system. The system can control the charging balance of lithium cells and prevent battery overcharge [18]. Qiu Binbin et al. studied the distributed active equalization charging system and found that too long equalization time will lead to low charging efficiency of the equalization system during single charging [19]. Wang Chenglong et al. designed a lithium cell equalization scheme. Based on the energy transfer method, this scheme can solve the imbalance of lithium cell charging and power consumption [20].

First, based on the intelligent material performance and working principle of the new lithium cell, the influence of different material processing on the performance of lithium cells is analyzed. Next, an equalized charging control system based on fuzzy control is created. Finally, according to different electrolytes, the thermal performance of BEV's new lithium cell and the performance of lithium cell under equalized control are tested. This thesis has certain research significance for the thermal properties of the electrolyte materials of BEV's new lithium cell and the equalized charging of lithium cells.

II. RESEARCH METHOD

2.1 Characterization of new lithium cell materials

2.1.1 Study on performance of lithium cell

Lithium-ion cell is a device that realizes the mutual conversion of chemical energy and electric energy through the back and forth embedding and de-embedding of lithium ions between positive and negative materials. Lithium-ion cell cathode candidate materials can be divided into the following three categories according to the structure: $LiMO_2$(M=Co, Ni, Mn) cathode material with a layered structure, $LiMn_2O_4$ cathode material with spinel structure, and $LiFePO_4$ cathode material with olivine structure [21]. Figure 1 shows the structure of the lithium cell.

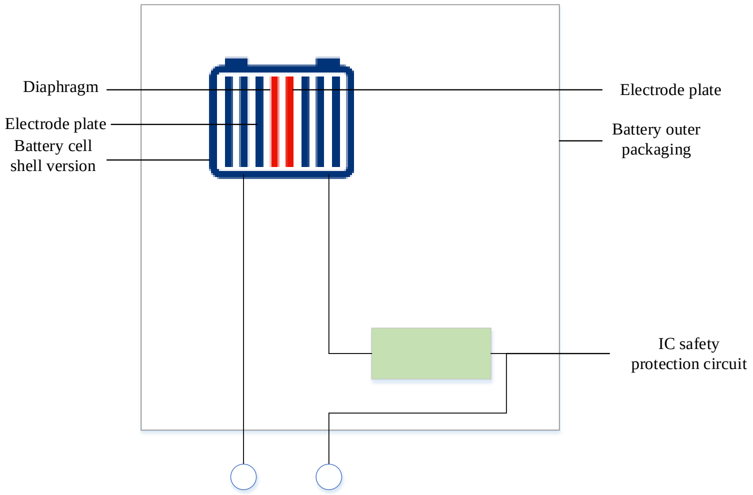

Figure 1: structure and composition of lithium cell

In Figure 1, the positive electrode in the components of lithium-ion cells is the active material. It is generally lithium manganite ($LiMn_2O_4$), lithium cobaltate ($LiCoO_2$), and Nickel Cobalt Manganese Based Cathode Materials (NMC). Electric bicycles generally use NMC (commonly known as ternary), while pure $LiMn_2O_4$ and ferrous lithium phosphate ($LiFePO_4$) gradually fade out due to their large volume, poor performance or high cost. The conductive electrode fluid uses electrolytic aluminum foil with a thickness of 10 ~ 20 microns. The diaphragm is a specially formed polymer film with a microporous structure, which allows lithium ions to pass freely, but electrons cannot. The active material of the negative electrode is graphite or carbon with a similar graphite structure. The conductive current collector uses electrolytic copper foil with a thickness of 7 ~ 15 microns. Organic electrolyte solution dissolves carbonic ester solvent containing lithium hexafluorophosphate ($LiPF_6$), while polymer uses gel electrolyte. The battery shell is divided into steel shell, aluminum shell, nickel-plated iron shell, aluminum plastic film, and the cover cap of the battery, which is also the positive and negative lead-out end of the battery [22]. Figure 2 shows the working principle of a lithium cell.

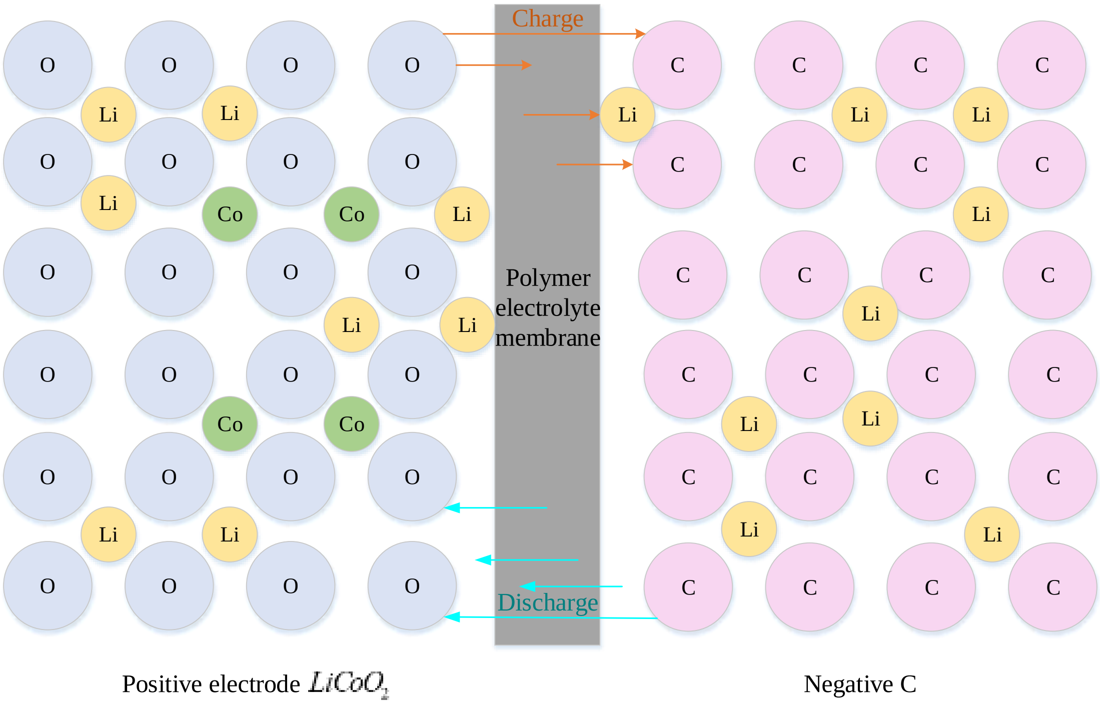

Figure 2: working principle of lithium cell

In Figure 2, the battery's positive electrode is generated by lithium-ion (Li). The generated lithium-ion "jumps" into the electrolyte from the positive electrode and "climbs" into the small hole on the diaphragm through the electrolyte to move to the negative electrode. Then, it is combined with the electrons that have already run to the negative electrode through the external circuit. O is oxygen, C is carbon and Co is cobalt. Equation 1 displays the total reaction:

$$Li_{(1-x)}CoO_2 + LiC_6 \rightleftharpoons LiCoO_2 + Li_{(1-x)}C_6 (x<1) \tag{1}$$

Equation 2 is the reaction on the positive electrode:

$$LiCoO_2 \to Li_{(1-x)}CoO_2 + xLi^+ + xe^- \tag{2}$$

Equation 3 is the reaction on the negative electrode:

$$C_6 + xLi^+ + xe^- \to Li_xC_6 \tag{3}$$

x in equations 1 ~ 3 is the change in the number of Li^+ during the chemical reaction. During charging, Li^+ is separated from the positive electrode $LiCoO_2$ and enters the electrolyte. Under the action of the external electric field attached to the charger, it moves to the negative electrode, successively enters the negative electrode composed of graphite or coke C, and forms compound Li_xC_6 on the negative electrode. When discharging, both electrons and Li^+ move simultaneously, with the same direction but different paths. Electrons run from the negative to the positive through an external circuit. Li^+ jumps into the electrolyte from the negative electrode and combines with electrons. The battery protection board is mainly an integrated circuit board to protect rechargeable batteries. The lithium cell needs protection because its material determines that it cannot be overcharged, over-discharged, overcurrent, short circuit and ultra-high temperature charge and discharge. Therefore, the lithium cell will always have a protection plate and a current protector. Figure 3 is the principle of lithium cell charging protection.

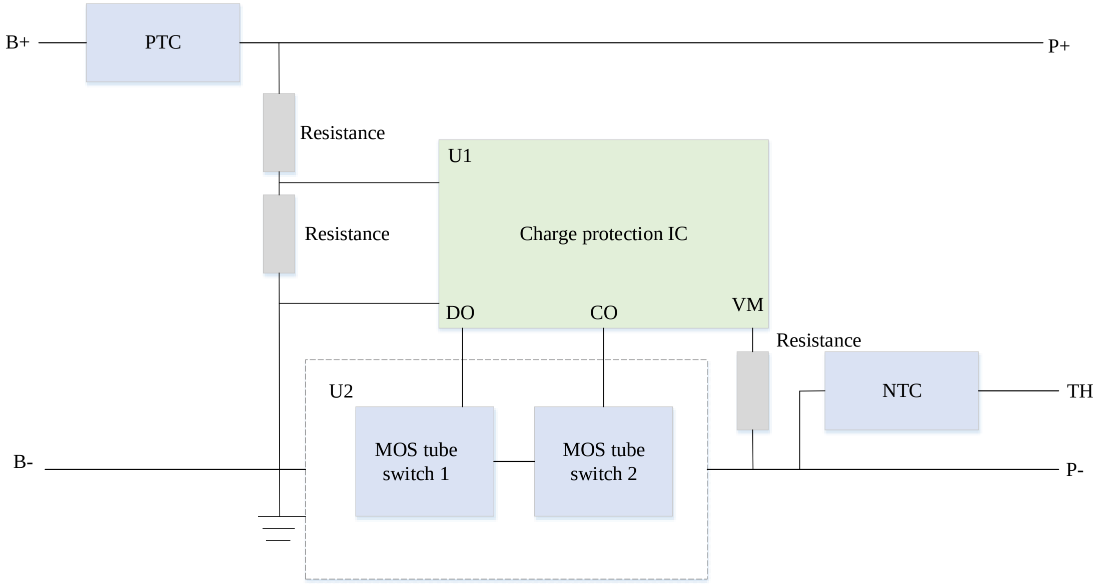

Figure 3: the principle of lithium cell charging protection

In Figure 3, PTC is a thermistor with a positive temperature coefficient. NTC is a thermistor with a negative temperature coefficient. When the ambient temperature rises, its resistance decreases, and the use of electrical equipment or charging equipment can respond in time to control internal interruption and stop charging and discharging. B+ is the positive pole of the electric core, B- is the negative pole of the electric core, P+ is the positive pole of the output port, and P- is the negative pole of the output port. PH is the output of the detection pole, which is used to detect and display the service status of the battery. U1 is the circuit protection chip and U2 is two reverse Metal Oxide Semiconductor Field Effect Transistor (MOSFET) switches. Under normal conditions, both Carry Output (CO) and Digital Output (DO) of battery board U1 output high voltage, and both MOSFETs are on. The battery can be charged and discharged freely. When U1 detects that the battery voltage reaches the overcharge protection threshold, the CO pin outputs a low level, and the Metal Oxide Semiconductor (MOS) switch 2 changes from on to off, the charging circuit is turned off. Then, the charger can no longer charge the battery to realize overcharge protection. In the process of battery discharge, when U1 detects that the battery voltage is lower than the over-discharge protection threshold, the DO pin changes from high level to low level, and the MOS switch 1 is closed, so that the battery cannot be discharged again. Under the condition of over-discharge protection, the battery voltage cannot be reduced anymore. It is required that the current of the protection circuit is very small and the control circuit enters low power consumption. Under normal conditions, the battery discharges the load, and the current passes through two MOS switches in series. The Voltmeter (VM) pin detects that the voltage drop of the two MOS tubes is U. If the load causes U abnormality for some reason, the loop current will increase. When U is greater than a certain value, the DO pin changes from high voltage to low voltage, and the MOS switch 1 is closed, so that the discharge circuit current is zero to achieve overcurrent protection [23].

2.1.2 Novel lithium cell materials for BEV

Battery material is the key to determining the performance of lithium cells. The battery materials of lithium cells include four main materials: positive electrode material, negative electrode material, electrolyte, diaphragm and other auxiliary materials such as conductive agent and binder. Lithium cells' charge and discharge process is the process of lithium-ion intercalation and deintercalation between positive and negative electrodes. When the battery is discharged, the lithium atoms in the negative electrode material will be de inserted into lithium-ions and embedded into the positive electrode through the electrolyte. During charging, the lithium-ion on the positive material will be de intercalated. After passing through the electrolyte, it will be reduced to lithium atoms on the negative electrode and embedded in the negative material. In the whole process of charge and discharge, the battery material has a direct and significant impact on the battery's capacity, charging speed, and safety, which is the key to determining the performance of lithium cells. Table 1 is lithium cell material.

TABLE 1: lithium cell material

Battery core components	Main materials	Considerations
Positive electrode materials	$LiCoO_2$, $LiMn_2O_4$ and $LiFePO_4$, NCM (NI, Co, Mn)	Low cost and high capacity
Negative electrode material	Needle coke, Mesocarbon microbeads (MCMB) artificial graphite and natural graphite, **hard carbon, soft carbon, lithium titanate, silicon carbon composites, composite metal lithium**	Increase capacity, reduce cost and prolong cycle life
Electrolyte	Differentiated recipe (solute (inorganic lithium salt and organic lithium salt, $LiPF_6$**)**, solvents (polybasic carbonates), additives (**Solid electrolyte interphase** (**SEI**) film-forming additives, conductive additives, flame retardant additives, overcharge protection additives))	Low cost, battery performance
Diaphragm	Polypropylene (PP), polyethylene (PE)	Battery safety and performance

Among the lithium cell element materials in Table 1, the positive electrode material is an important part of the lithium-ion battery. Its key indicators include specific capacity, cycle performance, cost, and safety. Then, the development history of negative electrode materials includes needle coke, MCMB, graphite, silicon carbon composites and other materials. Electrolyte plays an ionic conductive function between the positive and negative electrodes of the battery, which can directly affect the key performance of lithium cell, such as high voltage characteristics, charge-discharge ratio, cycle life, and safety. Due to the current technical limitations, lithium-ion batteries are mainly liquid electrolyte, which is mainly composed of solute, solvent and additive in a certain proportion under certain conditions. Unlike the traditional liquid battery, solid-state electrolysis has good safety, excellent flexibility and processability. It can also make the battery have higher energy density and better safety performance. In addition, the solid-state electrolyte can realize the integration of diaphragm and electrolyte and reduce the cost. The diaphragm is an important material to ensure the safety and performance of lithium cells and is mainly used to prevent battery short circuits and provide a lithium-ion transmission channel. Its main materials are PP and PE, which have the characteristics of high mechanical strength, excellent electrochemical stability and low cost. The disadvantage is that it is easy to shrink due to heating, resulting in an internal short circuit. Therefore, it needs to be modified by coating, impregnation and spraying to improve safety and durability.

2.2 Design of equalized charging control system for lithium battery

2.2.1 BEV working principle

BEV refers to the vehicle driven by the onboard power supply and driven by the motor. The high efficient rechargeable battery is generally used as the power source. The motor of BEV is equivalent to the engine of a traditional automobile, and the battery is equivalent to the original oil tank. Electric energy is secondary energy, which can come from wind energy, water energy, heat energy, solar energy and other ways. The electric drive and control system composed of motor, battery pack and controller is the core of BEV. Figure 4 shows the working principle of BEV.

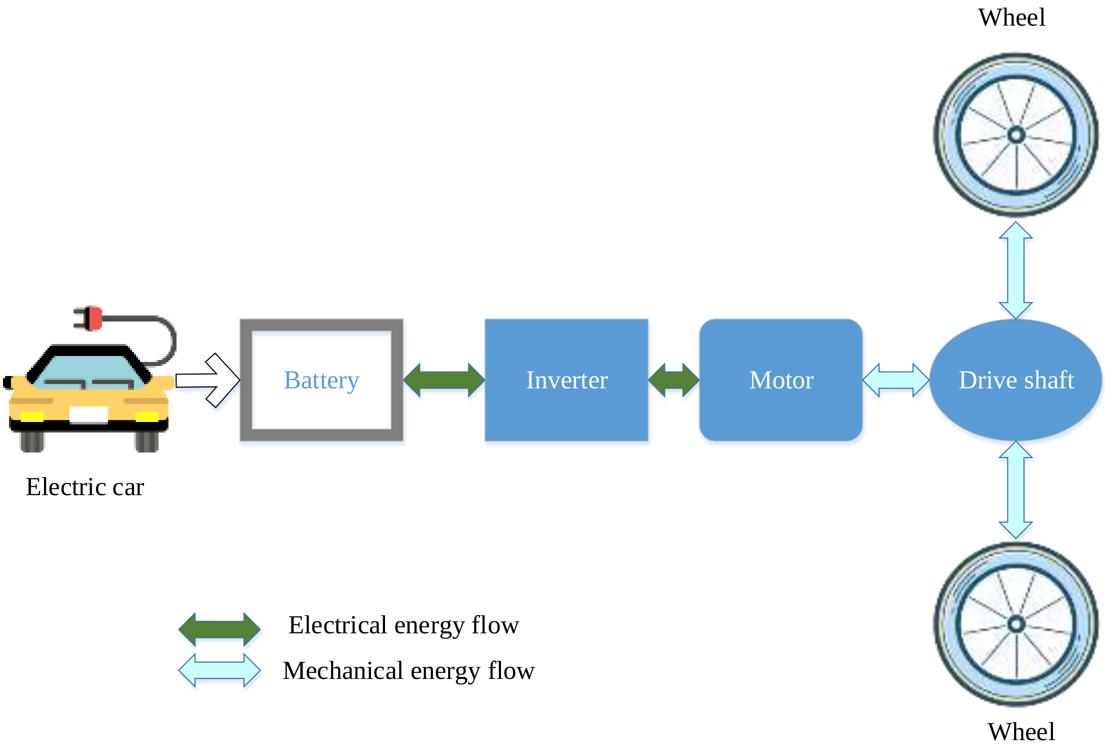

Figure 4: Working principle of BEV

In Figure 4, the BEV is mainly driven by the electric energy provided by the battery to the motor. The motor acts as a generator to recover energy during braking or deceleration. The main performance indexes of BEV batteries are specific energy (E), energy density (Ed), specific power (P), cycle life (L) and cost (c).

2.2.2 Control method of equalized charging

The number of single lithium cell protection chips is determined by the number of lithium battery pack batteries. They are used in series to protect the corresponding single lithium battery's charge and discharge, overcurrent and short circuit states. The protection chip controls the on-off of the switching device of the shunt discharge branch during charging protection to realize equalized charging. Unlike the traditional method of realizing equalized charging at the charger end, it reduces the design and application cost of the lithium cell pack charger. The lithium cell pack is composed of a plurality of single lithium cells in series. Due to the differences of individuals, the terminal voltage rise is inconsistent during series charging, and some monomers will be overcharged and some monomers will be undercharged. During equalized charging, all batteries are connected in parallel and connected in series during conventional charging and power consumption. In equalized charging, the parallel voltage of all batteries is equal, realizing the forced equalization of each battery [24].

When the lithium cell pack is produced and stored for a long time, the voltage of the whole battery pack is inconsistent due to the different static power consumption of each circuit of the protection board and the different self-discharge rate of each cell. Equalization has the function of equalizing voltage for lithium cell pack to achieve the effect of full charge and full discharge of cell pack capacity and maximize the effect of the cell pack. Charge equalization refers to the charging of equalizing battery characteristics. It refers to the imbalance of battery terminal voltage due to individual differences and temperature differences in the process of battery use. In order to avoid the deterioration of this unbalanced trend, it is necessary to improve the charging voltage of the battery pack and activate the battery to achieve the maintenance method of balancing the characteristics of each battery in the lithium cell pack and prolonging the battery life. Table 2 is the charging method of the lithium cell.

TABLE 2: Charging method

Charging method	Adjustment method	Existing problems
Constant current charging method	The switch regulates the charging current.	Long charging time, low charging efficiency and voltage overshoot
Constant voltage charging method	Battery voltage and current regulation	High battery temperature and high current
Constant current and constant voltage charging method	Combined with constant current and constant voltage charging method	No
Refiex charging method	Accelerate ion diffusion between battery poles	The control phase is not practical.
Pulse charging method	Pulse width	It is easy to make the two-pole activators fall off and result in a low conversion rate.

The pulse charging method in Table 2 uses pulse current to quickly charge the battery. Pulse charging is divided into negative pulse, positive pulse, positive and negative pulse, and can also be divided into low frequency, high frequency and frequency conversion. The constant current charging method is a charging method that keeps the charging current intensity unchanged by adjusting the output voltage of the charging device or changing the resistance in series with the battery. The control method is simple. However, since the acceptable current capacity of the battery decreases gradually with the charging process, in the later stage of charging, the charging current is mostly used to electrolyze water and produce gas, resulting in an excessive gas discharge. The charging power supply voltage of the constant voltage charging method maintains a constant value during all charging time. With the gradual increase of battery terminal voltage, the current decreases gradually. Compared with the constant current charging method, its charging process is closer to the optimal charging curve. Fast charging can be realized with constant voltage. Due to the low electromotive force and large battery charging current at the initial stage of charging, the current will gradually decrease with the progress of charging. This charging method has little electrolytic water and avoids the overcharge of the battery. However, the current is too large in the initial stage of charging, which has a great impact on the battery's service life, and it is easy to bend the battery plate, resulting in the scrapping of the battery. Constant current and constant voltage charging methods can make up for the influence in the process of constant current and constant voltage charging, respectively.

2.2.3 Equalized charging control system based on fuzzy control

A fuzzy control algorithm processes data and constructs a fuzzy mathematical model through real object analysis. It studies the fuzziness of the transaction itself [25]. Using fuzzy control can improve the accuracy of the equalized charging system and realize the equalization control between single batteries in the process of equalized charging. Figure 5 displays an equalized charging control system based on fuzzy control.

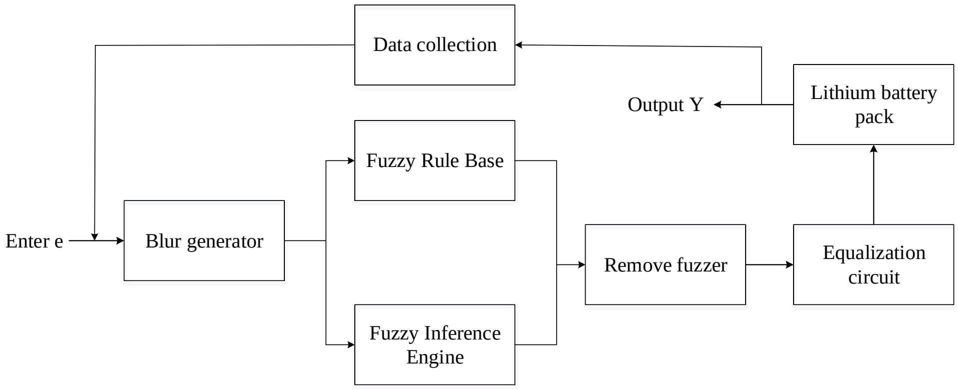

Figure 5: an equalized charging control system based on fuzzy control

The equalized charging control system based on fuzzy control in Figure 5 can realize State of Charge (SOC) equalization among monomers in the charging process of BEV's new lithium cell. The SOC of the battery is used to reflect the battery's remaining capacity. Equation 4 displays the calculation:

$$SOC = \frac{Q_C}{C_1} \tag{4}$$

Q_C is the remaining capacity of the battery, and C_1 is the capacity when the battery is discharged at a constant current. If $SOC = 1$ is defined in the full state of the battery, the calculation reads:

$$SOC = 1 - \frac{Q}{C_1} \tag{5}$$

Q is the discharged power. The output of input e and output Y in preventing battery overcharge reads:

$$e(n) = SOC_{ave} - SOC_i \tag{6}$$

e(n) is the maximum SOC difference of a single battery, SOC_{ave} is the average value of lithium battery

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pack, SOC_i is the SOC value of a single battery.

III. ANALYSIS OF EXPERIMENTAL RESULTS

3.1 Characteristic analysis of BEV's new lithium cell material

The purpose is to study the material characteristics of the new lithium cell and solve the problems of low safety, no high current discharge, high price, high production requirements, high cost, limited use conditions and high risk in high and low temperature. The material characteristics of lithium cells with different electrolytes of silicon dioxide and fluoropolyimide are studied. The thermal properties of $LiFePO_4$ battery materials are tested when the temperature rises from 25°C to 800°C at a heating rate of 10°C/min. Figure 6 displays the test results.

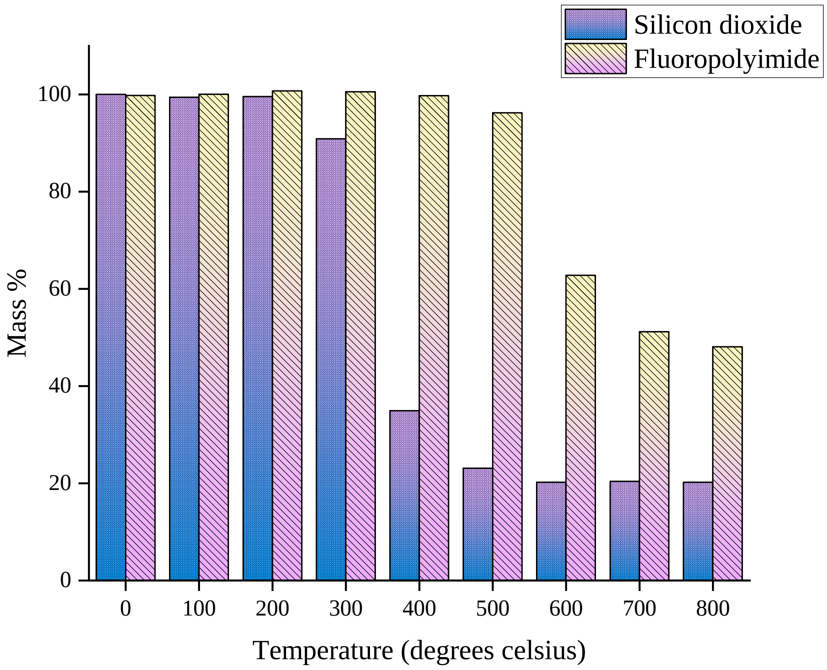

Figure 6: Analysis of test results

Figure 6 shows that with the increase of temperature, the mass fraction loss of silicon dioxide as the electrolyte of the new lithium cell is greater than that of the new lithium battery with fluoropolyimide as the electrolyte. Meanwhile, both two electrolytes can achieve good thermal stability when the temperature is less than 300°C. Within 500°C, the new lithium cell with fluoropolyimide as an electrolyte has good thermal performance. In conclusion, lithium cells with different electrolytes of silicon dioxide and fluoropolyimide have good thermal stability.

3.2 Analysis of equalized charging control of BEV's new lithium cell

LiFePO$_4$ cell is used to study the charge change of the new lithium cell before and after charging. Five monomers in the cell are studied and analyzed. The rated capacity of the new lithium-ion cell is set to 10Ah, the charging circuit frequency is 10kHz and the resistance is $30m\Omega$. Figure 7 is the analysis of equalized charging control of BEV's new lithium cell.

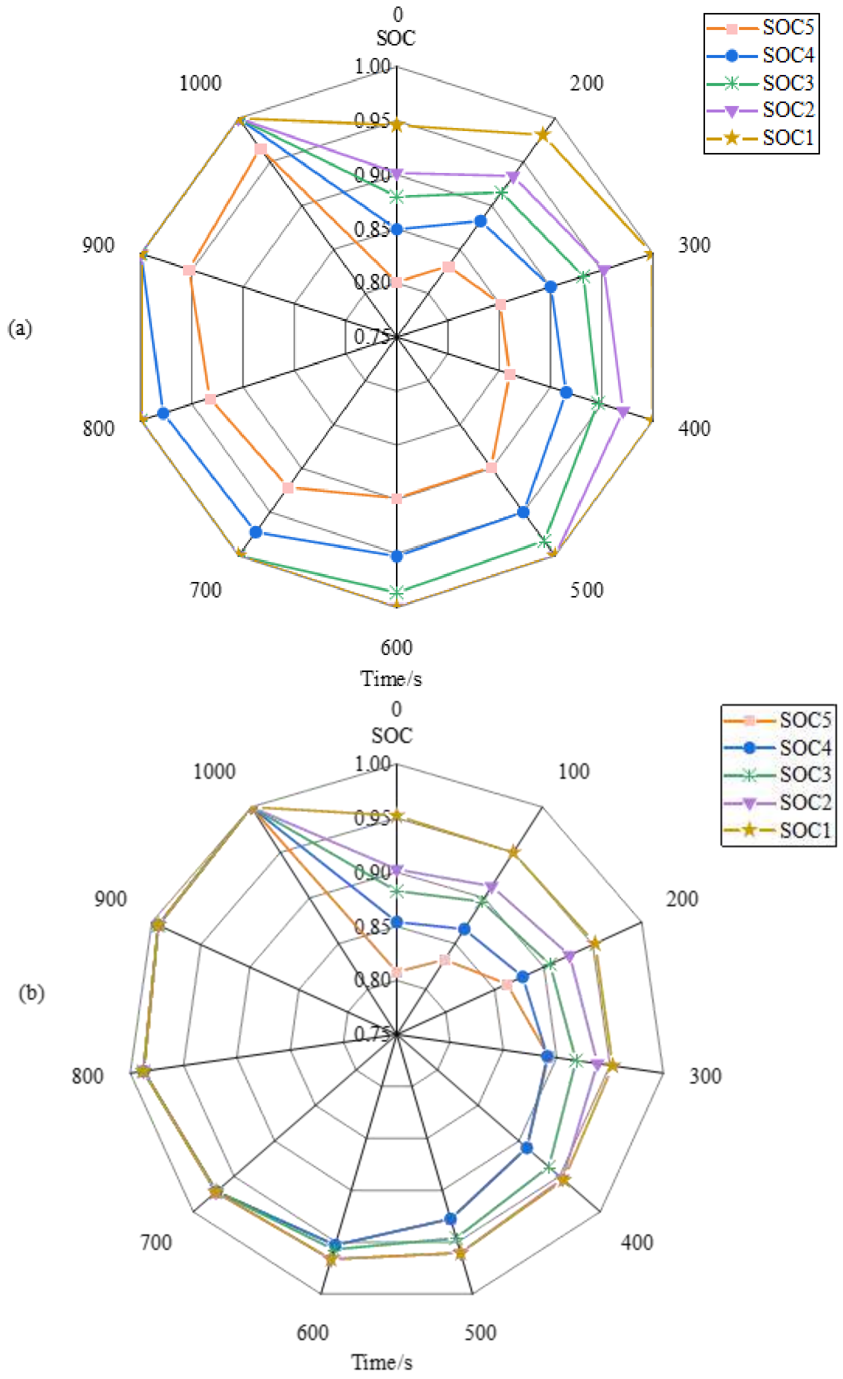

Figure 7: analysis on equalized charging control of BEV's new lithium cell ((a) is the charging state of a single lithium cell without equalized control, (b) is the charging state of a single lithium cell under equalized control)

Figure 7 suggests that when the BEV’s new lithium cell is not in the process of equalized control charging, the No. 1 single battery is first fully charged, and then the No. 2, 3, 4 and 5 single batteries are fully charged. At this time, the No. 1 single battery has already been overcharged, but the No. 5 single battery has not been fully charged. If continuous charging is conducted, the battery will be overloaded and then damaged. If the charging is stopped, the No. 5 single battery will not be fully charged, so the time utility of the battery in the process of recycling is short. When the equalized charging control system based on fuzzy control is used for equalized charge control, five single batteries in the lithium cell are filled successively around 900s. Therefore, the equalized charging control system based on fuzzy control can make the single charge state of lithium cells consistent, and there is basically no overcharge. It can protect the service time of BEV's new lithium cell.

IV. CONCLUSION

The results show that the lithium cells with different electrolytes of silicon dioxide and fluoropolyimide can achieve good thermal stability under the temperature of 300°C. Within 500°C, the new lithium cell with fluoropolyimide as an electrolyte has good thermal performance. In the process of charging without equalized control, if BEV’s new lithium battery is continuously charged, the battery will be overloaded and then damaged. When the equalized charging control system based on fuzzy control is used for equalized charging control, different single batteries in lithium cells are filled successively around 900s. The equalized charging control system based on fuzzy control can make the single charge state of lithium cells consistent, and there is basically no overcharge. It can protect the service time of BEV's new lithium cell. This thesis has certain research significance for the thermal properties of the electrolyte materials of BEV's new lithium cell and the equalized charging of lithium cells. However, only the thermal properties of BEV new materials are studied. The relationship between the material and the charge and discharge of BEV is not explored. It is hoped that the relationship between the material and charge-discharge stability of BEV's new lithium cell can be explored.

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