Performance Analysis Based on Desert Rescue UAV Power Battery in High Temperature Environment

Xinyu Kou

Department of SCEDT, Teesside University, Middlesbrough, UK

D3088056@live.tees.ac.uk

Abstract. The main purpose of this paper is to analyze and discuss the performance of the lithium iron phosphate battery and the new lithium titanate battery commonly used in UAV that affect the endurance in high temperature environment. This paper first introduces the functions of desert rescue UAV and the development status of UAV power battery technology. This paper first points out the main factors that affect their endurance at high temperature, expounds the reasons for the failure of lithium-ion batteries and high-temperature polymer batteries at high temperature, and introduces the materials and general performance characteristics of the two types of batteries, and then reviews the methods and results of various studies on the performance of lithium-ion batteries and lithium polymer batteries at high temperature. Finally, this paper points out the shortcomings of the existing research and points out the direction for the future development. By comparing the working performance of the two batteries at high temperature and combining with the practical problems that need to be considered in production and use, this paper puts forward selection suggestions according to the existing conditions, so that later workers can choose the type of UAV power battery according to different working environments.

Keywords: Quadrotor UAV, high temperature environment, lithium titanate batter, lithium polymer battery.

1. Introduction

Rescue operations in desert areas often face difficulties due to complex terrain and inconvenient transportation. At the same time, the transportation and delivery of materials is also a difficult task. Besides, people who are lost or in distress are often difficult to find and rescue in time. At this time, desert rescue UAV has a great role and significance to life, which is mainly reflected in the following aspects: desert rescue UAV can quickly reach the scene of the accident without being limited to ground traffic [1], provide remote reconnaissance and search, help rescue workers understand the accident situation and determine the best rescue plan [1]. The UAV can also carry medical equipment to carry out remote medical rescue and provide first aid and medical services for injured or sick people [2]. In addition, it can carry out environmental monitoring and weather warning, and carry meteorological instruments to monitor temperature, humidity, wind speed and other information in real time [2]. This helps people to take preventive measures and reduce the impact of natural disasters on life [2]. Secondly, it can also carry goods to achieve long-distance material transportation and delivery. This is crucial for providing emergency relief, food, water and medical supplies, especially in areas where transportation is blocked or inaccessible [3]. Finally, it is capable of conducting extensive search and surveillance, utilizing technologies such as high-definition video and thermal imaging to help locate the location of missing or distressed people and provide timely relief [3]. In this case, it is of great significance to realize the long endurance of Uavs, which ensures that Uavs can quickly reach the scene of accidents and improves the working time and efficiency of remote reconnaissance and search, material transportation and delivery, as well as environmental monitoring and weather warning. They can improve rescue efficiency, reduce casualties, and ensure people's life safety and quality of life.

At present, the power battery technology of desert rescue UAV in China is still not mature enough. Although in terms of UAV technology and application, China has made certain progress, there are still some challenges and limitations in the power battery technology. First, the current power battery technology still has certain limitations in terms of endurance. The complex environment and vast area of desert regions have put forward higher requirements for the endurance of Uavs. However, current battery technology has not yet been able to provide a long enough flight time, limiting the application of Uavs in desert rescue. Secondly, the high temperature environment in desert areas has a great impact on the performance and life of the battery. The current power battery technology is prone to overheating and capacity reduction in high temperature environment, which limits the flight performance and endurance of UAV. In addition, the charging time of the power battery is long, which cannot meet the needs of emergency rescue missions. Time is often of the essence in desert rescue, and more rapid charging technologies are needed to reduce the grounding time of drones. In general, although China has made certain achievements in UAV technology and application. For example, based on technological breakthroughs such as lightweight high-strength composite material structure, energy-efficient power system and overall optimization, the application of solar-powered UAV in emergency communication has begun to be explored [4]. In addition, China is also accelerating the development of unmanned intelligent combat forces, and UAV technology is constantly improving. However, there is still a need for further research and innovation in the power battery technology of desert rescue drones. With the continuous progress and innovation of technology, it is believed that these problems will be gradually solved to provide better power battery technical support for the development of desert rescue UAV.

Based on the development status of power battery technology of desert rescue UAV in China, it still has some defects as follows: Limited battery life: The current power battery technology still has certain limitations in terms of endurance. Due to the complex environment and vast area of desert areas, Uavs need to have a long endurance to effectively perform rescue missions. However, current battery technology has not yet been able to provide sufficient flight time, limiting the application of Uavs in desert rescue. Long charging time: Current power battery technology takes a long time to charge and cannot meet the needs of emergency rescue missions. In desert rescue, time is often of the essence; therefore, more rapid charging technologies are needed to reduce the grounding time of drones. Insufficient temperature adaptability: The high temperature environment in desert areas has a great impact on the performance and life of the battery. The current power battery technology is prone to overheating and capacity reduction in high temperature environment, which limits the flight performance and endurance of UAV. Safety and stability problems: There are certain safety risks in power batteries, such as overcharge, over discharge, short circuit and other problems. In desert rescue, the UAV may face harsh climatic conditions and complex terrain, which increases the risk of battery failure.

In view of the commonly used lithium-ion battery and high temperature lithium polymer capacity, charging time and cycle life of charge and discharge times, this paper analyzes the performance parameters of lithium titanate battery (Li-TiO2) and lithium iron phosphate as the cathode material (Li-Polymer) in high temperature environment. Explore the battery capacity, charging time and cycle life of the two kinds of batteries in high temperature environment at different temperatures. So that later workers can choose the type of UAV power battery according to different working environments.

2. Mainbody

2.1. Failure of Lithium-ion and High-temperature Polymer Batteries

Electrolyte evaporation and degradation: high temperature will lead to the evaporation of the electrolyte inside the battery and the degradation of the electrolyte. The evaporation of the electrolyte will lead to a decrease in the liquid inside the battery and increase the internal resistance of the battery. Degradation of the electrolyte can lead to a decrease in battery capacity and an increase in internal resistance. Electrode material deembedding and loss: high temperature will accelerate the rate of chemical reactions inside the battery, resulting in increased deembedding and loss of electrode materials, SEI film consumption of a large amount of Li^+, which is the main cause of battery failure. The positive electrode material has a large number of cracks in the aging process, the crystal defects on the surface of the negative electrode material graphite increase, and some of the diaphragm holes are blocked by the graphite shed by the negative electrode. The metal elements in the positive electrode material dissolve and precipitate, and some of them pass through the diaphragm to the negative electrode, resulting in the decline of structural stability and cycling performance of the material and accelerating the aging of the battery [5]. The de-embedding of the electrode material will lead to the reduction of the battery capacity and the increase of the internal resistance. Safety concerns: High temperatures increase the risk of thermal runaway of the battery, which may cause the battery to overheat, burn or even explode. Therefore, in a high temperature environment, the safety performance of lithium-ion batteries and lithium polymer batteries needs special attention.

2.2. Overview of High Temperature Polymer Batteries

High temperature polymer battery is a special type of lithium-ion battery, which can provide reliable storage and release of electrical energy in high temperature environment. Compared with the traditional lithium-ion battery, high temperature polymer battery has some unique characteristics and advantages. First, high temperature polymer batteries use polymers as electrolyte materials. Compared with traditional organic liquid electrolytes, polymer electrolytes have higher thermal stability and lower volatility, and can maintain better conductivity and ion transport performance in high temperature environments. Secondly, high temperature polymer batteries use high temperature stable positive and negative materials. The positive electrode material is usually lithium nickelate (LiNiO2) or lithium manganate (LiMn2O4), while the negative electrode material is graphite or silicon-based. These materials can maintain good cycle stability and electrochemical properties at high temperatures.

2.2.1 Performance analysis of lithium polymer battery at high temperature

At high temperature, the cathode material of high-temperature lithium polymer battery commonly used by UAV is usually lithium iron phosphate (LiFePO4), and the cathode material is usually graphite.

Capacity decay: High temperatures will accelerate the capacity decay of lithium iron phosphate batteries. In a high temperature environment, the chemical reaction rate inside the battery will increase, resulting in an increase inside reactions of the electrochemical reaction, resulting in a decrease in battery capacity. Reduced cycle life: In a high temperature environment, the cycle life of the battery may be reduced. High temperature will accelerate the rate of chemical reactions inside the battery, resulting in increased deem bedding of the battery material, thus accelerating the aging of the battery. Increase in internal resistance: high temperature will lead to the evaporation of the electrolyte inside the battery and the degradation of the electrolyte, thereby increasing the internal resistance of the battery. The increase in internal resistance will lead to a decrease in the discharge performance of the battery and a narrower operating temperature range of the battery. The critical temperature of thermal runaway of lithium iron phosphate battery reaches 190°C [6].

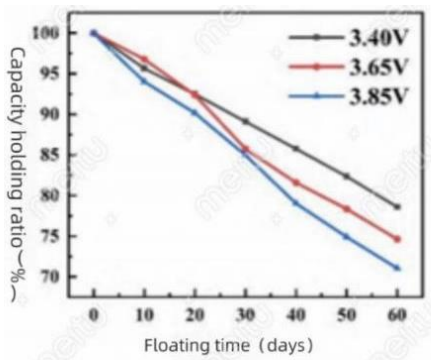

Figure 1. Battery capacity retention rate after 50°C high temperature floating charge [7]

In Figure 1 and 2, the battery was floating charged at 50°C for 60 days, and the capacity retention rate dropped to 80%-85%.

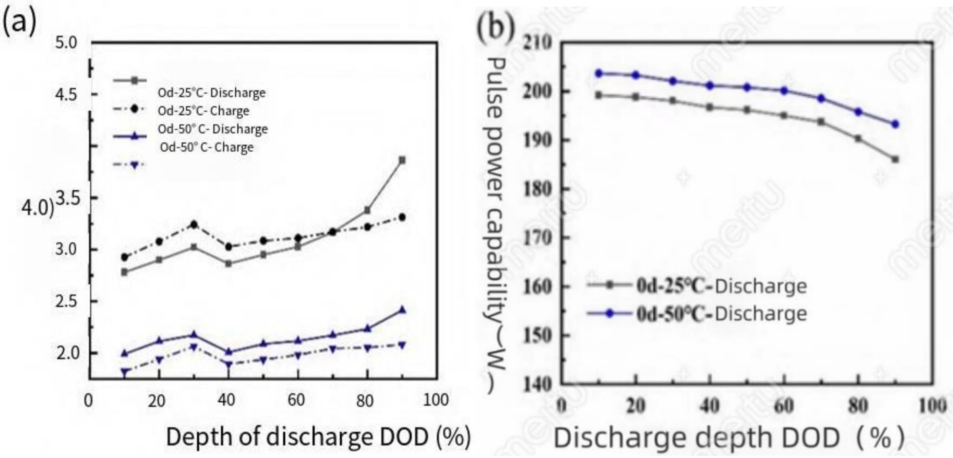

Figure 2. Internal resistance and pulse power capacity of batteries at different temperatures [7]

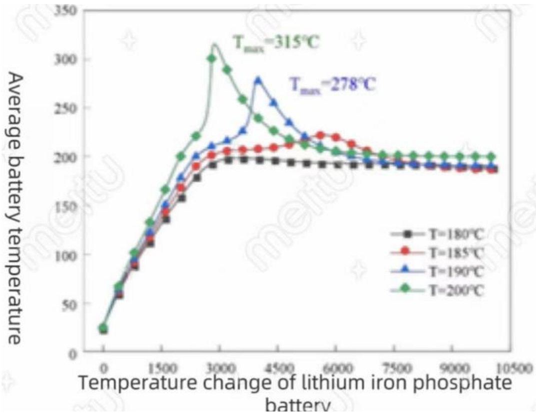

Figure 3. Temperature variation of lithium iron phosphate battery [8]

The thermal runaway simulation for lithium iron phosphate batteries is performed at 180, 185, 190, and 200°C, respectively, as shown in Figure 3. Figure displays the average change in battery temperature.

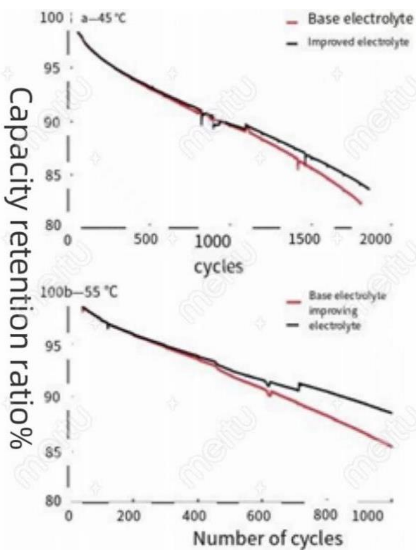

Figure 4. Cycle performance of battery at high temperature [8]

Figure 4 illustrates the cycle performance of the battery at 1C charge and 1C discharge at different temperatures as shown below. After 1790 cycles at 45°C, the capacity retention rate of the basic electrolyte system is 82.5%, and that of the upgraded electrolyte system is 84.5%, as shown in the figure. After 1000 cycles at 55°C, the volume retention rates of the enhanced and basic electrolytic liquid lines were 88.0% and 84.0%, respectively.

2.3. Overview of Lithium-ion Batteries

Lithium-ion battery (Li-ion battery) is a common secondary battery, which is widely used in mobile devices, electric vehicles, energy storage systems and other fields. It realizes the storage and release of charge by the migration of lithium ions between positive and negative electrodes. The basic structure of a lithium-ion battery includes a positive electrode, a negative electrode, an electrolyte and a diaphragm. The positive electrode is usually made of a lithium-ion compound (such as LiCoO2, LiFePO4, etc.), and the negative electrode is made of graphite or other carbon materials. Electrolytes, usually organic solutions or polymer gels, are used to provide channels for ion transport. A diaphragm is used to separate the positive and negative electrodes and prevent short circuits. Lithium-ion batteries work by storing and releasing charge through the migration of lithium ions between the positive and negative electrodes during charging and discharging. During the charging process, lithium ions are deem bedded from the positive electrode material and migrate through the electrolyte and diaphragm to be embedded in the negative electrode material. During discharge, lithium ions are deem bedded from the negative material and migrate through the electrolyte and diaphragm to be embedded in the positive material. Lithium-ion batteries have many advantages, such as high energy density, long cycle life, low self-discharge rate, and memoryless effect. They can also meet the needs of different applications by adjusting the combination of positive and negative electrode materials and optimizing the electrolyte. However, there are some challenges associated with lithium-ion batteries. For example, excessive temperature, overcharge or over discharge, mechanical damage, etc., can lead to performance degradation, capacity attenuation and even safety issues of the battery. Therefore, for the design, manufacture and use of lithium-ion batteries, it is necessary to strictly control the working conditions and take appropriate safety measures. In general, Liion batteries are a high performance and widely used secondary battery technology, and continued research and development will further improve their performance and application range.

2.3.1 Performance analysis of Li-ion batteries at high temperature

Li-Titanate battery is a new type of lithium-ion battery with high safety, long cycle life and fast charging and discharging ability. Compared with other types of Li-ion batteries, Li-titanate batteries have better performance in high temperature environments. Performance changes of lithium-ion titanate batteries at high temperatures: Cycle life and capacity decay: The cycle life of lithium-ion titanate batteries may be significantly reduced in high temperature environments, and their capacity decay rate will also be accelerated. This may be due to the volatilization of the electrolyte and the structural damage of the electrode material caused by high temperature. Charge transport and electrolyte migration: Problems in charge transport and electrolyte migration may increase under high temperature conditions. The increased mobility of the electrolyte may cause adverse reactions within the battery, resulting in capacity loss and reduced cycle life. 2 2. Thermal runaway: Lithium titanate batteries may also be at risk of thermal runaway, such as overheating, fire, or explosion, in high temperature environments. 3. It should be noted that the performance of lithium titanate batteries at high temperatures may be affected by a variety of factors, including electrode materials, electrolytes, and battery design. Lithium titanate batteries (Li4 Ti5O12, LTO) have very obvious advantages: 1) Good safety performance. When the positive and negative short circuit occurs, Li7Ti5O12 in the negative lithium intercalated state is rapidly transformed into LTO in the delithium state at the short circuit. This causes the electronic conductivity to drop from 10-3 to 10-4 S/cm to 1013 to 10-9 S/cm, the ohmic impedance to increase sharply, and the battery cell is not prone to thermal runaway. In addition, LTO and Li7 Ti5O12 are inherently non-combustible, which is fundamentally different from graphite, especially graphite in the lithium-embedded state. In short, this series of batteries is the highest safety among the existing lithium-ion batteries [9]. 2) The cycle life is very long. In the process of full charge, the volume expansion of graphite is usually 10%, and the zero-strain material has very good cycling performance. It is reported that the 18650 single cell battery has a cycle life of more than 20,000 times, which is the longest among all secondary batteries at present [9]. Figure 5 and 6 showed the change curve of ultimate overcharge test data of lithium titanate battery and short circuit test data change curve of lithium titanate battery, respectively.

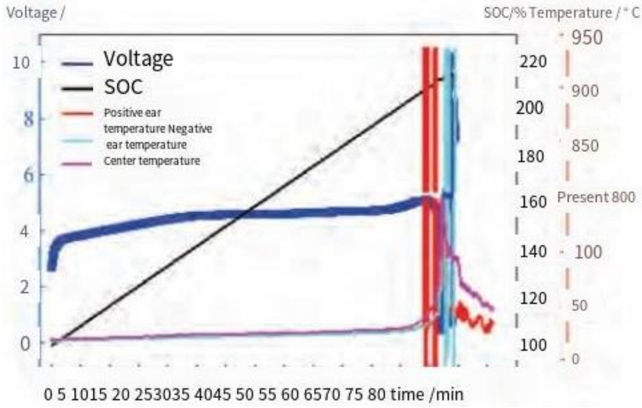

Figure 5. Change curve of ultimate overcharge test data of lithium titanate battery [10]

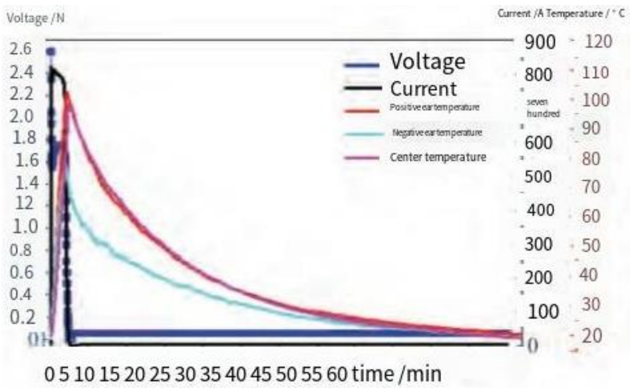

Figure 6. Short circuit test data change curve of lithium titanate battery [10]

2.4. Development of Batteries and Technologies

High energy density battery: In order to provide longer endurance and greater flight range, researchers have focused on developing high energy density battery technology. Currently, lithium-ion batteries are the most commonly used power batteries, but there are other types of battery technologies being studied, such as lithium-sulfur batteries and metal-air batteries. Fast charging technology: In desert rescue missions, fast charging is crucial because it can shorten the stay time of the UAV on the ground and improve the mission efficiency. Therefore, researchers have focused on developing fast charging technologies, such as fast charging algorithms and fast charging devices. Thermal management techniques: High temperatures are a common problem in desert environments that negatively affect the performance and lifetime of power batteries. Therefore, researchers are developing thermal management techniques, such as heat dissipation systems and temperature control algorithms, to ensure the stability and reliability of batteries in high temperature conditions.

Safety technology: The safety of UAV power batteries is also an important consideration. Researchers have focused on developing safety technologies, such as overcharge protection, over discharge protection, and short circuit protection, to prevent safety issues such as thermal runaway and fire in batteries.

3. Discussion

3.1. Strengths and Weaknesses of the Methods

According to literature [6], based on the thermal runaway side reaction mechanism of lithium battery, the thermal runaway model of single battery was established, and the thermal runaway characteristics of lithium iron phosphate battery at high temperature were simulated. The peak temperature of thermal runaway of lithium iron phosphate battery reached 190℃, indicating that the thermal stability of lithium iron phosphate battery was better, and the harm of thermal runaway was less.

According to literature [7], after high temperature floating charge, the main active substances and active lithium ions of lithium iron phosphate battery are lost, the interface reaction kinetics slows down, the internal resistance increases sharply, and the power capacity of the discharge pulse decreases. In addition, the discharge capacity of the battery decreases significantly after floating Charging, and the temperature rise at the corresponding point increases sharply with the increase of the discharge rate. (Float Charging is a common charging method, which is usually used to maintain the battery charging state and extend the battery life. In float charging, the battery is continuously charged at a lower current to compensate for the energy loss from battery self-discharge and load consumption.)

According to reference [8], after cycling, the lithium iron phosphate battery is discharged to 2.50V at 1 degree Celsius. Then, after 30 minutes of standing, the battery was discharged to 2.30V at 0.05 degrees Celsius. Dissect the battery at 0%SOC. The electrolyte composition was evaluated by Agilent 6890N-5973GC analyzer; JSM-7600F scanning electron microscope was used to evaluate the surface shape of the electrode. D/MAX-2550V/PC X-ray diffractometer was used to evaluate the lattice structure of the electrode. INSTRON3365 universal tensile machine was used to evaluate the bonding force of the electrode. Finally, the disassembled positive and negative electrodes were assembled into a button battery in an argon glove box, and the alternating current internal resistance (ACR) was evaluated by BS-VR3 core internal resistance tester. At the early stage of the cycle, the SEI film was destroyed and reformed, which led to a large consumption of active lithium in the lithium iron phosphate battery under the basic electrolyzer liquid system. After 300 cycles, the thickness of the SEI film increases, and fewer and fewer negative electrodes are in contact with the electrolyte. The expansion of the negative electrode is only caused by the process of lithium removal and intercalation during charging and discharging.

In reference [10], the safety test of lithium titanate battery was carried out, and the safety performance of the device in the process of acupuncture, extreme overcharge, short circuit and extreme heating was comparatively studied. In the extreme overcharge test, the lithium titanate battery had an overcharge fault, and the overcharge lasted for 48 minutes, and the SOC was 218%. In the extreme heating test, the temperature of the lithium titanate battery changed to less than 200°C, and the voltage dropped to 0 V rapidly, accompanied by severe smoke phenomenon. The safety of lithium titanate battery is higher, and its over-temperature capacity is much higher than the standard 130°C. Lithium titanate batteries have a high overcharge capacity and can withstand overcharge for a long time.

3.2. Views and Methods

According to the above research, the research on the performance characteristics of lithium-ion batteries and lithium polymer batteries at high temperature is still incomplete. We can establish simulation models through MATLAB simulation, set up simulation environment, and select appropriate models and algorithms for simulation experiments. The following are the experimental steps:

(1) Establish the model: First of all, the model of the UAV needs to be imported into the simulation software, including the geometry, mass, aerodynamic characteristics of the quadrotor UAV. At the same time, it is also necessary to establish the model of the battery, including the capacity of the battery, voltage characteristics, discharge curve, etc.

(2) Setting simulation parameters: According to the actual situation, set the simulation parameters, including the takeoff weight of the UAV, flight speed, flight height, flight mode, etc. At the same time, it is also necessary to set the simulation time step and simulation duration.

(3) Simulation calculation: After setting the parameters, simulation calculation is carried out. MATLAB simulation software will simulate the energy consumption and battery discharge of the

UAV during flight according to the set parameters and model. Through simulation calculation, the UAV's flight time, flight distance and battery power data can be obtained.

(4) Data analysis and evaluation: According to the results of simulation calculation, data analysis and evaluation are carried out. The average flight time, average flight distance and average power consumption of the UAV can be calculated to evaluate the battery life performance.

(5) Optimization design and verification: According to the simulation results, the optimization design of battery capacity and UAV parameters can be carried out. By continuously optimizing the design and simulation verification, the endurance performance of the UAV can be improved.

In the simulation test, the actual use scenario should be simulated as much as possible, taking into account the difference in energy consumption of different flight tasks. In addition, the accuracy and reliability of the simulation software should be ensured, and the appropriate model and algorithm should be selected for simulation calculation.

Through the rich data analysis and visualization tools provided by MATLAB, data analysis and evaluation of simulation results can be carried out. Indicators such as average flight time, average flight distance, and average power consumption of the UAV can be calculated to evaluate the battery life performance. (Consider the factors affecting UAV flight in high temperature and set up a simulated environment).

4. Conclusion

According to the literature, it can be concluded that the high temperature lithium polymer battery with lithium iron phosphate as the positive electrode and graphite as the negative electrode has good thermal stability, and the thermal runaway is less harmful, and the peak temperature of thermal runaway reaches 190℃. The capacity retention rate of the battery drops to about 85% for 1000 cycles at a high temperature of 55℃, and to 80-85% for 2000 cycles at a high temperature of 45℃. The operating temperature range of lithium iron phosphate batteries is usually -20°C to +75°C. In high temperature environment, the performance of lithium iron phosphate battery is relatively good, its internal structure is safe and intact, and it can maintain good battery performance at high temperature.

Lithium titanate batteries have high safety, long cycle life and fast charge and discharge capabilities, LTO and Li7 Ti5O12 themselves are non-combustible. The overtemperature capacity of lithium titanate battery is much higher than the standard 130℃. Lithium titanate batteries have the characteristics of high energy density, long cycle life, and wide operating environment temperature range. Lithium titanate battery has better performance at high temperature.

In general, the high temperature lithium polymer battery with lithium iron phosphate as the positive electrode and graphite as the negative electrode has better working performance and stability than lithium titanate battery in high temperature environment. However, the specific working performance is also affected by factors such as battery design, material ratio and manufacturing process, so it is necessary to consider specific application requirements and cost and other factors when selecting a battery.

References

[1] Aeromotus. Search and Rescue Operations in the Desert: An Overview of Drones in Use. 2022.

[2] DJI. Saving lives in the desert: How drones made Mesa Fire and Medical Department's search and rescue efforts more effective.

[3] Frąckiewicz M. Optimal UAV for search and rescue in desert areas. May 16, 2023.

[4] Ma Hongzhong, Li Qing, Liu Xiaochun, Ding Yiheng. Application of near space solar UAV in emergency communication. Blue ocean evergreen think-tank. 2018.

[5] Ruan Yizhao, Tian Yanhong, Li Shoutao et al. Failure mechanism of LiNi0.5Co0.2Mn0.3O2/graphite battery at High temperature [J]. Battery, 2020, 50 (03): 220-223.

[6] Ge Sang Duoji, Xie Yongliang. Fire hazard analysis of lithium battery with different cathode materials [J]. Refrigeration and Air Conditioning (Sichuan), 2023, 37 (01): 52-59.

[7] Wei Shouli, Yin Tao, Jia Longzhou et al. Soft package of lithium iron phosphate battery high temperature after floating of the electrochemical properties [J/OL]. Journal of electrical engineering: 2023, 1-11.

[8] Xu Ruilin, Zhao Lipeng, Liu Xingwei et al. To improve the performance of high temperature lithium iron phosphate cycle [J]. Journal of inorganic salt industry, 2022, 9: 108-112.

[9] Wang Qian, Zhang Jingze, Lou Yuwan, Xia Baojia. Gas evolution characteristics of lithium titanate - based Li-ion batteries. Progress in Chemistry, 2014, 26 (11): 1772-1780.

[10] Zhang Weixian, Yang Sheng, Tang Qianbin et al. Semi-solid lithium iron phosphate batteries and lithium titanate battery safety analysis [J]. Electric locomotive and the urban rail vehicles, 2021, 44 (6): 61-64.