Development of Rechargeable Batteries, Focusing on Sustainability and Comparison

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Keywords: Rechargeable Batteries, Sustainability, Advantage, Disadvantage.

Abstract: Rechargeable batteries (RBs) have become integral to modern energy storage solutions, with their development accelerating significantly over recent decades. Beginning with Gaston Planté's invention of the first rechargeable battery in 1859, the field saw notable advancements, particularly with the introduction and commercialization. This paper explores various types of RBs, comparing their advantages, disadvantages, and sustainability aspects. Lithium-ion batteries dominate the market but pose environmental challenges due to material extraction and disposal issues. The paper also delves into future development trends, highlighting emerging technologies which promise enhanced performance and safety. Sustainability is still a major issue, highlighting the necessity of efficient recycling and the usage of eco-friendly products. The integration of RBs in renewable energy systems and their role in reducing dependence on fossil fuels underscore their importance. Continued research, global collaboration, and investment are essential to advance rechargeable batteries (RB) technology, ensuring it meets growing demand and supports a sustainable energy future.

1 INTRODUCTION

The development of rechargeable RBs is growing rapidly. People discovered that rechargeable batteries could play an important role. A French physicist brought up the first rechargeable battery; however, rechargeable lithium-ion batteries were not invented until the 1970s (Motoma). The first prototype of a lithium-ion battery was not created until 1985(Motoma). Still, due to its great performance and outstanding feasibility, it made huge developments in the recent decade. The demand of the market also fostered the development of lithium-ion batteries. Different progress in rechargeable batteries is being made at different periods. Harris looks at how soluble lithium is in different types of non-aqueous electrolytes in 1958. This leads to the discovery of a passivation layer that can stop direct chemical reactions between lithium and the electrolyte, which piques interest in studies on this field (Souchay & Désilets, 2020). In the late 1960s market availability of non-aqueous batteries begins (Souchay & Désilets, 2020). Research into rechargeable (secondary) lithium-ion batteries was the main progress made in the 1970s (Souchay & Désilets, 2020). In 1972, Transition metal chalcogenides were evaluated as electrode materials (Souchay & Désilets, 2020). Later, from the late 1970s to the 1980s, Li//MoS2 cells (MOLICELTM) were manufactured (Souchay & Désilets, 2020). And NbSe3 emerged as a cathode element (Souchay & Désilets, 2020). The commercialization of lithium-ion batteries in the 1990s was made possible by other advancements in cathode materials, such as V2O5, which were developed in the late 1980s (Souchay & Désilets, 2020).

The process of charging general rechargeable batteries is primarily based on chemistry, as they store electrical energy in the form of chemical energy. These batteries have two electrodes including cathode and anode and what between them are electrolyte (IQ Direct). During discharge, the battery releases electricity through a chemical reaction at the electrodes, converting chemical energy into electrical energy (Matsusada Precision). The positive electrode will absorb the electron released from the negative electrode (Matsusada Precision). When the battery is recharged, it stores the electricity for future usage, the whole process will now reverse. The positive electrode will release the electron the negative electrode will absorb the electron released (Matsusada Precision). The aim of this paper is to compare the advantage and disadvantage of

Meng, L.
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DOI: 10.5220/0013877400004914

In *Proceedings of the 2nd International Conference on Renewable Energy and Ecosystem (ICREE 2024)*, pages 214-217
ISBN: 978-989-758-776-4

rechargeable batteries and analyse the further development trends.

2 COMPARISON BETWEEN DIFFERENT KINDS OF RECHARGEABLE BATTERIES

Scientists continue to try many different elements to see which can store the most energy and which works best. From 1958 when the Lead-acid battery was first invented to the Aluminum-ion battery which was brought up in the 2010s, scientists have been searching for better and better solutions. Different kinds of batteries have different chemical characteristics. Lead-acid batteries use lead plates and sulfuric acid to make the electrolyte. Nickel hydroxide serves as the cathode in nickel-cadmium batteries, while cadmium serves as the anode and potassium hydroxide serves as the electrolyte. In terms of nickel-metal hydride batteries, potassium hydroxide serves as the electrolyte, nickel hydroxide serves as the cathode, and an alloy anode that absorbs hydrogen is used. In lithium-ion batteries, graphite is the stuff in the anode, while the cathode is made of lithium cobalt oxide, lithium iron phosphate, or other lithium-based materials. The electrolyte is just some lithium salt. Unlike conventional Li-ion batteries, which employ liquid-polymer, lithium-polymer batteries use a solid or gel-like polymer substance. Rechargeable batteries (RBs) are essential for advancing versatile and efficient energy storage technologies, facilitating the global transition from traditional fossil fuels to renewable energy sources (Weiss et al, 2021). Rechargeable batteries (RBs) are widely employed in several sectors and have been shown to improve human well-being by providing us with a multitude of desirable and necessary products (Kim et al, 2019). Since RBs are a kind of renewable energy, they are better for the environment and don't release carbon dioxide when used in place of fossil fuels like extracting oil from the ground. Batteries perform a wide range of tasks, including powering power systems, electric automobiles, wearable technology, space exploration, medical equipment, and smartphone apps (Chao et al, 2020). Rechargeable batteries are most employed in two applications: electric cars and large power systems that use renewable energy sources such as solar, wind, waves, and internal earth heat (Abdul et al, 2020). Since they are lighter than other varieties, lithium-ion batteries (LiBs) are currently among the most often used batteries for electric vehicles (Duan et al, 2023). Recently, the use of electric vehicles has increased due to their ability to emit no emissions (Caneon et al, 2019). Although lithium batteries are seen to be the greatest option for electric vehicles, there may not be enough of them if everyone wants one (Caneon et al, 2019).

Rechargeable batteries have unique advantages and drawbacks. Lithium-ion (Li-ion) batteries are particularly popular, suitable for portable electronics and electric vehicles (Dala et al, 2010). However, they are sensitive to high temperatures and can pose a fire risk if damaged or improperly handled. NiCd batteries, although largely obsolete, are robust and perform well in extreme temperatures, but their use has significantly declined due to toxic metals and the memory effect. Lead-acid batteries have various uses but they are heavy and present significant environmental disposal challenges because of their toxic lead content (Zhang et al, 2022). Each type of rechargeable battery has its specific use cases, determined by its unique properties and limitations.

3 ANALYSIS OF SUSTAINABILITY

The performance of rechargeable batteries is relatively the most significant factor for people to look at. There are many characteristics of rechargeable batteries that count as their performance, gravimetric energy density, volumetric energy density, battery voltage, cycle life, self-discharge per month, charging time, toxicity, overcharge tolerance, and operating temperature range (Liang et al, 2019). Figure 1 shows the comparison of different batteries. As shown in the figure, although the whole performance of Li-ion batteries is good and ideal, the mining of lithium, cobalt, and other rare metals participated, which can cause significant environmental degradation and ethical concerns regarding labor practices (Endalkac, 2023). This is why we always say that recycling batteries is very important. In this way, people can reuse the rear metal and recover valuable materials in the battery without re-extracting them, and it saves the environment significantly. Effective end-of-life management of rechargeable batteries is crucial for sustainability (Endalkac, 2023). If improperly disposed of, these batteries can cause environmental hazards, including fires and the release of toxic substances (Endalkac, 2023). Nickel-metal hydride batteries are more environmentally friendly than lithium-ion and nickel-cadmium batteries, as they avoid the use of toxic cadmium and rely on more abundant materials (Müller & Friedrich, 2006). Improvements in battery technology and recycling methods are crucial for enhancing the sustainability of rechargeable batteries, reducing their environmental footprint, and ensuring a steady supply of essential materials. In summary, while rechargeable batteries are more sustainable than disposable ones, their overall environmental impact depends on advancements in recycling technologies and regulatory frameworks that ensure their safe and efficient end-of-life management (Endalkac, 2023).

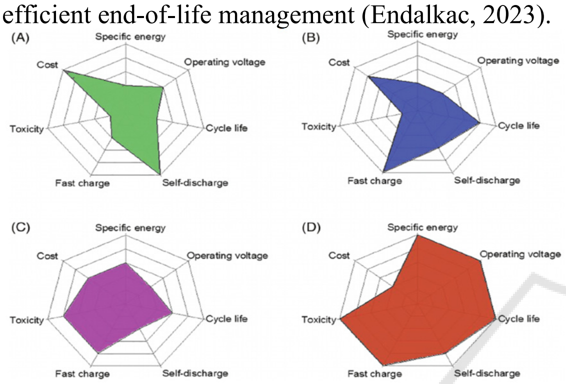

Figure 1. Performance comparison of four kinds of batteries (Müller & Friedrich, 2006)

4 FUTURE DEVELOPMENT OF RECHARGEABLE BATTERIES

Examining new technologies and advancements in rechargeable materials should be our first step in creating better rechargeable batteries. Modern lithium-ion batteries are inferior to solid-state-batteries in terms of safety, energy density, and charging speed. They might completely alter portable electronics and electric vehicles (Endalkac, 2023). Research into lithium-sulfur and lithium-air batteries is also gaining traction, offering the potential for even greater energy storage capacities, which could dramatically extend the range of EVs and the lifespan of portable devices (Endalkac, 2023). Additionally, advancements in nanotechnology and the use of advanced materials like graphene are being explored to improve battery performance, including higher energy densities and longer lifespans (U.S. Environmental Protection Agency). The shift towards sustainable materials is another critical development, with efforts to create cobalt-free and nickel-free batteries aimed at reducing the environmental impact and ethical concerns associated with battery production (U.S. Environmental Protection Agency). Global collaboration and significant investments in research and development by governments, universities, and private companies are vital to accelerate the development of next-generation battery technologies (U.S. Environmental Protection Agency). Efforts to improve battery recycling processes and promote a circular economy are also crucial, ensuring that valuable materials are recovered and reused, thus enhancing the sustainability of future battery technologies (Endalkac, 2023).

5 CONCLUSION

In conclusion, the rapid advancement of rechargeable batteries has significantly transformed energy storage technology. RB technology has advanced significantly, starting with the lead-acid battery's introduction and continuing with the creation and marketing of lithium-ion batteries. These days, lithium-ion batteries are the best option for portable electronics and electric cars due to their high energy density, extended lifespan, and excellent efficiency. These advancements are accompanied by challenges, notably the environmental and ethical concerns associated with the extraction and disposal of materials like lithium and cobalt. The sustainability of RBs hinges on effective recycling and the development of materials which have no negative effect on environment. Advancements in battery chemistry, such as the creation of cobalt-free and nickel-free batteries, aim to reduce the environmental impact and address resource scarcity issues. Moreover, innovations like solid-state, lithium-sulfur, and lithium-air batteries promise to further enhance energy storage capabilities, safety, and environmental sustainability. Solid-state-batteries, for instance, offer more energy per mass unit and faster charging times, potentially revolutionizing the electric vehicle market. Future developments in RB technology are crucial for supporting the global energy transition. Enhanced recycling processes and the promotion of a circular economy will be vital in mitigating environmental hazards and ensuring a sustainable supply of essential materials. Continued research, global collaboration, and substantial investment are necessary to drive these innovations forward, ensuring that RBs can meet the growing demand and contribute to a sustainable and energy-efficient future.

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