Impact of Electric Vehicle Battery Chemistry

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Abstract: ***The electric vehicle (EV) has emerged as one of the most advanced technologies in the green transportation system. Energy storage systems are the most crucial component of economic and environmental concerns in the EV automobile sectors. An essential component of electric vehicle technology, electrochemical batteries have a large market for energy storage systems. When using electrochemical energy storage technologies, it is crucial to understand system cost and lifetime, which result from the challenge of assembling a high - power, high - energy, energy - density, and adaptable electrochemical system. EV application battery features, formation, and comparison of benefits and drawbacks are thoroughly studied in this research. It has been noted that some batteries work well to power EVs. A energy storage system is required for green transportation. This analysis will highlight the benefits of various battery types, making it easier to select the right battery system for an electric vehicle.***

Keywords: Transportation, Electric Vehicle, Electrochemical battery, battery, and technologies

1. Introduction

Electrically propelled vehicles are now more feasible than a few years ago, thanks to lithium - ion (Li - ion) battery advancements [1]. Li - ion batteries' lifespan, safety, power, and energy density needed to be improved, and today, practically all commercial automakers are creating their own completely electric vehicles (EVs) based on this battery technology. However, even though many aspects of Li - ion batteries have improved, electric vehicles (EVs) still fall short of conventional combustion engine vehicles in terms of range, battery longevity, safety, and refuelling time.

The Li - ion battery family is large, and many different chemistries are already on the market. In addition, several chemistries are still in the early stages of development or study [2]. Li - ion batteries have specific qualities and restrictions because of the chemistry they were designed with. Numerous academic studies compare these technologies considering how well they work with electric vehicles (EVs) [3]– [4]. However, it is still very challenging to bring various Li - ion technologies to a common denominator and ensure a fair comparison between them due to the numerous factors that must be considered.

The significance of lithium iron phosphate (LFP) - based batteries has increased steadily since their initial invention in 1996 [5], especially in recent years. Batteries using LFP cathodes are already beginning to be taken into consideration for fully electric vehicles despite their lower energy density. Due to their exceptional qualities, which include a long cycle and calendar lifetime, high power capability (during both charging and discharging), intrinsic safety, a low self - discharge rate, and a very flat discharge curve, they can deliver their maximum power over a broad state - of - charge (SOC) interval [6]. Although certain facets of LFP/C batteries' appropriateness for EVs have been well researched in the literature [7]– [9], in - depth research on their lifetime, when employed for EV applications, is still lacking.

The rest of the paper is organized as follows. Section II addresses the overview of EVs and follows the battery concept explained in Section III. Section III will discuss the different types of battery chemistries. Comparison and conclusions will address sections IV and V.

2. Overview of Electric Vehicle

A viable and sustainable mode of transportation alternative to ICE cars is necessary to reduce global warming, protect the environment, and address oil depletion challenges. Plug - in hybrid electric vehicles (PHEVs), hybrid electric vehicles (HEVs), and ICE cars [8] represent a paradigm shift in transportation. The EV requires electric energy storage for motoring. Batteries or super capacitors are used to make electric energy storage systems. To achieve the necessary voltage or capacity to power the electric motor, all the cells or supercapacitors in a battery pack are linked in series, parallel, or series - parallel fashion [10].

Various types of cells are utilised in a battery pack, including lithium - ion, nickel - metal hydride, and lead acid battery cells [11–12]. The terminal voltage of cells varies from cell to cell and ranges from 2.7 - 4.2 V for lithium - ion batteries to 2 - 3.6 V for nickel - metal hydride batteries. A battery pack comprises modules containing 50–104 cells, depending on the required voltage. The number of battery cells varies depending on the amount of power required, with the Mitsubishi electric car having a 16 - kWh battery, Honda having a 20 - kWh battery, Ford having a 23 - kWh battery, Nissan having a 30 - kWh battery, BMW having a 22 - kWh battery, Mercedes having a 28 - kWh battery, Tesla having a 60 - kWh and 90 - kWh battery [13].

The battery pack that was given to General Motors is made up of 336 spark EV Li - Ion battery cells. A battery module is created by connecting the cells in parallel (each cell is 3.3 V).112 battery modules are connected in series to form a battery pack with a nominal voltage of 368.6 V DC and a maximum voltage of 425 V DC when fully charged. Several manufacturers are now working to enhance the fuel economy of EVs and HEVs to address local, national, and international difficulties. For an EV energy storage system to improve energy savings, small, increased efficiency, and affordability, work must be done on these aspects. Battery affects EV and HEV performance, cost, and life cycle. [14]

3. Battery Concept

A battery is a device that delivers electrical energy and stores energy chemically. Batteries come in two varieties:
1) Primary battery
2) Secondary battery

Primary batteries only produce power once upon discharge. Up until the end of their lifespan, secondary batteries deliver the stored energy cycle - wise (charge and discharge). In EVs, secondary batteries are typically utilized. In an optional battery, electric energy to compound energy (charging time) and substance energy to electric energy (releasing time) happens using electrons giving (oxidation) and electrons tolerating (decrease). Redox reactions, which occur between the positive and negative electrodes, are the names of such reactions [11]. A "cell" is the electrochemical energy storage component that is contained within a battery. To achieve the desired voltage or current, one or more cells in a battery are connected in series or parallel. Figure 3 [12] depicts the fundamental design of a secondary electrochemical cell, which typically consists of the following components:

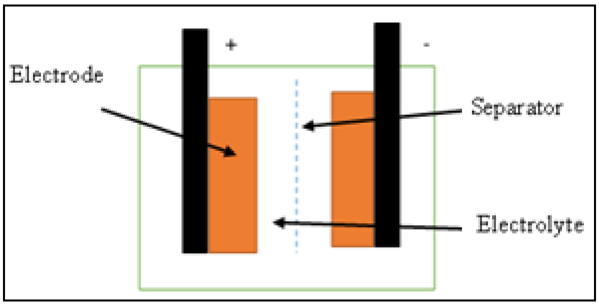

Figure 1: Battery Chemical Properties

a) Anode (Negative Electrode) -
Oxidation takes place at this electrode during the battery cell's electrochemical reaction. The electrode releases electrons about the cathode during this reaction. The anode material chosen for a battery depends on its performance, efficiency, stability, conductivity, cost, and ease of fabrication [13].

b) Cathode (Positive Electrode) -
At this electrode, reduction occurs during the battery cell's electrochemical reaction. The cathode takes up electrons from the anode. A battery cell's cathode material is chosen based on voltage and chemical stability [14].

c) Electrolyte
In a battery cell, the electrolyte is a medium for transferring ions and charge between the anode and cathode during the electrochemical reaction. Solid, gel or liquid electrolyte materials include water or solvent/dissolved salt. The material for the electrolyte is chosen for its non - reactivity with the electrode material, high conductivity, temperature stability, cost, and safety [15]. The voltage will define the difference between a cell's anode and cathode voltages. Combining anode and cathode materials determines the cell voltage and highest capacity. In a cell design, separators provide mechanical isolation between the anode and cathode.

4. Different Battery Chemistries

The anode and cathode electrodes can share electrons to reach the proper electric potential because of the chemical makeup of a battery's cell. The movement of electrons between electrodes. There are many different chemistries, each using different materials that cost different amounts. The cell's chemistry significantly influences the price of the battery. The battery is the most expensive part of an electric vehicle; therefore, keeping production prices low requires careful consideration. The secondary battery chemistry utilized in EVs and offered on the market is described in this section.

4.1 Lead Acid Batteries

In 1860, the first lead - acid battery was created, and it is currently one of the most often rechargeable batteries in use today. Absorbent glass mat batteries and valve - regulated lead acid batteries are the two most typical lead - acid batteries. The hybrid lead acid batteries category includes lead crystal, silver calcium, and other battery types. Lead, sulfuric acid, and lead oxide are the three main substances that make up a lead - acid battery. High voltage per cell, long capacity life, low cost, and outstanding performance at room temperature are just a few of the benefits of lead - acid batteries. But lead acid batteries are large, have a limited lifespan, have a low energy density, and have a significant depth of discharge [16] - [18].

4.2 Nickel - Based Batteries

Nickel - based batteries have become increasingly popular over the past few decades and have proven profitable. An alkaline - based electrolyte that is an aqueous solution from potassium hydroxide (KOH) and oxyhydroxide cathode makes all nickel - based batteries comparable to rechargeable batteries. Among the various nickel - based chemistries, nickel - cadmium (Ni - Cd) and nickel metal hydride (NiMH) are particularly well - liked. In the case of a NiCd cell, Nickel Hydroxide serves as the positive electrode, while Cadmium Hydroxide is the negative electrode. In the case of a NiMH cell, Metal Hydride serves as the negative electrode. Even though nickel - based batteries cost a lot, they have special governing characteristics like the high capacity to deliver continuous power, long service life, and quick recharge, which is important for energy revenue. Nickel - Zinc (NiZn), Nickel - Iron (NiFe), and Nickel - metal Hydride (NiMH) are all forms of nickel - based battery technology. Manganese - zinc, Silver - Hydrogen batteries, and Nickel Hydrogen (NiH) are additional options [17], [19] - [21].

4.3 Li - ion Batteries

Due to their high energy density, specific energy, and capacity to operate at high power, Li - ion batteries are rapidly becoming more common in portable electronic devices like mobile phones, tablets, laptops, digital cameras, toys, and power tools. The energy power pack for HEVs and

EVs, Li - ion batteries, are in high demand in the automotive market. Metal lithium serves as both the positive and negative electrodes in Li - ion batteries. Lithium ions (Li+) move between a battery cell's negative and positive electrodes during a cycle. Typically, graphitic carbon is used as a negative electrode with a layered structure, while metal lithium oxide is used as a positive electrode. On one side, these batteries seem, by all accounts, to be the most positive decision for different applications, given their long life, low upkeep cost, low self - release, high unambiguous power, high unambiguous energy, and high proficiency. However, these batteries must operate with extreme caution due to their limited tolerance for offensive charge and discharge cycles [2], [15], [17], and [26]. The following are the various Li - Ion battery types:

4.3.1. Lithium Cobalt Oxide -

Due to its high specific energy, lithium cobalt is frequently used in digital cameras, laptops, and mobile phones. The battery comprises a graphite carbon anode and a cobalt oxide cathode. Because the cathode is layered, lithium ions flow from the anode to the cathode during discharge. The flow changes when you charge. Li - cobalt has a couple of impediments, including a short life expectancy, unfortunate warm security, and a little burden limit (explicit power). Similar to other cobalt - blended Li - ion batteries, lithium - cobalt batteries have a graphite anode that shortens cycle life due to a changing solid electrolyte interface (SEI), thickening on the anode, and lithium plating when charging quickly and at a low temperature. In recent systems, nickel, manganese, and aluminium increased durability, loading capacity, and cost. Lithium - cobalt batteries should not be charged or discharged at currents higher than C ratings. Consequently, a 2, 400mAh 18650 cell can only be charged and discharged at 2, 400 mA; forced fast charging and loads exceeding 2, 400 mA result in excessive heat and stress. The manufacturer recommends a C - rate of 0.8C, or about 2, 000mA, for the best quick charge. The required battery safety circuit controls the Energy cell's charge rate and discharge to a safe level of approximately 1C [17] - [19].

4.3.2. Lithium Manganese Oxide -

Benefits include improved safety and high thermal stability, but cycle and calendar life is limited. It is possible to discharge high currents and charge quickly thanks to the low internal cell resistance. With little heat buildup, Li - manganese batteries in 18650 packages can discharge at currents of 20–30 A. Load pulses of up to 50A for one second are also possible. Under this current, the cell cannot reach a temperature above 80°C (176°F) under continuous heavy load. Lithium manganese is used in power tools, medical equipment, and hybrid and electric automobiles. Lithium manganese has about a third less capacity than lithium cobalt. Engineers can optimize a battery to have a high capacity, maximum load current, or best lifetime (life span). For example, the moderate limit of the 18650 cell's long - life adaptation is 1, 100mAh, though the high - limit variant is 1, 500mAh [17].

Most lithium - manganese batteries combine with lithium nickel manganese cobalt oxide (NMC) for increased specific energy and longer battery life. Numerous electric vehicles, including the Nissan Leaf, Chevrolet Volt, and BMW i3, use the LMO (NMC) system. This combination brings out each system's best features. LMO, which can boost current during acceleration and provide a long driving range, makes up about 30% of the battery's capacity.

Li - ion research favours using Li - manganese as the active cathode material alongside cobalt, nickel, manganese, and aluminium. In some architectural designs, the anode may contain a small amount of silicon. Since silicon expands and contracts with charge and discharge, mechanical stress on the device increases capacity by 25%, but the gain can sometimes be accompanied by a shorter cycle life [15].

In addition to silicon enhancement, selecting one of these three active metals to enhance a specific energy (capacity), power (load capability), or life is simple. Consumer batteries prioritize large capacity, whereas industrial applications require battery systems with good loading capabilities, long life, and safe and dependable service. [18].

4.3.3. Lithium Nickel Manganese Cobalt Oxide -

One of the most efficient Li - ion systems is the nickel - manganese - cobalt (NMC) cathode combination. Power and Energy Cells can be made of these systems, like Li - manganese. The maximum capacity of a silicon - based anode is 4, 000mAh, albeit with a reduced loading capability and a shorter cycle life. For instance, NMC in a 18650 cell optimized for specific power has a capacity of approximately 2, 000mAh but generates a continuous discharge current of 20A. On the other hand, NMC in the same cell optimized for moderate load situations has a capacity of approximately 2, 800mAh and can deliver 4A to 5A. The anode of graphite expands and contracts with charge and discharge, making the cell mechanically unstable [17], which is a drawback of adding silicon to the material.

The key to NMC is manganese and nickel together. Manganese has the advantage of developing a spinel structure with low specific energy but low internal resistance. Nickel is renowned for its low stability despite its high specific energy. The combined strengths of the metals are increased. NMC batteries are the primary power source for power tools, e - bikes, and other electric vehicles. The cathode combination, known as 1 - 1 - 1, consists of one - third of manganese, cobalt, and nickel. Cobalt is hard to come by and expensive. Cobalt concentrations are reduced in batteries while performance is sacrificed [19]. An efficient combination is NCM532, which consists of 5 parts nickel, 3 parts cobalt, and 2 parts manganese. There are additional combinations, NMC622 and NMC811. Cobalt stabilizes nickel, an active material with high energy. NMC - blended Li - ion is becoming increasingly popular due to its low cost and high performance. Combining the three active components of nickel, manganese, and cobalt can easily accommodate various automotive and energy storage system applications.

4.3.4. Lithium Iron Phosphate -

Li - phosphate has excellent electrochemical properties and low resistance. This is made possible by a nanoscale phosphate cathode material. The primary benefits are a high current rating, a long cycle life, outstanding thermal stability, increased safety, and abuse tolerance [20]. In return, its lower specific energy falls below lithium - ion with a cobalt blend due to its lower nominal voltage of 3.2V per cell. Li - phosphate batteries aren't any different; They, like most batteries, perform worse in cold temperatures and last less long in warmer storage conditions. As a result of their higher self - discharge rate than conventional Li - ion batteries, Li - phosphate batteries may experience issues with balancing over time. This can be reduced by purchasing high - quality cells and employing cutting - edge control electronics, which increase pack costs. Cleanliness in production is essential for longevity. There is no tolerance for moisture; [21]– [23] The battery can only run for 50 cycles.

When four Li - phosphate cells are connected in series, the appropriate full - charge voltage for each cell is 3.60V. Now is the time to turn the charge off; Nevertheless, it continues to top off while you are driving. Li - phosphate can withstand a small overcharge; However, holding the voltage at 14.40V for an extended period, as most automobiles do when travel for long distances, may stress the Li - phosphate.

4.3.5. Lithium Nickel Cobalt Aluminum Oxide -

The battery's chemistry is like the NMC's because it has a long lifespan, good specific power, and high specific energy. Safety and expense are less flattering. The cell chemistry of lithium nickel manganese cobalt oxide offers the advantage of modulating characteristics for use as a power or energy cell. These chemistries have the same energy densities as lithium cobalt oxide, even though they are carried out in energy cells. When applied as a power cell, the particular energy is dense to values between 100 - 150Wh/kg, while the particular power goes the most extreme with a battery temperature of over 300C. Contingent upon the arrangement, these batteries are utilized in the car area and on backup in movable gear [15] - [17].

4.3.6. Lithium Titanate -

Li - titanate batteries can be quickly charged with a nominal cell voltage of 2.40V and a high discharge current of 10C, or 10 times their rated capacity. The cycle count is claimed to be higher than a typical Li - ion. Li - titanate is safe, has excellent low - temperature discharge properties, and can hold 80% of its weight at - 30 degrees Celsius (- 22 degrees Fahrenheit). Compared to the conventional cobalt - blended Li - ion with a graphite anode, LTO (also known as Li4Ti5O12) achieves zero - strain properties, does not require SEI film development, and does not require lithium plating when fast charging and charging at low temperatures. Despite its high cost, the battery outperforms standard Li - ion systems regarding high - temperature thermal stability. With approximately 65Wh/kg, the specific energy is comparable to NiCd's. Lithium titanate discharges at 1.80V/per cell and recharges at 2.80V per cell [24].

5. Comparison of different battery chemistries used in EV vehicles

Specifications	Lithium Manganese Oxide	Lithium Nickel Manganese Cobalt Oxide	Lithium Cobalt Oxide	Lithium Iron Phosphate	Lithium Nickel Cobalt Aluminum Oxide	Lithium Titanate
Symbol	LMO	NMC	LCO	LFP	NCA	LTO
Cell voltage	3.70 V nominal voltage 3.80V	3.60 V, 3.70V nominal voltage	3.60 V	3.20 V, 3.30V nominal voltage	3.60 V, nominal voltage	2.40 V, nominal voltage
Operating Range	3.0 to 4.2 V / cell	3.0 to 4.2 V / cell or high	3.0 to 4.2 V / cell	2.5 to 3.65 V / cell	3.0 – 4.2 V / cell	1.8 – 2.85 V / cell
Specific Energy (capacity)	100 - 150Wh/kg	150 - 220 Wh/kg	150 - 200Wh/kg.	90 - 120 Wh/kg	200 - 260 Wh/kg	50 - 80 Wh/kg
Charge (C - rate)	0.7 - 1C, the charges to 4.2V for most of the cells	0.7 - 1C, the charges to 4.2V for most of the cells	0.7 - 1C, the charges to 4.2V for most of the cells (3h charge is nominal).	1C typical, charges to 3.65V	1C typical, charges to 4.20 V	1C typical, charges to 2.85 V
Discharge (C - rate)	2.50 V is cut off.	2.50 V is cut off.	2.50 V is cut off.1C shortens the battery life.	2.50 V is cut off.	3.00 V is cut off.	1.80 V is cut off.
Life cycle	500 - 1000	1000 - 2000	500 - 1000	2000 and high	500	3000 - 7000
Thermal runaway	250'C	210'C (typically 410'F)	150'C	270'C (typically 518'F)	150'C (302'F)	It is one of the safe Li - ion battery

6. Conclusions

This paper discusses the EV battery technologies that will be helpful for future research and selecting suitable batteries for EV applications. EV applications' batteries depend on short and long - run energy storage systems. Electrochemical batteries are primarily considered for EV applications due to their high energy and power density, high specific energy, low resistance, flat discharge profile, less memory effect, good overcharge and undercharge tolerance, performance over a wide temperature range, and long cycle life. Still, EV battery technologies are very interesting for researchers to develop the features.

This study focused on the effects of various battery chemistries on electric vehicles. Observations and surveys indicate that one advantage of this transition is a reduction in the cobalt content of the cathode. NCM chemistries are projected to sustain EV Li - ion batteries well into this decade, making batteries more accessible and denser. A separate cathode substance, Lithium Iron Phosphate (LiFePO4, LFP), has also made a name for itself in the commercial electric vehicle batteries market. LFP is more affordable, has better intrinsic thermal stability, and has a lower energy density when compared to NMC materials. The greater thermal stability of LFP batteries enables simple pack designs. LFP batteries containing cells may occasionally be combined into packs (cell to pack) without going through module - level packaging. This approach lowers costs and improves packaging efficiency, improving energy densities, and driving range.

Conflicts of Interest

The authors declare no conflict of interest.

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