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Review of Types of Batteries in Electric Vehicles

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Abstract - *Battery powered electric vehicle are starting to play a significant role in today's automotive industry. The importance of batteries for electric vehicles is equivalent to the importance of the heart to people. The battery can provide energy for electric vehicles and increase the power of electric vehicles, for this reason vehicle electric vehicle manufacturers should have a deeper understanding of the performance of electric vehicles. There are many batteries found in the construction of today's electric vehicle being hard to decide which one fulfils the best all the most important characteristics, from different view point, such as energy storage efficiency, constructive characteristics, cost price, and safety and utilization life. The study represents the autonomy of an Electric Vehicle that utilizes different types of batteries such as Lithium Ion (Li-ion), lead acid battery, Nickel Metal Hydride (Ni-MHM) anthem study also represents the comparison of batteries, battery performance and some future battery outlook such as sodium- ion batteries, Aluminium air battery, Nano wire batteries, Graphene batteries etc.*

***Key Words*: Electric vehicle, Types of batteries, Lead acid, Ni-MH, Lithium-ion battery**

1. INTRODUCTION

Due to high demand of fossil fuels on the international markets together with the aggravation of environment problems caused by an increased number of internal combustion engine v1ehicles, there is an increased interest in the research and development of batteries used in electric and hybrid vehicles. These vehicles represent a solution for the future in road transportation field, taking into consideration the interest in reducing greenhouse gas emissions, as well as air and sound pollution. Electrochemical storage includes various battery technologies that use different chemical compounds to store electricity.

According to transportation sector represents one of the determinant factors of climatic changes, 23% of the greenhouse gases from the atmosphere coming from this sector, being second in this classification after the industrial sector. Hence to reduce the global warming the electric vehicles must run on the road. Also, electric vehicles have higher efficiency, less noisy, no need in gearbox, transmission/motor oils, timing belts etc. Hence study of batteries must be done properly. Properties such as cost, efficiency are the main factor for electric vehicle. Hence different types of batteries such as Lead acid battery, Nickel-cadmium battery and lithium-ion battery are required.

Although Li-Ion batteries are now in an advanced development stage, close to the theoretical values obtained through researches, this type of battery cannot yet satisfy requests regarding especially the autonomy. Hence research should be done on batteries for the advanced development in electric vehicles.

2. LEAD ACID BATTERY

Lead acid is a commercial battery. In lead acid battery positive electrode consist of lead dioxide (PbO2) and negative electrode is of lead. Electrolyte in lead acid battery is sulphury acid(H2SO4). The charging and discharging in two ways

Discharging:

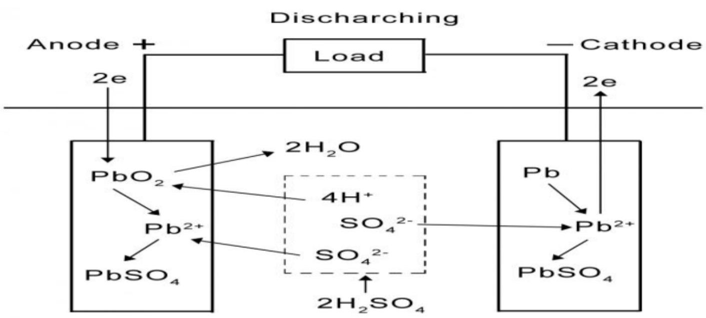

Fig -1: Discharging of lead acid battery

At cathode on reaction with Pb^{2+} with SO_4^{2-} PbSO4 is formed and 2 electrons are released from the cathode per one chemical reaction. At positive electrode gain of two electrons take place; hence the nominal cell voltage is 2V.

Negative electrode:

$Pb + SO_4^{2-} - 2e- \rightarrow PbSO_4$

Positive electrode:

$PbO_2 + SO_4^{2-} + 4H+ + 2e- \rightarrow PbSO_4 + 2H_2O$

Overall reaction (discharge):

$Pb + PbO2 + 2 \cdot H2SO4 \rightarrow 2 \cdot PbSO4 + 2 \cdot H2O$

Charging:

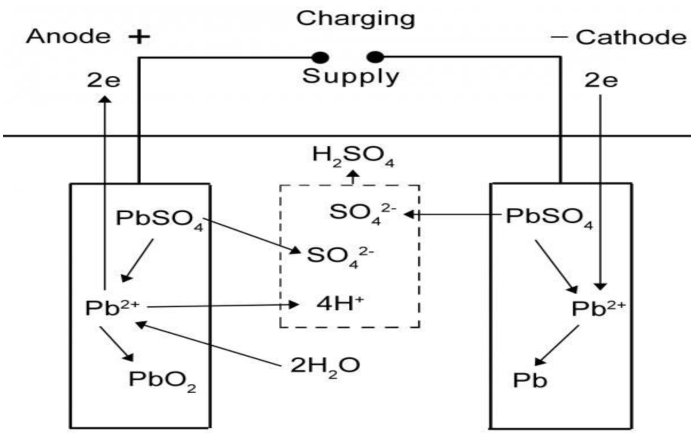

Fig -2: Charging of lead acid battery

In charging reactions at cathode and anode are opposite of discharging reaction. At positive electrode loss of electrons take place that is oxidation and at negative electrode gain of electrons take place that is reduction.

Negative electrode:

$Pb + SO_4^{2-} - 2e^- \leftarrow PbSO_4$

Positive electrode:

$PbO_2 + SO_4^{2-} + 4H^+ + 2e^- \leftarrow PbSO_4 + 2H_2O$

At Positive electrode two electrons are released when PbO2, SO42-, H forms a reaction and this released electron is gained by the negative electrode forming PbSO4 at cathode.

Overall reaction (charge):

$Pb + PbO_2 + 2 \cdot H_2SO_4 \leftarrow 2 \cdot PbSO_4 + 2 \cdot H_2O$

2.1 CHARACTERISTICS OF LEAD ACID BATTERY

Specific energy:

Capacity of the lead acid battery is calculated by using the formula of law of electrolysis that is m=Q*M/F*Z where 'm' is the mass of substance liberated at an electrode. 'Q' is the total charge through the substance. 'F' is the Faraday constant (96485 C mol-1). 'M' is the molar mass of the substance and 'Z' is the valency number of the ions in the substance (electrons per ion).

Molar mass of the lead battery =molar mass of Pb + molar mass of PbO2 + mass of PbSO4

=207g/mol +239g/mol +2*90g/mol

=642g/mol =0.642kg/mol

Valency of the lead acid battery is 2 since two electrons are gain or released hence Z=2.Therefore capacity of the lead acid battery is,

Q/m=96485c mol-1*2/0.642kg/mol

=300000 C/mol=300000 A.s/kg =300000/3600 A.h/kg

=83.3A.h/kg

Specific energy capacity=Q/m*V=83.3*2 .... since nominal voltage of lead acid battery is 2.

=167Wh/kg it is estimated that real specific energy varies from the theoretical specific energy. The value of the real specific energy is in between 30-50Wh/kg and the theory

Specific energy is 167Wh/kg because whole part of electrodes takes part in the Chemical reaction but not the whole part of sulphuric acid is taking part in the Chemical reaction. Real specific energy also depends on the depth of discharge.

Price -The price of the lead acid battery is low because no elements in lead acid battery are costlier. The estimation cost of lead acid battery is less than $100kW.h

Cycle ability - Cycle ability of the battery mainly depends on the depth of discharge. If depth of discharge is 10% then the cycle ability is 2000 cycles likewise if the depth of discharge is 50% then the cyclability is of 500 cycles and if the depth of discharge is 90% then the cyclability is of 200 cycles. Hence the more the depth of charge, less is the cycleabilty. Since in lead acid battery the capacity is more therefore the cyclability will be less.

Power- The power in the lead acid battery is high because of the high capacity. For a 2-volt cell, this comes to 167 watt-hours per kilogram of reactants, but in practice lead–acid cell gives only 30–40 watt-hours per kilogram of battery, due to the mass of the water and other constituent parts.

Safety-Safety in the lead acid battery is moderate because of the toxic elements such as sulphuric acid which can lead to the damaging of the human skin. Lead acid battery is very hard to recycle. The overcharging of the lead acid battery is highly dangerous because of the hydrogen gas. Since hydrogen gas is highly flammable. Charging over 2.4V should be avoided,

$2H_2O \rightarrow H_2 + O_2$ Overcharging lead-acid batteries cause the electrolyte water to break into oxygen and hydrogen gas, which depletes electrolyte levels in the batteries. This has two effects. This reduces the ability of the battery to accept a full charge, and undercharging worsens. This leads to premature battery failure [1]

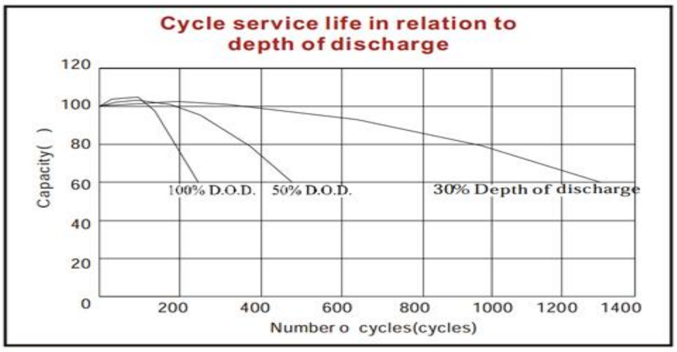

Chart -1: Cycle service life in relation to depth of discharge

Summarily the characteristics of lead acid battery:

Table -1: characteristics of lead acid battery.

Specific energy(capacity)	Low
Cyclability	Moderate
Price	Low
Power	High
Safety	Moderate

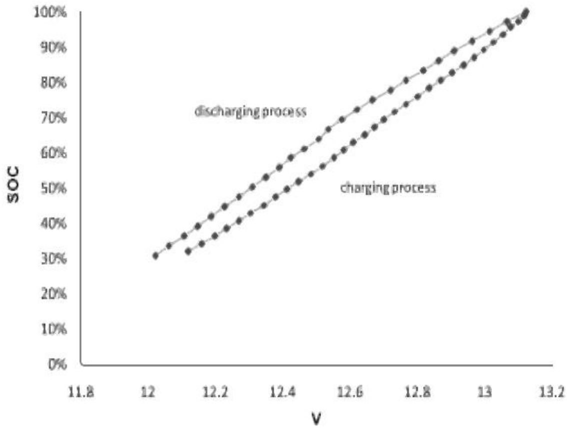

Chart -2: State of charge vs. Voltage graph of lead acid battery

2.2 Lead Acid Battery Types:

I. Starter batteries with Low Depth of discharge (DOD)-In this type of battery high power is achieved by a large number of thin plates with sponge surface.

II. Deep cycle batteries with high Depth of discharge (DOD)-It has much thicker solid plates. This plate does not have spongy surface.

III. Marine batteries -Marine batteries are the hybrid of the starter batteries with low DOD and Deep cycle batteries with high DOD.

2.3 Environmental effect of lead acid battery

a. High self-discharge-When you left your vehicle without starting for long time then the battery starts discharging this is known as self-discharge. For lead acid battery the self-discharge is 1% per day which will be 30% in month which is huge precent which can lead to decrease the life of battery.

b. Low charge/discharge efficiency-Efficiency of the battery can be obtained by calculating energy spent for each charging of battery and energy you have obtained that is discharging. Efficiency of lead acid battery per charge /discharge is about 50-90%.

c. Low specific energy-Because of low specific energy of lead acid battery there will be requirement of more raw materials.

d. Low cyclability - Since the lead acid battery has low cyclability therefore more often recycling will be required

2.4 ADVANCED LEAD ACID BATTERIES

1. **Gelled electrolyte-**In this type of battery the acid is “gelled” by addition of silica gel because the gel has less tolerable to overcharging hence safety is more in Gelled electrolyte. Gelled electrolyte has low charging voltage.

2. **Absorbent glass mat-**Absorbent glass mat has lower heating under heavy charge. It has low self-discharged that 1-3% per month. They have less maintenance.

3. **Carbon lead batteries-**carbon lead battery can improve the conductivity of the electrode. Lead carbon battery has high surface, low gassing but because of carbon it increases the price of the battery.

Hence lead acid battery is suitable in following ways.

a. For starter batteries in vehicles lead acid battery can be used.

b. It can be used in the commercial vehicles such as Hybrid electric vehicle (HEV), Plug-in hybrid electric vehicle (PHEV), and low speed electric vehicles.

3. Nickel-Cadmium Battery

Nickel cadmium battery has cadmium (Cd) on negative electrode. On positive electrode it had nickel ox hydroxide (NiO (OH)) and the electrolyte used in nickel cadmium battery is potassium hydroxide (KOH) that is alkaline electrolyte.

Negative electrode: Cd cadmium

Positive electrode: NiO(OH) nickel oxyhydroxide

Electrolyte: KOH potassium hydroxide (alkaline electrolyte)

On positive electrode that is on anode the following reaction takes place:

Positive electrode:

2NiO (OH) + 2H2O + 2e- – 2OH- ↔ 2Ni (OH)2

Reaction between nickel oxyhydroxide takes place and water takes and 2 electrons are released from positive electrode during charging. On negative electrode that is on cathode following reaction takes:

Negative electrode:

Cd + 2OH- – 2e- ↔ Cd(OH)2

The electrons which are released from the positive electrode are gained in negative electrode with cadmium and hydroxide and cadmium hydroxide is formed. The nominal cell voltage of the nickel cadmium is 1.2V because of the low potential difference between the positive and negative electrode. The relative atomic mass of the cadmium is 112 that of nickel are 59 comparing it with lead the mass of Pb is 207.therefore due to light weight of the element nickel cadmium battery has the high specific energy than the lead acid battery which is 40-80W.h/kg.

3.1 Ni-Cd vs. Lead acid battery

Table -2: Comparison of lead acid battery and Nickel cadmium battery

	Lead acid battery	**Nickel-cadmium battery**
Specific energy	lower	higher
Price	lower	higher
Cyclability	lower	higher
Power	lower	higher
Safety	moderate	moderate
Toxicity	high	higher

Nickel cadmium battery is better than lead acid battery in the characteristics such as specific energy, cyclability, power due to the nickel and cadmium elements since the elements are light in weight. The price of Ni-Cd battery is high because of the Cd elements which is expensive.

3.2 Main drawbacks of Ni-Cd battery

1. High self-discharge-Monthly self-discharge of the nickel cadmium is high that is 20% monthly.
2. Memory effect-Nickel cadmium battery requires deeper discharge hence it reduces the longevity of the battery.
3. Toxicity-Cadmium element is highly toxic to the environment [2]

4. Ni-Fe Battery

Negative electrode of the Ni-Cd battery is replaced by the Fe and positive electrode remains the same.

Ni-Fe VS lead acid battery

Table -3: Comparison of lead acid and Ni-Fe

	Lead acid	Ni-Fe
Specific energy	lower	Higher
Price	lower	higher
Cyclability	lower	higher
Power	lower	higher
Safety	lower	higher
Toxic	Higher	lower

Since the negative electrode is replaced by the Fe and the Fe element is less toxic in nature than cadmium and lead.

- **Drawbacks-**Ni-Fe batteries have high self-discharge than the nickel cadmium battery. It also has low charge and discharge efficiency.
- **Application-**The Ni-Fe battery can be used as the standby power in the rail roads and the fork lifts.

5. Ni-MH Battery

In nickel metal hydride battery negative electrode is replaced by the hydrogen absorbing alloy.

Negative electrode:

MH + OH- – e- ↔ M + H2O

Positive electrode:

NiO(OH) + H2O + e- – OH- ↔ Ni(OH)2

Net reaction:

NiO(OH) + MH + 2H2O ↔ 2Ni(OH)2 + M

Where M is the hydrogen absorbing alloy of the chemical formula AB5 where A includes elements such as La, Ce, Nd, Pr and B includes elements such as Ni, Co, Mn, and/or Al .While using AB5 formula it is estimated that the self-discharge rate of the battery is high which is about 20-50% hence low self-discharge Ni-MH is used which includes AB2 formula where A includes elements such Ti, V and B includes elements such as Zr, Ni with Cr, Co, Fe, Mn it has self-discharge of only 1-3%.The nominal cell voltage of Ni-MH battery is 1.2V.[2]

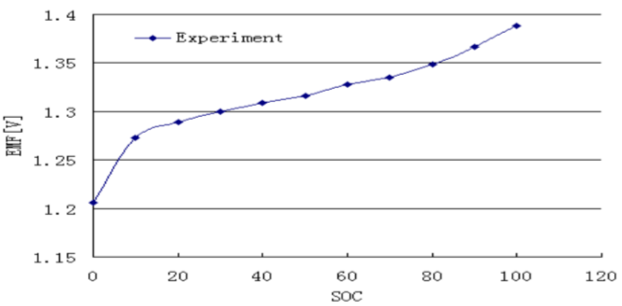

Chart -3: SOC in relation with EMF (v) of the battery

Tab

- Ni-Cd vs. Ni-MH

Table -4: Comparison of Ni-Cd and Ni-MH

	Ni-Cd	Ni-MH
Specific energy	Lower	higher
Price	Lower	higher
Cyclability	higher	lower
Power	higher	lower
Safety	moderate	moderate
Toxicity	Higher	lower

6. LI-ION BATTERY

The first lithium-ion battery was TiS2 and lithium metal the problem with this battery was it was very expensive, having low cyclability and major factor was the formation of the SEI (solid electrolyte interface).

6.1 LiCOO2-C cell

LiCOO2 as a positive electrode and graphite as a negative electrode the following reaction of lithium-ion battery takes place:

Positive electrode:

LiCoO2 → CoO2 + Li+ + e-

Negative electrode:

C6 + Li+ + e- → LiC6

Net reaction:

C6 + LiCoO2 ↔ LiC6 + CoO2

The nominal voltage of the battery is 3.6V and specific capacity of this battery is 631 W.h/kg theoretically and the practical value of specific capacity is 200 W.h/kg because this cell cannot extract all lithium from lithium cobalt oxide and to accumulate on the carbon to have proper cyclability.

Table -5: Comparison of Ni-MH and $LiCOO_2$

	Ni-MH	$LiCOO_2$
Specific energy	lower	Higher
Price	lower	higher
Cyclability	moderate	moderate
Power	higher	lower
Safety	higher	lower
Memory effect	Yes	no
Self-Discharge	higher	lower

LiCoO2-C cell drawbacks

Cobalt is expensive element results to have price, low power, low cyclability and low safety due to formation of SEI layer are the drawbacks of this cell

7. POSITIVE ELECTRODES

7.2 Layered LCO

The net reaction of the LCO is:

Net reaction: C6 + LiCoO2 ↔ LiC6 + CoO2 It is theoretical reaction, practically the net reaction is different C6 + LiCoO2 ↔ Li0.5C6 + Li0.5CoO2 because of chemical instability. Only the half of the lithium ions can be extracted /inserted reversibly. If we apply 4.2V less lithium is extracted but less amount of cobalt is lost.[3]

Solution to this problem is cover cobalt oxide, the particles of electrode are some material or a new electrolyte should be introduced.

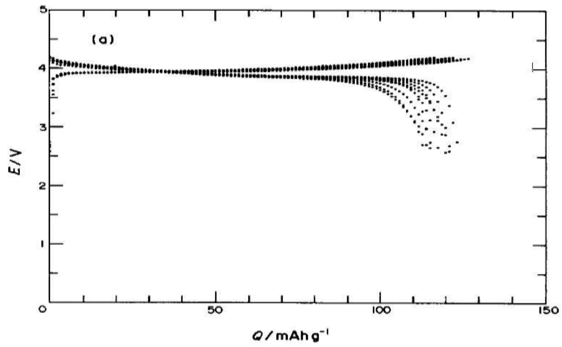

Chart -4: charge and discharge characteristics of the layered LCO

7.3 LITHIUM NICKEL OXIDE(NCO)($LiNiO_2$)

Comparing with Co Ni is less expensive and less toxic. The main drawback of LiNiO2 is Ni is very hard to synthesize. Nickel more easily occupies position of lithium and it changes your structure.[5] Solution for this is Ni substitution by Co and doping by Cr, Al, B, so the chemical formula will be

LiNiO2 → LiNi1-y-zCoyAlzO2

The specific capacity of the battery will also increase. The specific capacity of the LiCoO2 is 140 mA·h/g and the specific capacity is 180 mA·h/g for LiNi0.8Co0.2O2

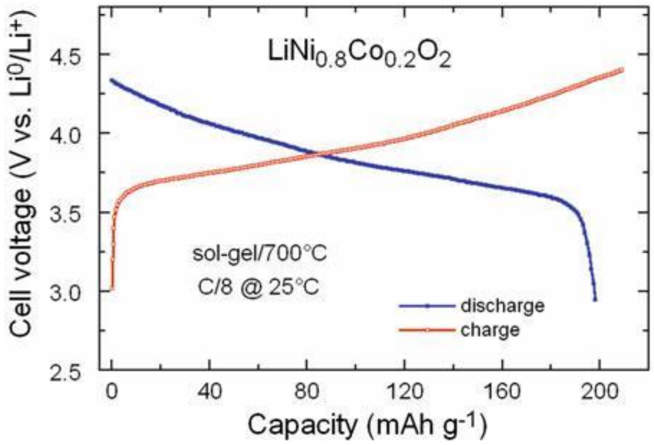

Chart -5: Charge and Discharge characteristics of Li//LiNi0.8Co0.2O2

For thermal stability higher the peak is more energy is released which lead to the fire can therefore if you add aluminum energy will decrease.[4]

7.4 NCA

NCA belongs to the nickel rich material family. It is of chemical formula LiNi1-y-zCoyAlzO2 .Ni reach NCA is less expensive and less toxic it has improved structural stability and because of doping aluminum it has high thermal stability.[6]

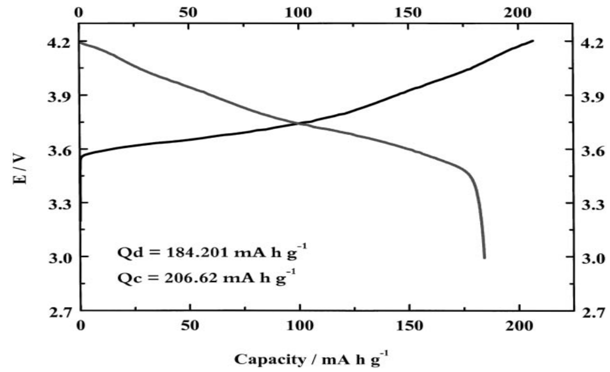

Chart -6: Charge discharge characteristics of the NCA

7.5 NMC

NMC is known as the ternary material. It has higher specific capacity and more thermal stability.[7] The chemical formula for NMC is LiNi1/3Mn1/3Co1/3O2 and the specific capacity of the NMC is 200 mA·h/g which is more than NCA and LCO.

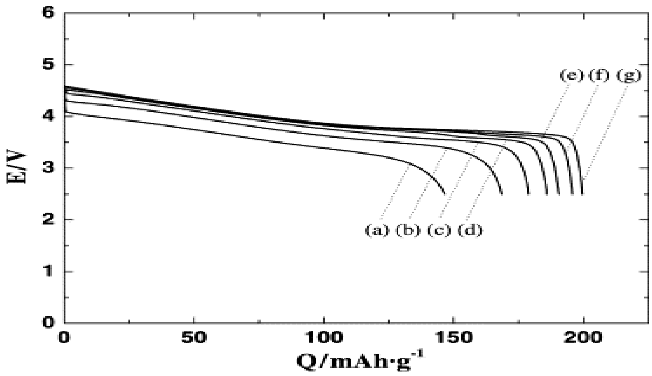

Chart -7: Charge-Discharge characteristics of NMC

Table -6: Comparison of LCO, MNC, NCA

	LCO	MNC	NCA
Specific capacity	140	180	200+
Price	higher	high	high
Cyclability	500	6000	4000
Power	1C	1C	1C
Safety	Low	Moderate	Moderate

7.6 Spinal positive electrode (LMO)-LMn2O4

Table -7: Comparison of MNC and LMO

	MNC/NCA	LMO
Specific capacity	High	moderate
Price	high	low
Cyclability	moderate	Low
Power	moderate	High
Safety	moderate	Good

Spinal LMO has the 3D structure.LMn2O4 has the higher safety they have lower price and LMn2O4 has lower toxicity in nature. From cobalt, nickel and manganese element manganese is less expensive. The advantage of the spinal structure over layered structure is the spinal structure has the 3d movement; it is less dependent on grain structure .[8]The specific capacity of the spinal structure is less.

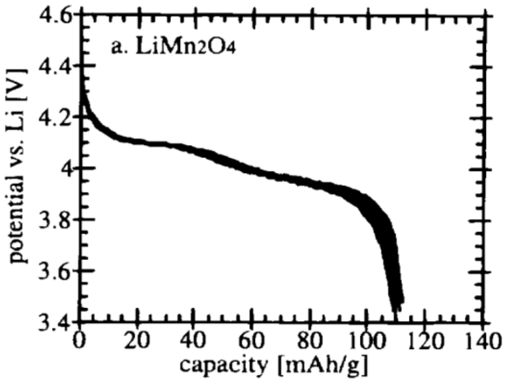

Chart -8: Charge discharge characteristics of the spinal LMO

7.7 Olivine LFP(LiFePO4)

Olivine LFP has the 1d dimensional structural has the 1D ionic transportation. The average potential of the olivine LFP is 3.5v less than the layered and the spinal structure. LiFePO4 has the high ionic conductivity and SEI layer is decreasing [8]

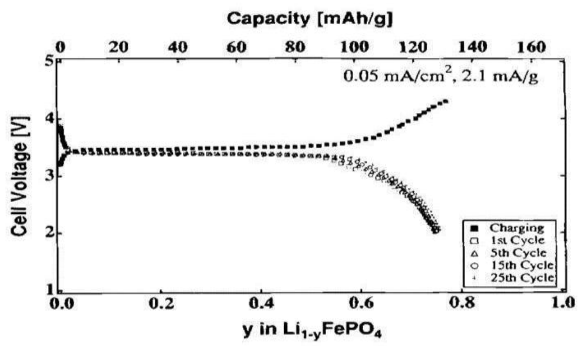

Chart -9: Charge-discharge characteristics of LFP

Table -8: Comparison of Positive electrode materials

	MNC/NCA	LFP
Specific capacity	high	moderate
Price	high	low
cyclability	high	high
Power	high	high
Safety	moderate	high

8. NEGATIVE ELECTRODE MATERIALS

8.1 CARBON

Graphite is dominating in the negative electrode materials. It has high specific capacity. Lithium metal can be considered as the ideal negative electrode because of the potential zero of the lithium metal so the potential of the negative electrode is calculated relative to the lithium metal. The specific capacity of the graphite is 372mA.h/g and potential of the graphite electrode is 1.2V. [9]There are two types of carbon negative electrode material that is hard and soft. Hard carbon material is of disordered carbon and soft type is of graphitized carbon. Hard (disordered) carbon has higher reversible capacity (200 - 600 mA·h/g) due to defects and voids and the lower volumetric capacity due to larger fraction of voids. Hard carbon has the lower initial columbic efficiency. The Soft (ordered) carbon has the Lower capacity, close to one for graphite (372 mA·h/g). The Soft carbon variety are Massive Artificial Graphite (MAG), Partially Graphitized Porous Carbon (PGPC), MesoCarbon MicroBead (MCMB), MesoPhase-Pitch-based Carbon Fiber (MCF, MPPCF), Vapour Grown Carbon Fiber (VGCF).

Main drawbacks of carbon materials are Notable volume change during charge/discharge (cyclability decreasing), Safety issue and the SEI (solid-electrolyte interface) formation.

8.2 ADVANCED CARBON MATERIALS

The advanced carbon materials are carbon Nano tubes (CNT) and the graphene. Carbon nanotubes (CNT) are of two types single-walled carbon nano tubes (SWCNTs) whose specific capacity is 1116 mA·h/g (LiC2) and the multi-walled carbon nano tubes whose specific capacity (MWCNTs) is lower.[10] The grapheme type carbon material has the specific capacity of (780-1116mA.h/g) (Li2C6 or LiC3).

Main drawbacks of advanced "high-performance" carbon materials are the High cost of production due to complicated and energy-intensive synthesis, Large amount of waste products, Fossil-derived precursor and the Toxic or ecologically unfriendly reactant.

8.3 SPINAL LTO

Alternative negative electrode for the carbon is Lithium titanate (Li4Ti5O12). comparing LTO with carbon and lithium metal.

Table -9: Comparison of negative electrode materials

	Li metal	Carbon	LTO
Specific capacity	3860	372	175
Potential vs. Li v	0	0.1	1.5

LTO has high cyclability, high rates, high safety and low toxicity and LTO has abundant materials. [11] Key advantage of the spinal LTO is it has zero strain, and no SEI formation.

9. CONCLUSIONS

Lead acid batteries have proven to be the best choice from an energy consumption point of view (12.6 kWh/100 km). Besides that, other important advantages are their low price, increased life cycle or great functioning under normal parameters in harsh environments. One disadvantage of these batteries is increased operating temperature, which is causing the battery electrolyte to solidify if the vehicle is not used. That is why, it is necessary to have one external system which maintains the battery's operating temperature under functional parameters.

According to these conducted studies, it has been demonstrated that the highest energy consumption (17.2 kWh/100 km) is accomplished by Nickel cadmium batteries. However due to their low weight, increased energy storage capacity and low price, compared to other battery technologies, they might be one of the best solutions for systems with high energy storage capacity. Ni-MH batteries, despite having a reasonable energy consumption, (15.7 kWh/100 km) they are inefficient, having an increased energy density and power, heavy weight as well as an outdate technology.

Nowadays, Li-Ion batteries have the biggest market segment in equipping electric vehicles. Moderate energy consumption (14.7 kWh/100 km), continuous decline of the cost price, advanced manufacturing technology, increased cycle life, low weight and high energy storage potential make Li-Ion batteries an optimal choice in this field. Their disadvantage is represented by high functioning temperatures, which may have negative effects on their energetic performances and life cycle.

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