Comparative Analysis of Lithium Iron Phosphate Battery and Ternary Lithium Battery

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Abstract. This article analyses the lithium iron phosphate battery and the ternary lithium battery. With the development of new energy vehicles, people are discussing more and more about the batteries of electric vehicles. Nowadays, electric vehicles mainly use the lithium iron phosphate battery and the ternary lithium battery as energy sources. Existing research and articles have given the current performance of the two batteries but have not systematically compared the two batteries with more details. This article introduces the basic principles, cathode structure, and standard preparation methods of the two batteries by summarizing and discussing existing data and research. The article discusses the two types of batteries and concludes the advantages and disadvantages of the two batteries at the present stage. This article aims to help readers have a more comprehensive understanding of the basic information of the two batteries at this stage and provide theoretical guidance for future research on batteries for electric vehicles.

Keywords: Lithium iron phosphate battery; Ternary lithium battery; Cathode structure; Energy density; Charging efficiency

1. Introduction
With the gradual reduction of fossil fuels on the earth and the increasingly severe pollution problem, the world's energy infrastructure has to consider the use of clean and renewable energy. For example, many automobile manufacturers have already begun to study electric vehicles or hybrid vehicles to replace traditional internal combustion engine vehicles. Rechargeable batteries are widely used in the implementation of electric vehicles. At present, standard rechargeable batteries can be divided into four categories according to their chemical composition: nickel-cadmium battery (NiCd), nickel-metal hydride battery (NiMH), lead-acid battery (PbSO4), and lithium battery. The internal resistance of nickel-cadmium batteries is minimal and can be quickly charged. When discharging, it provides a large current to the load, and the voltage change is minimal. Nevertheless, the fatal disadvantage of nickel-cadmium battery is that it has a "memory effect," improper use will significantly shorten its service life. Nickel-metal hydride battery has a greater energy density than nickel-cadmium battery and is more environmentally friendly. It has a longer service life than nickel-cadmium and lead-acid batteries, and the current technology is very mature. However, nickel-metal hydride battery has poor self-discharge performance, poor endurance, and poor battery performance at low temperatures. The main advantages of a lead-acid battery are that it has a stable voltage during discharge, the use temperature and current range are comprehensive, and the cost is low. However, lead-acid requires a small battery's specific energy, which is cumbersome, has a large self-discharge, and is highly...
corrosive to the environment. Lithium battery is widely used daily due to their higher energy density, long service life, lightweight and lower self-discharge efficiency. Among them, the lithium iron phosphate battery and the ternary lithium battery are the more commonly used lithium batteries. This article focuses on introducing and discussing the basic principles and structures of the two batteries and then compares the two batteries to conclude the fundamental theories of the two batteries for the future development and performance improvement of lithium batteries.

2. Introduction of lithium iron phosphate battery and ternary lithium battery

This section mainly introduces the basic information of the two batteries, including principle, imprint structure, and standard preparation methods.

2.1. Lithium iron phosphate battery

2.1.1. Principle. Lithium batteries first appeared in the 1990s. The anode of a lithium battery is usually a graphite carbon electrode, and the cathode is made of LiNiO2, LiMn2O4, LiCoO2, LiFePo4, and other materials [1]. Researchers have extensively studied Lithium iron phosphate because of its rich resources, low toxicity, high stability, and low cost. A lithium iron phosphate battery uses lithium iron phosphate as the cathode, undergoes an oxidation reaction, and loses electrons to form iron phosphate during charging. When discharging, iron phosphate becomes the anode, and a reduction reaction takes place to obtain electrons and form lithium iron phosphate again. Lithium iron phosphate has reducing properties, and iron phosphate has oxidizing properties, which is an essential condition for lithium iron phosphate to become the cathode of a rechargeable secondary battery.

2.1.2. Cathode structure. As Borong, Yonghuan and Ning demonstrate, the crystal structure of lithium iron phosphate is a typical olivine structure [1]. The P-O covalent bond has vital chemical bonding energy, making lithium iron phosphate stable enough even in high-temperature environments. The three-dimensional olivine structure presented by the lithium iron phosphate crystal forms a one-dimensional lithium-ion transmission channel to limit the diffusion of lithium ions (Figure 1).

![Figure 1: Structure of cathode material for lithium iron phosphate battery [2]](image-url)
2.1.3. **Common preparation method.** Lithium iron phosphate appears as a mineral in the natural world, but it contains many impurities and cannot be used directly. The preparation of lithium iron phosphate is mainly divided into a solid-state preparation method and a liquid-state preparation method [3]. Solid-state preparation methods include solid-state synthesis, mechanochemical activation, carbothermic reduction, and microwave heating. Among them, solid-state synthesis is the most conventional method. Lithium iron phosphate is obtained by repeatedly grinding and calcining the raw materials under a high temperature and a high pressure. This method is simple to operate and easy to realize industrialized large-scale production, but the product usually has a lower electrochemical performance than other methods. Mechanochemical activation uses grinding media to grind the raw materials to synthesize pure lithium iron phosphate powder with a good crystal structure. The carbothermic reduction method uses graphite and other common reducing agents to reduce Fe (II) compounds to obtain acceptable and uniform lithium iron phosphate powder. The microwave heating method uses microwaves to heat the molecules of the raw materials to obtain lithium iron phosphate powder with good electrochemical properties. This method can heat the raw materials uniformly and consume less energy and cost. Compared with solid-state preparation methods, liquid-state preparation methods can often produce smaller particle sizes, higher purity, and better electrochemical properties and consume less time and energy. The hydrothermal synthesis method obtains lithium iron phosphate powder with higher purity by heating the solution under high pressure. This method has simple operation and low cost. The sol synthesis method controls the reaction parameters and heats the colloidal suspension at a high temperature to obtain lithium iron phosphate powder with high purity and good electrochemical performance.

2.2. **Ternary lithium battery**

2.2.1. **Principle.** The cathode of a ternary lithium battery is a mixture of nickel, cobalt, and manganese. Each element plays an important role, and the characteristics of the missing elements also restrict the battery's performance. Therefore, the ternary lithium battery has the combination of the advantages of lithium cobaltate battery, lithium nickelate battery, and lithium manganate battery [4]. The electrolyte of the ternary lithium battery is in the form of gel polymer. The gel polymer electrolyte formed by mixing the polymer, organic solvent, and lithium salt has not only the advantages of solid electrolyte but also the advantages of liquid electrolyte.

2.2.2. **Cathode structure.** The cathode material of a ternary lithium battery has a layered structure, and Ni, Mn, and Co atoms and oxygen atoms form a MO6 octahedron. Lithium ions are located between the MO6 octahedral layers and can be reversibly inserted and extracted between the layers. The cathode material of a ternary lithium battery has a layered structure, and Ni, Mn, and Co atoms and oxygen atoms form a MO6 octahedron. Lithium ions are located between the MO6 octahedral layers and can be reversibly inserted and extracted between the layers (Figure 2). The presence of nickel helps to increase the battery capacity. Cobalt helps to maintain the layer stable and improves the electronic conductivity. Manganese can reduce costs and improve structural stability and safety. Therefore, the proportions of manganese, cobalt, and nickel in the cathode of the ternary lithium battery can be adjusted according to different requirements and usage conditions.
2.2.3. Common preparation method. The preparation of ternary lithium battery materials is not a single chemical reaction process. The structure and physical properties of the material may be different during the synthesis of the structure because of the different control conditions of a chemical reaction in the synthesis process. Standard preparation methods include the solid-phase method, co-precipitation method, sol-gel method, spray method, and combustion method. The high-temperature solid-phase method directly mixes the lithium source and the transition metal salt in a certain stoichiometric ratio. Grinds then perform low-temperature pre-sintering and then perform high-temperature calcination after grinding. This method is simple to operate, and the reaction process is easy to control, so it has been widely used in industry. The co-precipitation method adds a precipitation agent and a complexing agent to a solution of multiple cations \[6\]. After the precipitation reaction, uniform precipitation of each component is generated, and then the precipitation is dried. The product obtained by this method has fine particles and uniform distribution of various elements, a simple operation process, and high reaction stability. In the sol-gel method, compounds containing highly chemically active ingredients are uniformly mixed. Then the mixed compounds are successively hydrolyzed and condensed to form a more stable sol system. This method can achieve uniform doping at the molecular level, and the reaction temperature is low and easy to proceed with \[7\]. However, the preparation process of this method is very time-consuming and complicated to operate. The spray drying method uses a spray device to atomize the reaction liquid and introduce it into the reactor. The solution is quickly volatilized and dried so that the reactant undergoes a decomposition reaction. Although this preparation method is simple to operate, using a large amount of organic complexing agent has become the main drawback of this method.

3. Discussion

Nowadays, lithium iron phosphate batteries and ternary lithium batteries have been widely used, and electric vehicles generally use these two batteries as energy supplies. This section compares and discusses the two batteries from five aspects: energy density, safety, low-temperature discharge, charging efficiency, and cycle life.

3.1. Energy density

The energy density of the current ternary lithium battery is generally 200Wh/kg. As more research and technology matures, it may reach 300Wh/kg in the future. The energy density of lithium iron...
phosphate batteries currently on the market is generally around 105 Wh/kg, and a few can reach 130–150 Wh/kg. However, it will be challenging to break through 200 Wh/kg in the future [8]. Therefore, the lithium iron phosphate battery's volume is more significant while providing the same energy, making lithium iron phosphate batteries take up more space than ternary lithium batteries. When the battery volume is specified, ternary lithium batteries have a more vital endurance than lithium iron phosphate batteries due to the greater energy density.

3.2. Safety
Safety is the most significant advantage of lithium iron phosphate batteries. Due to its unique olivine structure, lithium iron phosphate has highly stable chemical properties and good high-temperature resistance. Lithium iron phosphate batteries will not release oxygen molecules when faced with impacts, needle sticks, short circuits. It will not burn even if it is damaged. In contrast, ternary lithium batteries have lower safety. The cathode of a lithium iron phosphate battery will only undergo internal decomposition at 700 to 800 degrees Celsius. However, the cathode of a ternary lithium battery will begin to undergo internal decomposition at 250 to 300 degrees Celsius [9]. Poor thermal stability makes the ternary lithium battery more prone to internal decomposition. The decomposed cathode will react quickly to generate enormous heat after encountering the battery's combustible electrolyte and carbon materials. At the same time, in the event of an external force impact, the separator between the cathode and cathode of the ternary lithium battery is easily damaged and short-circuits the battery. A short-circuited ternary lithium battery will experience thermal runaway and rapidly heat up until it spontaneously ignites.

3.3. Low-temperature discharge
Although lithium iron phosphate battery has better thermal stability and is safer at high temperatures, its discharge performance is worse than that of a ternary lithium battery in a low-temperature environment. It can be seen from Figure 3 that at -20 degrees Celsius, the capacity of the ternary lithium battery drops to 70.14% of that at 25 degrees Celsius. However, the capacity of lithium iron phosphate batteries drops to only 54.94% [9]. Therefore, the discharge performance of the ternary lithium battery at low temperatures is better.

| Temperature (℃) | Capacity (Ah) | Discharge platform (V) | Relative capacity at 25℃ |
|-----------------|---------------|------------------------|-------------------------|
| 55              | 7.87          | 3.271                  | 100.20%                 |
| 25              | 7.86          | 3.24                   | 100.00%                 |
| -20             | 4.32          | 2.87                   | 54.94%                  |

| Temperature (℃) | Capacity (Ah) | Discharge platform (V) | Relative capacity at 25℃ |
|-----------------|---------------|------------------------|-------------------------|
| 55              | 8.581         | 3.668                  | 99.36%                  |
| 25              | 8.636         | 3.703                  | 100.00%                 |
| -20             | 6.058         | 3.411                  | 70.14%                  |

3.4. Charging efficiency
The ratio of the battery current while charging and discharging to the battery rated capacity is called the constant current ratio. When the two batteries are charged at ten times the constant charging current, the constant current ratio of the two batteries has no obvious difference. When the charging
current is higher than ten times the constant charging current, the gap between the two batteries begins to manifest. When charging at twenty times the constant charging current, ternary lithium batteries’ constant current ratio drops to 52.75%. Furthermore, the constant current ratio of lithium iron phosphate batteries is 10.08% [9].

Table 3. Charging efficiency of lithium iron phosphate battery [9].

| Recharging current (Ah) | Constant current capacity (Ah) | Total capacity (Ah) | Constant current capacity/Total capacity |
|-------------------------|--------------------------------|---------------------|-----------------------------------------|
| 6.5                     | 6.52                           | 6.25                | 90.00%                                  |
| 32.5                    | 5.91                           | 7.23                | 81.64%                                  |
| 65                      | 5.43                           | 7.26                | 74.71%                                  |
| 97.5                    | 3.51                           | 7.29                | 48.11%                                  |
| 130                     | 0.74                           | 7.31                | 10.08%                                  |

Table 4. Charging efficiency of ternary lithium battery [9].

| Recharging current (Ah) | Constant current capacity (Ah) | Total capacity (Ah) | Constant current capacity/Total capacity |
|-------------------------|--------------------------------|---------------------|-----------------------------------------|
| 7.5                     | 8.21                           | 8.62                | 95.24%                                  |
| 37.5                    | 7.17                           | 8.54                | 95.24%                                  |
| 75                      | 6.42                           | 8.58                | 74.82%                                  |
| 112.5                   | 5.65                           | 8.6                 | 65.71%                                  |
| 150                     | 4.55                           | 8.62                | 52.75%                                  |

3.5. Cycle life
Ternary lithium batteries have 2000 times the theoretical service life that of charging and discharging. After 3900 cycles of use, the battery capacity may be reduced to 66%. Lithium iron phosphate batteries can still have 84% battery capacity after 5000 cycles of use [9]. Therefore, the lithium iron phosphate battery has more longer cycle life in contrast.

4. Conclusion
Through the comparison and discussion of the lithium iron phosphate battery and ternary lithium battery, we can conclude ternary lithium battery has higher energy density and higher charge and discharge efficiency. Nevertheless, it is not resistant to high temperatures and is prone to thermal runaway when the battery is damaged. Lithium iron phosphate battery has a lower cost, more stable cathode structure, and longer cycle life. However, it also has low energy density, low charge and discharge efficiency, and poor performance under low-temperature conditions. Nowadays, electric vehicles companies use these two kinds of batteries widely as the electric vehicles' power source. Private electrical cars generally use ternary lithium batteries as energy sources, while public electrical vehicles generally use lithium iron phosphate batteries. So far, ternary lithium batteries and lithium iron phosphate batteries have not separated the winners and losers, and both batteries have their advantages. Under different external environments and customer requirements, both batteries are widely used in different conditions. These two kinds of batteries are not the perfect solution at this stage, but the research and performance improvement of the two kinds of batteries continues. At the same time, other batteries, such as graphene batteries and fuel cells, and other alternative energy technologies are also developing rapidly. Maybe a perfect battery solution will appear someday in the future.
References

[1] B. Wu, Y. Ren, and N. Li, “LiFePO4 Cathode Material,” Electric Vehicles â€“ The Benefits and Barriers, Mar. 2011. [Accessed on: 23-Jul-2021]. Available doi: 10.5572/18995.

[2] J. Yang, “Development of nanostructured LiMPO4 (M=Fe, Mn) as Cathodes for high performance lithium-ion batteries,” Scholarship@Western. [Online]. Available: https://ir.lib.uwo.ca/etd/1597/. [Accessed: 02-Aug-2021].

[3] T. V. S. L. Satyavani, A. Srinivas Kumar, and P. S. V. Subba Rao, “Engineering Science and Technology, an International Journal”, ScienceDirect, vol. 19, no. 1, pp. 178-188, 2016.

[4] K. Zuo, “Classification of ternary lithium battery,” Linkedin, 04-Jan-2020.

[5] Richard, “Cobalt's Role in Lithium-Ion Batteries,” News about Energy Storage, Batteries, Climate Change and the Environment, 08-Aug-2018. [Online]. Available: https://www.upsbatterycenter.com/blog/cobalts-lithium-ion-batteries/. [Accessed: 02-Aug-2021].

[6] H. J. Guo, X. H. Li, Z. X. Wang, W. J. Peng, M. Zhang, Q. Y. Hu, Y. H. Zhang, and Z. Yang, “Lithium-nickel-cobalt-manganese-oxygen material for lithium ion battery positive electrode and preparation method thereof.” CN18384853A, Mar. 23, 2005. Available: https://patents.google.com/patent/CN1838453A/en. [Accessed: 24-Jul-2021]

[7] S. T. Zhang, W. Wei, X. H. Yang, and H. H. Zhou, “Preparation method of lithium ion battery ternary cathode material.” CN102509784A, Oct. 17, 2011. Available: https://patents.google.com/patent/CN102509784A/en. [Accessed: 26-Jul-2021]

[8] Impress Energy™, “Ternary lithium batteries(NCM) VS lithium iron phosphate batteries(LiFePO4),” Impress Energy™, 19AD. [Online]. Available: https://www.impress-energy.com/blogs/news/ternary-lithium-batteriesncm-vs-lithium-iron-phosphate-batterieslifepo4. [Accessed: 03-Aug-2021].

[9] “What is the difference between ternary lithium and lithium iron phosphate batteries?,,” The Cowboy Channel, 10-Mar-2021. [Online]. Available: https://www.thecowboychannel.com/story/43479532/what-is-the-difference-between-ternary-lithium-and-lithium-iron-phosphate-batteries. [Accessed: 03-Aug-2021].