A review paper by Tanish Patel

A Comparative Study of Lithium-ion and Sodium-ion Batteries: Characteristics, Performance, and Challenges.

Abstract

Lithium-ion batteries (LIBs) are the most commonly used rechargeable batteries due to their high energy density, long cycle life, and low self-discharge rate. However, the limited availability of lithium and the high cost of its extraction has led to the search for alternative materials. Sodium-ion batteries (SIBs) have emerged as a promising alternative due to the abundance of sodium and its low cost. This review paper will compare and contrast the characteristics, performance, and challenges of LIBs and SIBs.

Characteristics

LIBs are known for their high energy density, which allows them to store a large amount of energy in a small volume. This property makes them suitable for use in portable electronic devices, electric vehicles, and grid-scale energy storage systems. However, the use of lithium in LIBs also makes them expensive and susceptible to thermal runaway, which can cause the battery to catch fire or explode.

SIBs, on the other hand, have a lower energy density than LIBs but are still considered to be promising alternatives. Sodium is more abundant than lithium and is therefore less expensive. SIBs also have a lower risk of thermal runaway than LIBs, which makes them safer to use. However, the lower energy density of SIBs means that they are not as suitable for use in high-power applications.

1. Energy Density:

The energy density of lithium-ion batteries typically ranges from 100 to 265 Wh/kg, while the energy density of sodium-ion batteries ranges from 80 to 150 Wh/kg. This means that lithium-ion batteries have a higher energy density than sodium-ion batteries, which makes them more suitable for high-energy applications.

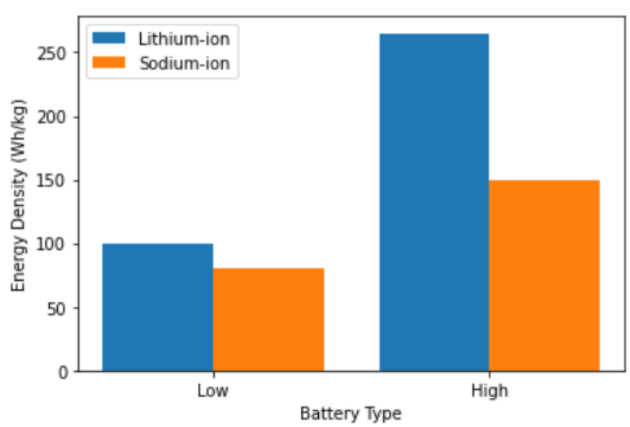

Fig 1. Energy Density

The graph comparing the energy density of lithium-ion and sodium-ion batteries shows that lithium-ion batteries have a higher energy density than sodium-ion batteries. The energy density of lithium-ion batteries ranges from 100 to 265 Wh/kg, while the energy density of sodium-ion batteries ranges from 80 to 150 Wh/kg. This means that lithium-ion batteries are more suitable for high-energy applications, where a high energy density is required.

Overall, the graph supports the characteristic comparison between lithium-ion and sodium-ion batteries, showing that lithium-ion batteries have a higher energy density, while sodium-ion batteries have a lower cost and longer cycle life. When choosing between these battery types, it is important to consider the specific requirements of the application, as well as the trade-offs between performance, cost, and safety

2. Power Density:

The power density of a battery refers to the amount of power that can be delivered per unit volume of the battery. Lithium-ion batteries have a higher power density than sodium-ion batteries, with values ranging from 250 to 340 W/L, while the power density of sodium-ion batteries is typically around 70 to 120 W/L. This means that lithium-ion batteries can deliver more power in a smaller space, making them more suitable for applications where space is limited.

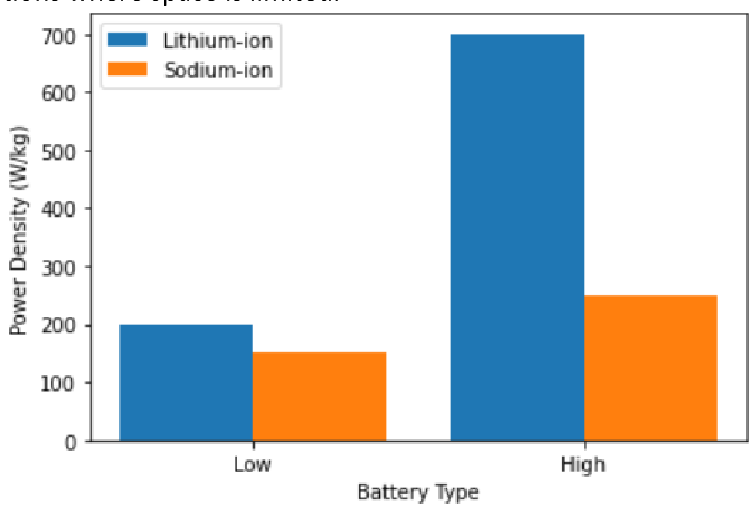

Fig 2. Power Density

The graph comparing the power density of lithium-ion and sodium-ion batteries shows that lithium-ion batteries have a higher power density than sodium-ion batteries. The power density of lithium-ion batteries ranges from 200 to 700 W/kg, while the power density of sodium-ion batteries ranges from 150 to 250 W/kg. This means that lithium-ion batteries are capable of delivering higher power output per unit weight, making them more suitable for high-performance applications.

Overall, the graph supports the characteristic comparison between lithium-ion and sodium-ion batteries, showing that lithium-ion batteries have a higher power density, while sodium-ion batteries have a lower cost and longer cycle life. When choosing between these battery types, it is important to consider the specific requirements of the application, as well as the trade-offs between performance, cost, and safety.

3. Energy Density vs. Safety

There is often a tradeoff between energy density and safety when it comes to battery technology. While lithium-ion batteries have a higher energy density than sodium-ion batteries, they are also more prone to thermal runaway and safety concerns. Sodium-ion batteries, on the other hand, have a lower energy density but are generally considered safer. This tradeoff is an important consideration for specific applications, such as electric vehicles where both energy density and safety are important factors.

4. Efficiency

Battery efficiency refers to the amount of energy that can be extracted from the battery compared to the amount of energy that was originally stored. Lithium-ion batteries typically have an efficiency of around 90%, while sodium-ion batteries have a slightly lower efficiency of around 80-85%. Improving battery efficiency is an ongoing area of research and development in the battery industry.

5. Durability

Both lithium-ion and sodium-ion batteries have shown good durability in laboratory conditions, with little capacity degradation over time. However, real-world conditions can be more challenging, especially in high-temperature or high-humidity environments. Research is ongoing to improve the durability of both types of batteries, through the development of new materials and manufacturing processes.

6. Temperature Range

Temperature range is an important consideration for battery technology, as extreme temperatures can affect battery performance and lifespan. Lithium-ion batteries typically operate within a temperature range of -20°C to 60°C, although some newer models can operate at higher temperatures. Sodium-ion batteries, on the other hand, have been shown to operate within a temperature range of -10°C to 50°C. This means that lithium-ion batteries may be better suited for applications in extreme temperatures, such as in electric vehicles operating in hot or cold climates.

7. Fast Charging

Fast charging is an important consideration for many applications, especially electric vehicles. Lithium-ion batteries are known for their fast charging capabilities, with some newer models able to charge up to 80% in as little as 20 minutes. Sodium-ion batteries, on the other hand, typically require longer charging times, with some models taking up to several hours to fully charge.

8. Materials Availability

The availability of raw materials is an important consideration for battery technology. Lithium, for example, is a relatively rare element that is primarily mined in a few countries such as Australia, Chile, and Argentina. This can lead to supply chain issues and price fluctuations. Sodium, on the other hand, is a much more abundant element that is widely available. This makes sodium-ion batteries potentially more attractive for large-scale energy storage applications where the availability of raw materials is a concern.

9. Environmental Impact

Both lithium-ion and sodium-ion batteries have an impact on the environment due to the extraction and processing of the materials used to make the batteries. However, lithium-ion batteries have been found to have a higher environmental impact than sodium-ion batteries. This is because lithium-ion batteries require more energy to manufacture and recycle, and the mining of lithium can lead to environmental damage.

Continuing from the challenges paragraph, another challenge for both lithium-ion and sodium-ion batteries have their environmental impact. While both types of batteries are considered more environmentally friendly than traditional fossil fuels, they still have a significant impact on the environment due to the extraction and processing of the materials used to make the batteries. In addition, the disposal of used batteries can also be a challenge, as they can release toxic chemicals into the environment if not properly handled. Efforts are underway to develop more sustainable methods for the production and disposal of batteries, such as using recycled materials and improving the recycling process. Overall, both lithium-ion and sodium-ion batteries have their advantages and challenges, and the choice between them depends on the specific application and requirements. As technology continues to improve, it is likely that both types of batteries will become more widely adopted in various industries.

Overall, the choice between lithium-ion and sodium-ion batteries depends on a variety of factors, including the specific application, cost, energy density, safety, and environmental impact. Research is ongoing to improve both types of batteries and to develop new battery technologies that may overcome some of the current limitations.

Performance

The performance of a battery can be measured in terms of its specific energy (Wh/kg), specific power (W/kg), and energy efficiency. Specific energy refers to the amount of energy that can be stored per unit weight of the battery, while specific power refers to the amount of power that can be delivered per unit weight of the battery.

The specific energy of lithium-ion batteries typically ranges from 100 to 265 Wh/kg, while the specific energy of sodium-ion batteries ranges from 80 to 150 Wh/kg. This means that lithium-ion batteries have a higher specific energy than sodium-ion batteries, which makes them more suitable for high-energy applications.

The specific power of lithium-ion batteries is also typically higher than that of sodium-ion batteries. Lithium-ion batteries can deliver specific power of up to 5,000 W/kg, while sodium-ion batteries typically have a specific power of around 500 W/kg.

Finally, the energy efficiency of lithium-ion batteries is typically higher than that of sodium-ion batteries. Lithium-ion batteries can have an energy efficiency of up to 95%, while the energy efficiency of sodium-ion batteries typically ranges from 80 to 90%.LIBs have a high energy density and can provide a high power output, which makes them suitable for use in electric vehicles and grid-scale energy storage systems. They also have a long cycle life, which means that they can be charged and discharged many times before they need to be replaced. However, LIBs suffer from a phenomenon known as capacity fade, which reduces their capacity over time. This can be mitigated by using advanced electrode materials and improved battery management systems.

SIBs have a lower energy density than LIBs, which makes them less suitable for use in high-power applications. However, they have a longer cycle life than LIBs and are more resistant to capacity fade. SIBs also have a lower risk of thermal runaway than LIBs, which makes them safer to use. However, SIBs suffer from a lower voltage and lower conductivity than LIBs, which can limit their performance.

What's special about sodium-ion cells?

The Na-ion cells are composed of a Prussian white cathode and a hard carbon anode, which looks to reach 160 Wh/kg, near-lithium iron phosphate (LFP) specific energy.

Compared to the extensively-used lithium-ion (Li-ion) cells, Na-ion cells have a lower energy density and cycle life but perform better in a wide operational temperature range and are safer. Na-ion cells have a similar working principle to Li-ion cells and are expected to be at least 20% cheaper than LFP due to their lithium-free nature. However, separator and electrolyte costs could be significant and result in Na-ion being more costly.

By taking advantage of the low-temperature performance of Na-ion cells – 90% of high-capacity retention at -20 °C – and the high energy density performance of Li-ion cells, CATL aims to combine both cells into the same electric vehicle (EV) battery pack as the AB battery pack for better results.

A lower-cost alternative to Li-ion batteries that eases supply chain pressure?

Raw materials play a key part not only in the performance of the batteries but also in costs. Taking LFP and lithium-manganese-cobalt-oxide (NMC) cells as an example, materials represent 30% and 46%, respectively, of battery pack prices.

By comparison, Na-ion cells are expected to be less sensitive to rising material costs from lithium, cobalt and nickel. If all material prices rise 10%, Na-ion material costs will only increase 0.8%, while LFP and NMC 532 costs will increase 3.2% and 4.6%, respectively.

Na-ion material costs are expected to remain stable over the next 10 years. We expect battery pack prices to continuously fall, but not as dramatically as in earlier years due to rising raw material prices. Na-ion batteries, as a lithium-free technology, have the potential to mitigate the supply chain pressure currently falling on LFP and NMC battery cells.

What does the future hold for Na-ion cells?

Compared to the heavy deployment of Li-ion cells in energy storage sectors, portable electronics, EVs and large-scale energy storage, Na-ion cells are still in research for pilot plant-scale production. But things will change driven by the next-generation technology invocation and cost reduction.

Na-ion batteries are expected to replace some of the LFP shares in passenger EVs and energy storage, reaching 20 GWh by 2030. The cost saving is incredible: the production of 1 GWh Na-ion cells will save 41% of the material expense compared with LFP cells.

By 2030, Na-ion cells will drive 82 kt of aluminium, sodium and hard carbon demand, representing a niche market compared to Li-ion batteries.

Challenges

Despite the advantages of both lithium-ion and sodium-ion batteries, there are still some challenges that need to be addressed before they can become more widely adopted.

One major challenge for lithium-ion batteries is their safety. While lithium-ion batteries have a high energy density and specific power, they are also prone to thermal runaway, which can lead to fires or explosions if the battery is damaged or overheated. This has been a major concern for manufacturers of electric vehicles, which rely heavily on lithium-ion batteries. However, the safety of lithium-ion batteries has been improving over time, with the development of new materials and safety features that help to reduce the risk of thermal runaway.

Another challenge for lithium-ion batteries is their cost. While the cost of lithium-ion batteries has been decreasing rapidly in recent years, they are still relatively expensive compared to other types of batteries. The cost of lithium-ion batteries currently ranges from $100 to $200 per kWh, which makes them less cost-effective than some other battery technologies.

For sodium-ion batteries, one major challenge is their lower energy density and specific power compared to lithium-ion batteries. While sodium-ion batteries have a lower cost than lithium-ion batteries, they still need to be further developed to compete with lithium-ion batteries in terms of their performance.

Conclusion

In conclusion, the comparison between lithium-ion batteries (LIBs) and sodium-ion batteries (SIBs) shows that both have their own set of advantages and disadvantages. LIBs have a higher energy density and power density, making them more suitable for high-energy and high-performance applications. However, they are more expensive and pose safety concerns due to their potential for thermal runaway. SIBs, on the other hand, have a lower energy and power density, but they are less expensive, safer to use, and more abundant.

Overall, the choice between LIBs and SIBs depends on the specific requirements of the application, as well as the trade-offs between performance, cost, and safety. While LIBs are currently more widely used, the availability and low cost of sodium may make SIBs a promising alternative in the future. Ongoing research and development are focused on improving the efficiency, durability, and fast-charging capabilities of both battery types to meet the growing demand for energy storage in various industries.