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Lithium-ion battery in Electric vehicles and its distinctiveness

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Abstract - *Lithium-ion battery (LIB) currently powers most of the electrical and electronic appliances/devices. Even though this technology is still evolving; this paper critically reviews the emergence and the evolution of the LIB battery. It also covers the working principle, chemistry involved, types, etc. This paper also provides the advantages of using this battery in Electric Vehicles in depth with case studies.*

Key Words- Lithium-ion battery, Electric Vehicle, Hybrid Electric Vehicle.

1.INTRODUCTION

Since the early 1800s, Electric automobiles have been in use, but they were not successful enough due to the lack of charging facilities, high maintenance, and limited driving range, hence there was a shift from electrically driven vehicles to gasoline-fuelled vehicles. But we know that traditional IC engine automobiles create a negative impact on the environment, as a result of emission of CO_2, SO_2, NO_x, Carbon monoxide, which lead to air pollution. Hence a viable solution for this issue is shifting back to electric mobility. Why shifting back to electric mobility? The recent growth in technology has helped to overcome the limitations which were a hindrance in the past and the major shifting towards e-mobility is due to excessive emissions of pollutants, limited source and high pricing of gasoline.

There are many types of electric vehicles (EV) such as Battery electric vehicles (BEV), Plug-in Hybrid electric vehicles (PHEV), Hybrid electric vehicles (HEV), Fuel-cell Electric vehicles (FCEV). In 2015 China has become the largest market for EVs. Though there are various types of electric vehicles, the heart of an electric vehicle is a battery. It is the replacement for the fuels used nowadays.

There are many types of batteries used in the electric vehicle. They are Lithium-ion batteries, Nickel-metal hydride (Ni-MH), Lead-acid (PbAc), Nickel Cadmium (NiCd), ultracapacitors (UC), sodium **nickel** chloride ("zebra") batteries. The predominantly used battery is a Lithium-ion battery. Why does EV rely on the lithium-ion battery over other batteries? It is because of its less self-discharging nature, less maintenance, reasonable cost, large charge-discharge cycle, great reliability and adaptability, abundant nature of Lithium (Use of li-ion batteries in EVs). Also, it plays a minor role regarding the environmental burdens. Another point is that lithium has a high tendency to lose electrons from its outer shell, due to this lithium is very reactive, hence, it is used in batteries.

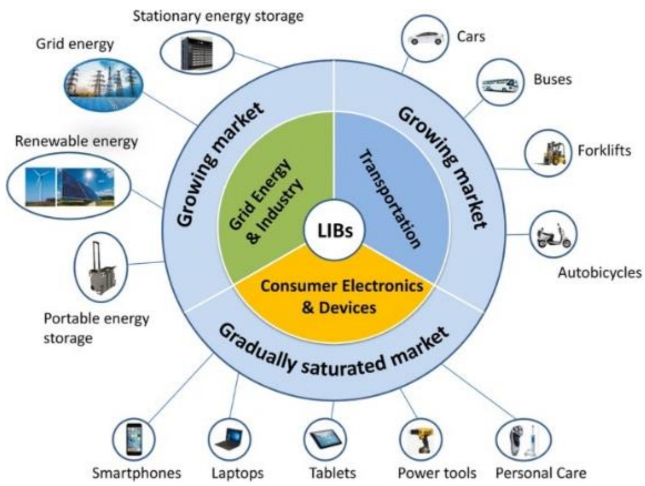

Fig 1. Applications of LIB [12]

In 2018, global sales of Li-ion batteries used in passenger electric vehicles reached 65.1 GWh showing a year-on increase of 81% [1]. Though we await the potential development of innovations in solid-state batteries, lithium-ion technology today represents the best compromise between capacity, volume, and mass in the electric mobility sector [1].

2. HISTORY OF LI-ION

LIB was created in 1970 when there was an oil crisis. this was a replacement for oil [2]. It was rather created unaware. A scientist named Akira Yoshino who worked at Meiji university in Nagoya, Japan used petrol coke anode instead of lithium, which was the prototype of LIB. The first commercial LIB was developed by a Sony and Asahi Kasei team led by Yoshio Nishi in 1991.

3. LIB IN EVs

While we await the potential development of innovations in solid-state batteries, lithium-ion technology today represents the best compromise between capacity, volume, and mass in the electric mobility sector [3]. Hence, the standard battery used in modern electric vehicles is considered to be Lithium-ion batteries [1]. In the current era, there are variations made in LIB chemistries that sacrifice energy and specific power to provide fire resistance, environmental friendliness, rapid charging, and long lifespans in EVs(wiki). LIBs also have to charge and discharge cycles, just like other batteries. The charging occurs when the car is plugged in, and the discharging cycle occurs while driving.

Fig 2. LIB Used in EVs

4. WORKING OF LIB:

In a LIB the anode used is graphite and the cathode used in Lithium-ion along with manganese/cobalt/nickel etc. The electrolyte is comprised of lithium salts such as Lithium Phosphorous Fluorite (LiPF6) Lithium atom contains an electron in the outermost shell in turn which makes it very unstable. But in metal oxides, lithium atoms are very stable. When a power source is connected to the battery, electrons are attracted to the positive side. Just like other batteries, there is an electrode present between the anode and the cathode of the LIB.

The electrolyte prohibits the flow of electrons, instead, the electrons flow through the external circuit and get trapped in the graphite layer. Lithium-ion also gets trapped in the graphite layer. Eventually, lithium ions are stored with higher electrochemical potential.

This process is called charging. Nowadays silicon is used as anode instead of graphite, by this the energy density is increased by 4.4 times but, silicon expands and compresses in volume during each cycle. Thus, manufacturers are using 5% silicon along with graphite.

When the power source is removed and the load is connected (device or equipment) is connected, all the electrons flow through the load and hence electricity is achieved. This process is called discharge.

The battery is connected to one or more electric motors, which drive the wheels when you press the accelerator the car instantly feeds power to the motor, which gradually consumes the energy stored in the batteries.

5. SORTING OF LITHIUM-ION BATTERIES [4]:

Usually, Lithium-ion batteries are sorted, it is because each battery depends on various parameters for their efficiency and performance, hence sorting helps in improving the efficiency and performance of the battery.

i. Single parameter sorting method
ii. Multi-parameter sorting method
iii. Dynamic character sorting method
iv. Model sorting method

i. Single parameter sorting method

There are 3 parameters considered during sorting in this method. They are internal resistance, open-circuit voltage (OCV), multi-point spectral impedance of the battery (MPSI).

This method has its advantages and disadvantages. The advantage of the internal resistance sorting method is that it is simple to carry on. But the drawback of this method is its less accuracy, open-loop, and can be easily affected by temperature. Similar to the internal resistance sorting method, the OCV process is easy. The disadvantage of this method is that it is less accurate and is sensitive to voltage sensor precision. Unlike the above 2 methods, MPSI is more accurate and it also reflects the internal information of the battery, but it reflects the characteristics of the battery in a particular state.

ii. Multi-parameter sorting method

This method of sorting is done using these parameters, they are capacity+OCV+internal resistance (COI), Voltage charging time ratio + self-discharge rate (VS), OCV+short circuit current+internal resistance+maximum PowerPoint (OSIM).

The benefits of the COI method are that they are generic and accurate. The limitations of this method are that they are time-consuming and complex. Apart from the advantages of COI, the OSIM sorting method is more comprehensive, but it is very difficult to obtain data and it is having a complex structure.

iii. Dynamic character sorting method

In this method the batteries are sorted using this parameter, i.e., pulse charging and discharging under different conditions (PCD), voltage curve under different capacity curves at different temperature (VCT).

The merits of this PCD method are it also generic and reflects the dynamic information of the battery, but it is not comprehensive enough. Apart from the simple process, generic nature the data extraction in the VCT method is quite easy. The demerit of this method is that it is sensitive to the collecting data.

iv. Model sorting method

Two models are considered for this type of sorting, they are the Thevenin model, Partnership for a new generation of vehicles (PNGV) model.

The pros of the Thevenin model are that it also reflects the battery dynamic characteristics but it requires a large number of computations.

The benefit of the PNGV method is that it has higher accuracy than the Thevenin model but it has too many parameters and has a complex model.

6. VARIETIES OF CHEMISTRIES IN LI-ION:

Although lithium is a key ingredient in lithium-ion batteries, they also include other metals, such as cobalt, graphite and nickel, manganese, titanate, iron, phosphate.

These extra included metals decide the chemistry of the battery, and each chemistry has its advantages as well as disadvantages. There are various types of chemistries in Li-ion battery, which are:

i. Lithium cobalt oxide (LCO)
ii. Lithium nickel manganese cobalt oxide (NMC)
iii. Lithium manganese oxide (LMO)
iv. Lithium titanate
v. Lithium iron phosphate (LFP)
vi. Lithium nickel cobalt aluminum oxide (LNCA)

i. Lithium cobalt oxide:

Lithium cobalt oxide batteries constitute lithium carbonate and cobalt which provide stable capacities along with high specific energy. Internally, it is composed of cobalt oxide as cathode, carbon graphite as anode, and lithium salt as electrolyte. Cobalt is chosen as a critical element in cathode materials since it enables increased energy density and structural stability.

These batteries have high energy densities leading to a long run time. Also, LCO is said to have comparatively better cyclingperformance, low-temperature dissipation, than that of other existing chemistries.

On the other hand, LCO has its drawbacks, one of which is its resource. The total cobalt resources in the world are limited. Also, the cost of cobalt is high. Due to overcharging, there are heating issues in this battery, which may tend to the explosion of the battery. The majority of research is currently focusing on the cathode and electrolyte solution to improve the technology of LCO.

ii. Lithium nickel manganese cobalt oxide:

One of the most successful Li-ion chemistries used in the automotive battery industry is the combination of nickel, manganese, and cobalt in the form of an oxide, which is used as the cathode [4]. The anode used in this battery is graphite similar to other chemistries.

Even though the cobalt content in this battery is low, the specific capacity of this battery is similar or comparatively higher to LCO [5]. Since the cobalt content in NMC is less, it is less expensive. Electric vehicle industries prefer using NMC battery technology, due to its low self-heating rate [4].

This battery can have either a high specific energy density or a high specific power. They cannot, however, have both of the above-mentioned properties. Another drawback of this battery is that the decomposition in the electrolyte leads to a higher operating voltage.

As this battery has a higher percentage of nickel, battery manufacturers are considering switching to this battery chemistry so that they can use less cobalt, which in turn leads to a lowering of the battery's price [5].

iii. Lithium manganese oxide:

This battery consists of Lithium metal as its anode and Mno2(treated at 350°) as its cathode and its electrolyte is Lithium Halide (dissolved in organic solvent). Usually, the battery is packed in an aluminum shell.

Its major advantage is that it has a very long lifespan, so it is used in security alarms such as fire and smoke alarms. Another advantage of this battery is that its initially setting up and the manufacturing cost is very low. The battery is usually granulated with aluminum, which helps it to improve its high-temperature performance as well as its cycling performance.

The drawbacks of this battery are that its cycling life is relatively short, and it is prone to bulge. It is also not available in small sizes. Due to the low price and abundant resources of manganese oxide, it is easier to be produced as compared to that of other Li-ion batteries.

iv. Lithium titanate:

Lithium titanate is also similar to that of a typical lithium-ion battery because it uses Li titanate crystals instead of graphite, which is used as an anode.

As the battery is composed of Li titanate crystals as its anode, its surface area is larger compared to that of graphite, hence the electrons enter and leave the anode quickly, which in turn, increases the rate of recharging and the amount of current supplied. Another advantage of this battery is that it has a higher charge cycle and a longer life span.

The major drawback of this battery is that it has a lower inherent voltage as compared to the conventional Li-ion batteries which lead to lower specific energy. And another disadvantage of this battery is that it is very expensive compared to that of a Li-ion battery.

Titanate batteries are currently used in some electric vehicles (even in some sports cars), mobile appliances, car radio applications due to their higher level of safety and recharge capabilities.

v. Lithium-ion phosphate:

The first model of the lithium iron phosphate battery was made after the discovery of phosphate for usage in lithium-ion batteries in 1996 [6]. The cathode used in this battery is $LiFePO_4$ and the anode used is graphite [6].

The major distinction that LFP has over other batteries is that it has a higher charge cycle [6]. It also capable of producing constant voltage over a long period. This battery is more tolerant to full charge conditions and is less stressed than other Li-ion systems if kept at high voltage for a prolonged time [4]. LFP has high self-discharge compared to other battery chemistries. The heat dissipation in this battery is very low, hence it is considered to be safe for home use [6].

Like all chemistries, Iron phosphate also has its disadvantages, like, less energy for given volume/weight and more sensitivity to storage at higher temperatures, and poor performance at a lower temperature [7].

This battery is used in the applications of cars, bicycles and solar devices, heavy-duty vehicles like buses, trucks due to their capability of delivering constant voltage and providing safe discharge [6][4].

The rising demand for hybrid electric vehicles and electric vehicles with growing environmental apprehensions and high requirement for lithium iron phosphate (LiFePO4) batteries in battery energy storage systems are driving the market. Hence, increasing focus on energy storage technologies is a major factor boosting the market growth [8].

vi. Lithium nickel cobalt aluminium oxide:

Lithium nickel cobalt aluminum oxide battery is made of a group of substances that consists of metal oxides. The cathode used in this battery is Lithium nickel cobalt aluminum oxide and the anode is graphite. In the NCA battery, the expensive cobalt (which is used in a conventional Li-ion battery) is replaced by nickel.

It features high specific energy, high thermal stability, provides good specific power, and a decent life span. This battery is also available in different volume capacities. The major drawback of this battery is its low level of safety in comparison with other Li-ion batteries. The aluminum ions in NCA make the battery stable and safe, but the ions themselves do not help in the redox reaction taking place in the battery, due to which the capacity of the battery reduces.

These batteries are majorly used in electric powertrains in EVs, and electronic devices, due to their high specific energy and moderate life span.

To make NCA operate at a higher temperature, it is usually coated. The materials used for coating are aluminum fluoride AlF_3 and crystalline oxides or glassy oxides.

7. FAILURES IN LI-ION BATTERY [9]:

Lithium-ion batteries are becoming commonplace in recent electric vehicles however, the failures in it can cause major harm to the vehicle. An enormous number of physical and chemical factors contribute to lithium-ion degradation. Some of the main sources of failures in the Li-Ion Batteries are

1. Chemical Failures.

2. Thermal Failures.
3. Anode Failures.
4. Cathode Failures.

7.1 Chemical failures:

Chemical failures occur due to reactions happening among the chemicals in the battery. These are caused due to electrolyte decomposition and reduction, binder decomposition, loss of lithium, solid electrolyte interface formation, gas evolution, fabrication of the battery component, and history of its usage.

7.2 Thermal failures:

Thermal failures are failures where unwanted heat is dissipated from the battery. The roots of this failure are poor design and integration of the battery, deficient safety monitoring of the battery, substandard manufacturing, poor handling.

7.3 Anode failures:

i. Solid electrolyte interphase (SEI) growth:

A passivated layer is formed on the negative electrode surfaces from the decomposition product of the electrolyte. In the case of the SEI formation, there is a hindrance of electrolyte molecules to travel the layer to the active material surface where they can react with lithium ions and electrons. Thus, the formation of this layer causes internal battery loss and reduces the life span of the battery.

ii. Lithium plating:

In this condition, the lithium-ion deposits itself at inactive metallic lithium which degrades the battery life. In addition to this, active lithium plating leads to capacity loss, frequent short circuits, and instant battery failure.

iii. Anode loss of contact:

Anode loss of contact occurs among various entities of the battery such as between graphite particles, graphite and the current collector (such as aluminum/copper foil), graphite and binder, between current collector and binder which causes higher cell impedance. The anode active material allows the electrolyte to penetrate through it, making it more porous, which degrades the battery, reducing its lifetime.

iv. Electrolyte decomposition:

The electrolyte is decomposed which is influenced due to the thermal impact on the battery.

v. Formation of lithium grains:

One of the most undesirable reactions in the anode is the formation of Lithium grains. The formation of Lithium grains leads to the aging of the battery. Hence, the lithium cations are not transported to the electrode surface and may cause electrostatic failure in the battery.

electrode surface and may cause electrostatic failure in the battery.

7.4 Cathode failures:

i. Structural changes and mechanical stress.

Mechanical stress in the battery influences the cathode more than the anode. Hence during the delithiation process, there is a distortion in the crystal lattice of the cathode leading to mechanical stress in LIB.

ii. Active material dissolution.

Due to several physiochemical processes, the cathode is dissolved. Especially in lithium manganese oxide, manganese dissolute into the electrolyte contributing to the aging of the battery. The dissolved manganese ions will travel to the anode and forms an SEI layer on it leading to the internal impedance of the battery.

iii. Active material isolation.

Due to active material isolation, the following disadvantages occur:

- Crack formation on the active material and its fragmentation.
- Breaking of the binder.

iv. Oxidation of electrolytes.

The process of oxidation means the loss of an electron from the outer shell of an atom. Oxidation is a common process in a battery but, the electrolyte oxidation on the surface of the cathode leads to degradation of the lithium-ion battery under normal operating conditions.

8. SECOND LIFE OF LIB:

LIBs can be recycled or reused right after they are used in EVs. The reutilization stage is known as the second life of the battery. Automotive LIBs usually must be retired from EVs when their capacity falls below 70% to 80% of the initial value according to automotive standards [13]. Second-life applications of LIBs are mainly stationary and are not like in EVs, such as for residential uses.

9. MANUFACTURING OF LIBs:

A large number of industries are involved in the production of Lithium-ion batteries which includes the selection of raw material up to the final product. They are,

i) Mining industry - raw materials
ii) Inorganic chemical industry - cathode materials
iii) Organic chemical industry - electrolytes
iv) Polymer chemical industry - binder and separator
v) Metal industry - can and electrode foils
vi) Electronic industry - Battery management system (BMS)

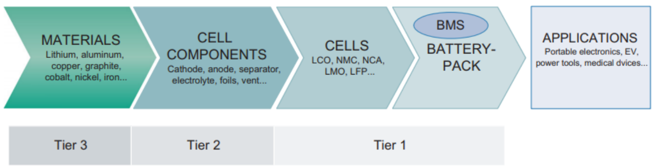

Fig 3.[9] Manufacturing stages of LIB

The main requirement for the production of the Li-ion battery is nothing but Lithium & graphite [10].

The top countries producing lithium are Australia, China, New Zealand, Portugal, Brazil, USA. Western Australia accounts for around half of global lithium productions.

The top producers of Graphite are China, India, Brazil.

How is Lithium mined?

Lithium is often recovered in 2 ways. One way is that mining from hard rock ores which are rich in Lithium, I.e., Ores are crushed, then chemicals, such as sulfuric acid are used to separate Li from the rest of the rock [11]. The second way is from brines. This process is the most convenient method but a very lengthy process. Brines are usually drilled which are present underground and are filtered to separate them from solid precipitators, and then are distributed on large ponds to evaporate excess water and other salts.

10. DISADVANTAGES OF LITHIUM-ION BATTERY:

Even though the batteries used in the electric vehicle are considered to emission-free many studies claim that the production of LIBs still causes emissions.

And, when it comes to manufacturing it cost 40% more compared to that of NiMH [14].

Usually, in EVs, a large number of large-capacity batteries are connected in series and parallel, so it leads to the deficit of space for the accommodation of the batteries in the vehicle.

CONCLUSION:

This paper presents a review on the battery used in Electric vehicles, their characteristics, chemistries, failures, and sorting, etc.

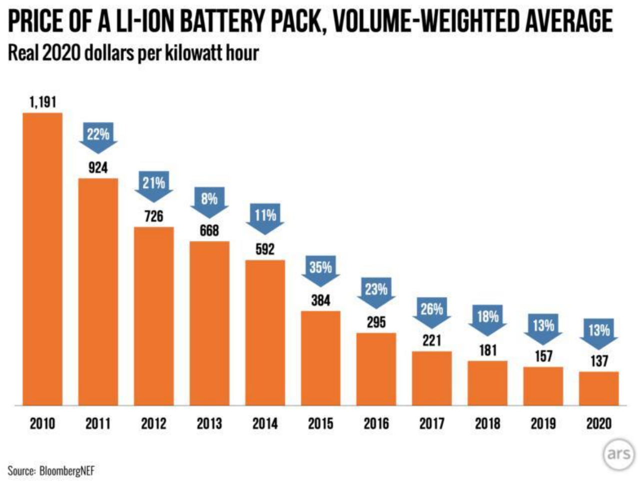

Fig 4. Price variation in the past decade [15]

Major breakthroughs are yet to bloom in the chemistries of the battery such as Ni-rich NMC and silicon. Though LIB is the most commonly used battery in EVs, yet various research is conducted regarding the chemistries, anode, cathode and separator materials. Also, as the demand rises, the price of the battery has been consistently reducing, and is set to reduce even more in the further years. Hence this connection with Lithium-ion batteries is not expected to cool down any time soon.

REFERENCES

[1] The-Lithium-Ion-Battery-and-the-Electric-Vehicle-Whitepaper.pdf (interactanalysis.com)

[2] A Brief History of Lithium-Ion Battery Development (hidenanalytical.com)

[3] chen 2019 review of li - ion battery - a review of lithium-ion battery application in electric vehicle and beyond.

[4] Automotive Li-ion batteries: Current status and future perspectives

[5] 6 Lithium-ion Battery Types for Investors to Know About | INN (investingnews.com)

[6] What is a Lithium Iron Phosphate Battery (LFP Battery)? - Definition from Techopedia

[7] When to choose lithium-iron phosphate batteries - Electronic Products

[8] Lithium Iron Phosphate Battery Market Size Report, 2020-2027 (grandviewresearch.com)

[9] Concept of reliability and safety assessment of lithium-ion batteries in electric vehicles: Basics, progress, and challenges, Foad H. Gandoman*, Joris Jaguemont, Shovon Goutam, Rahul Gopalakrishnan, Yousef Firouz, Theodoros Kalogiannis, Noshin Omar, Joeri Van Mierlo.

[10] The lithium-ion battery: State of the art and future perspectives

[11] What is Lithium Extraction and How Does It Work? (samcotech.com)

[12] Automotive Li-Ion Batteries: Current Status and Future Perspectives | SpringerLink

[13] Experimental assessment of cycling ageing of lithium-ion second-life batteries from electric vehicles.

[14] Lithium Batteries in Electric Cars (metapress.com)

[15] Battery prices have fallen 88 percent over the last decade | Ars Technica