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STATE OF THE ART IN BATTERY TECHNOLOGY: INNOVATIONS AND ADVANCEMENTS

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Abstract: This paper examines various types of batteries and their modes of operation in a rapidly evolving technological world. From the definition of batteries and the distinction between cells and batteries, to their history and uses in various applications, this study provides a comprehensive overview of the subject. Primary and secondary batteries are explored, with examples such as alkaline and nickel-metal hydride batteries, highlighting the characteristics of each. Additionally, lithium-ion batteries are examined in detail, including their specific properties and innovative mode of operation. The article also addresses charging and discharging methods, including LiFePO4 technology, providing a comprehensive understanding of these essential components in modern devices.
Key words: batteries, lithium-ion, operation mode, charging

1. INTRODUCTION

A battery is a device that directly converts the chemical energy contained in a drug into electrical energy through an electrochemical redox (oxidation-reduction) reaction. In this type of reaction, the exchange of electrons from one substance to another takes place through an electrical circuit.[1]

Although the term battery is often used, the cell is the actual electrochemical unit used to generate or store electrical energy.[2]

To understand the difference between a cell and a battery, we should think of a battery as one or more cells arranged in pairs in series, parallel or both, depending on the specified voltage and output capacity.[3]

Batteries play a vital role in our lives, providing power to everything from small appliances to cars. They come in various shapes and sizes, each tailored to specific applications and advantages. However, choosing the right type of battery for your needs can sometimes be a perplexing task.[4]–[7]

In 1800, Italian physicist Alessandro Volta invented the first battery, marking a significant milestone in battery technology. Since then, battery innovation has been explored and adopted worldwide.[8]

A battery functions as a device that stores and releases electrical energy through chemical reactions. It is composed of one or more cells, each containing an electrical charge.[8]

- Positive electrode
- Negative electrode
- Electrolyte

When a battery is linked to a circuit, a chemical reaction occurs between the positive and negative electrodes (+ and -). This reaction results in the conversion of expelled chemical energy into electric current.[9], [10]

Currently, batteries play a significant role in environmental protection by reducing CO_2 emissions, as they have the capacity to store electric energy from renewable energy sources.[11] A major global issue today is the pollution generated by ships, as 80% of worldwide transportation occurs through maritime shipping. A potential solution to mitigate this pollution involves generating electric energy onboard ships using renewable sources and storing it in batteries.[12]–[16]

2. TYPES OF BATTERIES

Electrochemical cells and batteries are categorized into two types.[2]

- Primary (non-rechargeable)
- Secondary (rechargeable)

2.1 Primary batteries:

Essential batteries serve as a control source for real devices and gadgets. These include radios, observatories, toys, lights and cameras. It's cheap, easy and convenient to use without a stand.[17]–[19]

They are usually round and hollow like alkaline batteries. A critical battery of this type can be a chemical composed of zinc (Zn) and manganese dioxide (MnO_2).[4], [20]–[22]

Button battery chemistry is also fusible. However, it also contains the chemicals lithium and silver oxide. These connections make this small battery more

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productive and provide a uniform and constant voltage. These include a control current of 270 Wh/kg .[23], [24]

2.2 Secondary batteries

The biggest advantage of these batteries is that they can be recharged and reused. It is therefore also called a rechargeable battery.[3], [25], [26]

Auxiliary batteries usually consume more energy than the backup batteries. However, because it is rechargeable, it lasts a long time. They can be used in two applications.[27]–[30]

- energy storage devices
- applications where the battery is used and discharged as a primary battery.

Once it has been completely or almost completely discharged, it can be fed with charging components. For example, smartphone batteries. Most models have a lithium-ion battery that will last a long time if recharged regularly.[31]–[33]

Another good example is the lead-acid battery found in most cars and vehicles. Lead-acid batteries power the car's lighting system. The nominal voltage is from 2V to 24V and the power density is 7Wh/kg[28], [34]

2.3 Alkaline Batteries:

A water-soluble battery using commercially available primary batteries. They were invented simultaneously but independently by Waldemar Jungner and Thomas Edison. However, early batteries were overshadowed by the first dry antacid developed by Canadian Lewis Alley in the 1950s.[1], [2]

Soluble batteries require zinc as a negative electrode and manganese dioxide as a positive electrode. Both substances are consumed as the battery discharges. Acid batteries are therefore disposable, consumable batteries. Once discharged, it cannot be safely reactivated. Acid-resistant batteries have the lowest price per unit. They deliver reliable performance from start to finish. In other words, you won't notice loss of control until the lead-acid battery reaches the end of its life. Unfortunately, recycling lead-acid batteries is very difficult.[8], [21], [35]

2.4 Lithium Batteries

Lithium-Ion Batteries – A lithium-ion battery is a rechargeable battery variant that consists of a lithium cathode, a typically graphite anode, and an electrolyte. During the charging cycle, lithium ions shift from the cathode to the anode, and they reverse direction during discharge. While charging, lithium compounds decompose into lithium ions, electrons, and other lithium compounds.[1]

Electrons transition from the cathode to the anode via external conductors, while lithium ions traverse from the cathode to the anode through the electrolyte. Simultaneously, current travels from the anode to the cathode. Graphite is predominantly employed as the anode material in most Li-ion batteries due to its intercalated configuration, which effectively captures lithium ions and augments battery capacity. Through a reaction with carbon on the anode, lithium ions and electrons combine to form a lithium carbon compound. This sequence of reactions is inverted when addressing the discharge phase.[1], [2], [36] Li-ion cells typically exhibit extended lifespan, with even the smallest ones designed for approximately 300 cycles, if the battery is discharged to no less than 70% of its maximum storage capacity. Under specific usage conditions specified by the manufacturer, certain Li-ion cells can achieve a longevity exceeding 1000 cycles.[20]

Lithium manganese oxide batteries ($LiMn_2O_4$ or Li-manganese) – This battery type derives its name from the utilization of a manganese-based matrix structure within the cathode. It was developed during the late 1970s and early 1980s, establishing itself as a well-established and dependable cell.[18] Li-manganese batteries exhibit the capacity to handle relatively high-power output in brief bursts while maintaining excellent thermal stability. Consequently, they are regarded as exceptionally safe cells, demonstrating resistance to elevated temperatures and aggressive chemical reactions.[20] These cells can be customized to prioritize either increased power or enhanced energy storage capacity, although this customization comes at a trade-off between the two. The primary drawback of these cell types is their limited lifespan, which is not their strong suit when compared to other lithium-based batteries.[5]

Batteries with lithium and cobalt oxide (LiCoO_2, Li-cobalt, Li-cobalt) – The development of Li-cobalt batteries occurred in tandem with the emergence of Li-manganese batteries, solidifying their position as one of the pioneering lithium-ion battery technologies. These batteries are characterized by their distinctive cathodes, featuring a layered cobalt structure. This structural design was a key innovation at the time and played a vital role in their early success.[18]Li-cobalt batteries gained recognition for their affordability and remarkable energy storage capacity. Their ability to store substantial amounts of electrical energy was a significant advancement, making them suitable for various applications where energy density was a critical factor.[37]However, it's essential to note that Li-cobalt batteries have certain limitations. They typically exhibit a lower nominal current, which means they may not provide as much instantaneous power as some other lithium-ion variants. Additionally, their lifespan tends to be shorter when compared to alternative lithium-ion battery types. This limitation made them less suitable for applications where long-term durability was paramount.[18], [37]

Nonetheless, Li-cobalt batteries have been favored in situations where safety is a top concern. The chemical reactions occurring within these batteries generate

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relatively low temperatures, reducing the risk of overheating and thermal runaway. This inherent safety characteristic has made Li-cobalt batteries a preferred choice in critical applications where stable and secure power sources are essential.[20], [37]

In conclusion, Li-cobalt batteries, which evolved alongside Li-manganese batteries, mark one of the early phases in the history of lithium-ion battery technology. Their cost-efficiency, impressive energy storage capacity, and safety attributes have rendered them indispensable for applications, notwithstanding their constraints regarding current output and longevity.[38]–[40]

Batteries with Lithium Nickel Cobalt Aluminum (NCA) – These batteries bear a striking resemblance to NMC batteries, with their primary distinction lying in the use of aluminum within the cathode instead of manganese. [37]The incorporation of aluminum into the cathode bestows upon these batteries the highest energy storage capacity when compared to all other lithium-ion battery technologies available. However, they are not without their limitations, including a modest reduction in cycle life and power output. Much like NMC batteries, this type holds great promise for driving significant advancements in lithium-ion cell technology in the foreseeable future.[35] NCA batteries excel in their ability to store substantial quantities of electrical energy, making them particularly suitable for applications that demand high energy capacity. When employing larger-sized cells, their relatively lower power output can be effectively compensated for. Tesla's choice to employ NCA batteries in their electric vehicles serves as a prime example of this suitability.[39], [40] Nevertheless, ongoing research in this field remains focused on refining and augmenting the power output of NCA batteries, seeking to further enhance their performance.[9], [21], [24]

3. TECHNICAL SPECIFICATIONS OF BATTERIES

This section explains the significance of the technical specifications of a battery. These specifications may be inscribed on the battery (although it's not mandatory) but are typically found in the product's manual or technical specifications sheet:[8], [21], [23], [24]

Nominal Voltage (V) – The reported or reference voltage of the battery, sometimes also referred to as the battery's "standard" voltage.

Cut-off Voltage – The minimum allowable voltage. Generally, this voltage defines the "empty" state of the battery.

Capacity or Nominal Capacity (Ah for a specific C rate) – When the battery is discharged at a specific discharge current (specified as a C rate) from a 100% charge state to the cut-off voltage. Capacity is calculated by multiplying the discharge current (in amperes) by the discharge time (in hours) and decreases with increasing C rates.

Energy or Nominal Energy (Wh (for a specific C rate)) – The "energy capacity" of the battery, the total watt-hours available when the battery is discharged at a specific discharge current (specified as a C rate) from a 100% charge to the cut-off voltage. Energy is calculated by multiplying the discharge power (in watts) by the discharge time (in hours). Like capacity, energy decreases with increasing C rates.

Cycle Life – The number of charge-discharge cycles a battery can undergo before it no longer meets certain performance criteria. Cycle life is estimated under specific charge and discharge conditions. The actual battery lifespan is affected by the rate and depth of cycles and other conditions such as temperature and humidity. A higher depth of discharge (DOD) results in a shorter cycle life.

Specific Energy (Wh/kg) – The nominal energy of the battery per unit mass, sometimes referred to as gravimetric energy density. Specific energy is a property of the battery's chemistry and packaging. Along with the vehicle's energy consumption, it determines the battery weight required to achieve a specific electric range.

Specific Power (W/kg) – The maximum power available per unit mass. Specific power is a property of the battery's chemistry and packaging. It determines the battery size required to achieve a specific performance target.

Energy Density (Wh/L) – The nominal energy of the battery per unit volume, sometimes referred to as volumetric energy density. Energy density is a property of the battery's chemistry and packaging. Along with the vehicle's energy consumption, it determines the battery size required to achieve a specific electric range.

Power Density (W/L) – The maximum power available per unit volume. Power density is a property of the battery's chemistry and packaging. It determines the battery size required to achieve a specific performance target.

Maximum Continuous Discharge Current – The maximum current at which the battery can be continuously discharged. This limit is typically defined by the battery manufacturer to prevent excessive discharge rates that could damage the battery or reduce its capacity. Together with the maximum continuous power of the motor, it defines the sustainable maximum speed and acceleration of the vehicle.

Charging Voltage – The voltage at which the battery is charged when charged to full capacity. Charging schemes usually involve constant current charging until the battery voltage reaches the charging voltage, followed by constant voltage charging, allowing the charging current to decrease to very low levels.

Float Voltage – The voltage at which the battery is maintained after being charged to 100% State of Charge (SOC) to preserve this capacity by compensating for battery self-discharge.

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Charging Current (Recommended) – The ideal current at which the battery is initially charged (at around 70% SOC) in a constant current charging mode before transitioning to constant voltage charging.
Internal Resistance – The resistance within the battery, typically differing for charging and discharging processes.

4. CONCLUSIONS

This paper highlights the importance of batteries in our everyday lives and categorizes them into two main types: primary batteries and secondary batteries. This division is essential for understanding the uses and advantages of each battery type.

Primary batteries, also known as non-rechargeable batteries, are suitable for devices that require a temporary and efficient power source. These include radios, toys, flashlights, and many other everyday objects. They are convenient and cost-effective, making them a popular choice for most consumers. However, it's important to note that primary batteries are single-use, and once depleted, they cannot be recharged. Additionally, recycling them can be challenging.

In contrast, secondary batteries, or rechargeable batteries, are essential for applications with higher energy consumption and for devices that require a long-term power source. They can be recharged multiple times and are ideal for devices such as mobile phones, laptops, or electric vehicles. Secondary batteries are a cost-effective long-term solution because they can be recharged and reused. However, they may have a shorter lifespan and lower nominal power than primary batteries in certain circumstances.

In addition to clarifying the differences between primary and secondary batteries, the article also provides an important overview of the technical specifications of batteries. These technical data include essential specifications such as nominal voltage, cutoff voltage, nominal capacity, and nominal energy. This information is crucial for choosing and using batteries correctly in various applications.

Furthermore, the article emphasizes a crucial aspect of batteries in the context of environmental protection. Batteries play a significant role in reducing CO2 emissions as they have the ability to store electric energy generated from renewable sources. Thus, they play an essential role in promoting the use of clean energy and sustainable power sources. In a world where pollution from maritime vessels is becoming increasingly problematic, batteries can offer a potential solution by storing electric energy from renewable sources and using it onboard ships, thereby contributing to reducing the negative impact on the environment. Understanding the differences between primary and secondary batteries is crucial for making the right choice based on individual needs and applications. Each type of battery has specific advantages and disadvantages, and the correct choice can lead to cost savings and efficient use of energy resources.

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