Lithium-ion batteries recycling process: A comprehensive review

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Abstract. Lithium-ion batteries are used in high sum in the vehicle business. Presently nowadays these batteries are depended upon to finish the life of the vehicle, they won't finish their accommodating life in colossal numbers for 10 to 15 years. Lithium atom batteries applications in buyer contraptions and the mix and electric vehicles are quickly making, accomplishing the boosting assets interest, including the cobalt and the lithium. The reusing of batteries which will be need, not exclusively to reduce the utilization of the energy, yet additionally to encourage the deficiency of the noteworthy assets and shed the debasement of hazardous parts which towards the worthy undertakings identified with customer contraptions and crossbreed and electric vehicles. Breaking down reusing examples of spent lithium particle batteries, it presents the structure and sections of the batteries, and sum up all accessible single contacts in gathering mode development, including pre-treatment, optional treatment, and critical recuperation. Furthermore, different issues and prospect of the current reusing cycles will be introduced and investigated. It accepted that exertion would be enable further pay in spent of lithium atom batteries reusing and, in the thankfulness, and of its benefits.

1. Introduction

A battery is the device which stores the energy and converts into current. The substance response in which during a truly battery include the now of electrons from one material to an uncommon material, through an outer circuit. The progression of electrons gives current which might be acclimated work the battery [1]. Lithium-ion battery is one among the battery that’s mostly utilized in electronic devices and also within the electrical vehicles. Now on a day to day the quantity of electrical vehicles is increased on the roads once a year. Because increase within the assembly volume variety of the challenges is also faced within the use of Lithium-ion batteries recycling processes. In the event that we straightforwardly removal of the Lithium particle batteries that end in the reasoning for climate harm [2]. Because within the Lithium-ion batteries have the heavy metals like cobalt, manganese,
nickel etc. this sort of metals will damage the soil and water. This type of metals also will release the harmful gases. There’s one solution that’s we’ve to recovery and reuse the materials by using some recycling process. By the recycling of these elements, we'll reduced the damage of the environment. One of the recycling processes that's Pyro metallurgical process. This process is incredibly expensive and also, it’ll consume very high energy [3]. It gives the top in loss of several materials like slag. During this process we didn’t get the material effectively. During this process even have variety of the environmental issues like burning of the organic materials. It also finishes up within the emission of the fluorine gas, dioxins and also the other materials.

Lithium particle batteries have anticipated that the age of three should five years which recommends gigantic the measure of end of the existence lithium particle batteries are arranged inside the not so distant future without appropriate removal the executives[4], landfilled spent lithium particle batteries may cause a worker climate sway, as an illustration lithium particle batteries could likewise be detonate when harmed to high temperatures, lithium particle batteries contains substantial metals which can be taint the dirt and thusly the groundwater, and lithium particle batteries are electrolyte and that they are poisonous and combustible[5]. Furthermore, in addition, the spent of lithium particle batteries contains high centralization of significant metals. Examination regions for lithium particle batteries incorporate expanding the lifetime of battery, expanding the energy and thickness, and improving the security, and diminishing the estimation of battery, and speeding up the battery among others. Lithium molecule battery fuses cathode, electrolyte element and separator. The cathode may be consistently formed on an aluminum plate covered with a thin layer of lithium metal oxide development, while the anode contains a copper plate covered with a thin layer of graphite [6]. The entire cathode in the same way contains a polymer cover, which looks at the corresponding contact with the current and holds the particles of the strong material together, and provides vital energy to the actual interface structure for direct maintenance of anode molecule batteries. To separate the coated film from the current metal surface, usually the actual handling step is used during re-use [7]. On the other hand, delamination between the current state of the metal and the composite film is generally considered to be another major specificity after point decay and as a result of battery frustration. In particular, the evolving model for capturing film cathode sizes, 3-term terminals, and Si electrons used for prime and high power.

1.1. Components used in lithium-ion batteries

1.1.1. Cathode

A cathode is that the metallic electrode through which current flows call at a polarized device. Conversely, an anode is that the electrode during a polarized device through which current flows in from an outdoor circuit.

1.1.2. Anode

An anode is a terminal through which the conventional current goes into an energized gadget. These differences with a cathode, a terminal through which traditional current leaves a gadget.

1.1.3. Electrolyte
An electrolyte may be a material that makes an electrically driving plan when separated during a polar dissolvable, like water. The broke down electrolyte detaches into feline particles and anions, which disperse reliably through the dissolvable.

1.1.4. Separator

Particle course through the separator of Li-particle. Battery separators give an obstruction between the anode (negative) and in this manner the cathode (positive) while empowering the trading of lithium particles from one side to the inverse.

1.2. Material and Methods

The use of lithium particle batteries was used during this study, and in particular the same product batteries were allowed to continue reproduction analysis. The typical Li structure is a battery particle that basically consists of a cathode, electrolyte, separator, anode, gasket, proper gas discharge, and plate adjustment [8]. The cathode is the positive end of the battery, which suggests that it is a source of fine particles (Li +) and allows negative particles (e−). In embedded cathodes, the fragment is represented by LiMO2, where the instrument is compared to Co, Ni, and Mn. LiCoO2 is currently the first well-known battery method, despite the high cost of cobalt, as it is probably easier to update an anode with a high-quality coated structure. And, hence the anode that is the wrong end of the Li particle battery, which contains graphitic carbon coated. The separator provides a barrier that prevents short circulation of the cathode and moreover the anode. It should be sufficiently permitted to allow the electrolyte to interact uncontrollably with two cathodes [9]. Usually, the separator is composed of polytetrafluoroethylene and other subtle polymer layers with visible porosity and ionic conductivity. In addition, the most commonly used electrolyte for lithium particle batteries includes propylene carbonate and compounds of those solvent.

Charging and discharge of the battery occurs through the flow of lithium particles between the cathodes and anodes and in these lines electron trade through doping and de-doping. Clearly, during charging the lithium is de-doping from the cathodes containing the lithium-containing compound, and in addition the carbon interlayers on the anodes are fitted with lithium [10]. On the other hand, during the extraction of lithium is de-doped from between the carbon layers on the anodes, and in addition the layers attached to the cathodes are fitted with lithium. Responses to lithium particle battery-powered batteries use LiCoO2 on cathodes and carbon on anodes. In the case of initial charging methods, and which occurs during battery production, lithium particles move from the lithium cathode area to the anode carbon material. The newly proposed re-cycle cycle for electric powder recovery is developed with a different metal [11]. This cycle was mainly focused on preventing battery dissipation with warm treatment under a calm environment, because oxidation of metal particles during air conditioning in the presence of heat treatment may be the cause of an emotional response ready to trigger a destructive explosion within the battery. Table 1 and 2 summarizes the various recycling process in-use for lithium-ion batteries.
Figure 1. Cycle of lithium-ion battery

2. Estimating the “Proportion of Energy Inputs that are Wasted” (PEIW)

Mass of batteries = $E_{\text{grav}} / C$ \{$E_{\text{grav}}$ is gravimetric energy and $C$ is capacity\}

Electrical energy Inputs ($E_i$) = $C \times 3600 \times N$ \{N is number of cycles\}

Electrical energy output ($E_o$) = $E_i \times D$ \{D is Discharge factor\}

Total energy of battery production ($E_{P,pf}$) = $E_{pr/ex} + E_{\text{man}}$ \{ $E_{pr/ex}$ is the process if raw material, $E_{\text{man}}$ energy of manufacture\}

Total energy of battery production ($E_{P,pl}$) = $E_{P,pf} \times 0.35$

Total energy to transport batteries ($E_{T,pd}$) = $2L_{\text{truck}}$

Total energy to transport batteries = $E_{T,pf} \times 0.35$

Total energy produced and transport batteries ($E_{P & T}$) = $E_{P,el} + E_{T,el} \times M$

Energy loss ($E_{\text{loss}}$) = $E_i \times (1-p)$

Total energy wasted ($E_W$) = $E_{P&T} + E_{\text{loss}}$

Total energy inputs ($E_{i,TOT}$) = $E_i + E_W$

PEIW = ($E_W / E_{i,TOT}$) $\times$ 100
Table 1. Different types of processes used for recycling of Li-ion batteries.

| Type of battery | Cathode material | Anode materials | Materials Electrolysis | Separators | Process and Manufacturing |
|-----------------|------------------|-----------------|-------------------------|------------|--------------------------|
| Lithium-ion batteries [12] | 1-Lithium metal oxides, LiMnO2, LiMnO2, LiMn2O4, 2-Vanadium oxides, olivine, 3-Cobalt and Nickel are layered oxides | Lithium, Graphite, Lithium-Alloying Materials, Intermetallic, silicon | Electrolytes of state Fluid, Polymer, and Solid. Fluid electrolyte is usually a natural, supported electrolyte containing LiBO2-8 (LiBOB), LiPF6, Li [PF6] (C2F5) 3, or comparable | Shrinkage Modulus, Drying temperature, wettability, Thickness, weight, ionic resistance, Porosity, Penetration resistance, Meltdown. | Dispersion measure: conveying lithium particles to the outside of the anode, and the progressing to the dissemination through the electrolyte, and changing to the dispersion into the cathode. Chamber cells producing measure the electrolyte is shaped from the dynamic materials powders, fasteners, solvents, added substances and are taken care of to cover distribution equipment on current authority filters, for example, such as aluminium cathode side, and copper anode side. |

Table 2. Summary of type of elements and their corresponding recycling process

| Type of Battery | Elements Recycled | Process Used | Chemical Anode | Cathode Used | Operating Condition | Efficient process | Conclusion |
|-----------------|-------------------|--------------|----------------|--------------|---------------------|------------------|------------|
| Li-ion battery [13] | Li, Ni and Co, | Hydrometallurgy pyro metallurgy | Li salt solution or gel type polymer | Lithium compound s | Carbon materials | 750 deg Celsius, 90–180 density | Hydrometallurgy pyro metallurgy | Waste management |
| lithium-ion batteries via microwave processing route [14] | lithium, cobalt, manganese, and nickel | Hydrometallurgical Processing, Reduction Microwave based | inorganic acids, organic acids | Graphite, Charcoal | LCO/LC O+ LMNO+ LMO | 25 ºC, 600 deg Celsius | pyro metallurgy | Simple, economical, energy, and time saving promising process. |
| lithium iron phosphate batteries [15] | lithium, iron and phosphate | Hydrometallurgical processing | methan sulfonic acid, hydrogen peroxide | Lithium compounds | Germanium | 90 min at room temperature | hydrometallurgical process | green and ecologically appropriate as we evade utilization of solid mineral corrosive |
| Li-ion batteries, Lithium cobalt oxide & Nickel/manganese/cobalt oxide [16] | Lithium (Li), cobalt (Cu), nickel (Ni), manganese, Oxide (MnO2) | 1-pyro metallurgy (smelting) 2-Hydrometallurgy (melting) 3-direct recycling process | Li salt solution or gel type polymer | Graphite, Charcoal | Germanium dioxide (GeO2) and SnO2 nanoparticles | temperature | For recycling of li-ion battery all the three process is must as it extracts different elements |
| Lithium-ion battery [17] | Co-Ox, LiCoO2 | Leaching & Hydrothermal treatment Calcination & solid-state reaction | Ammonia solution, Urea | Graphite, Charcoal | LCO, (LCO+LMNO+LMnO) | Heating process | pyro metallurgy process | This waste to resource study demonstrated the great potential of methanesulfonic acid in recycling variable metals from batteries |
Table 3. Type’s of battery and materials

| Type of Battery | Pb-acid battery | Nickel metal hydride battery | Lithium-ion battery |
|-----------------|-----------------|-----------------------------|---------------------|
| Type of automobile energy density [20] | ICE engine vehicle | hybrid electric vehicles and plug-in-electric vehicles 41-50 | Electric vehicle 91-180 |
| Cathode | Lead oxide | Ni(OH)₂ | C materials |
| Anode | Spongy lead | M(OH)₂ | Li compounds (LiMn2O4, LiFePO4, Li4Ti5O12, LiNiMnCoO2) |
| Electrolyte | Diluted H₂SO₄ | Alkaline solution | gel type polymer |

Table 4. Advantages and disadvantages of recycling methods of lithium ion batteries

| Recycle method | Advantages | Disadvantages |
|----------------|-------------|---------------|
| Pyrometallurgical [21] | simple processes, high productivity, industrial capacity | high temperature, high energy consumption, harmful gases |
| Hydrometallurgical | low power consumption, low waste, high purity, high emissions rate | complex measures, excessive use of reagents, pollution of contaminated water |
| Bioleaching | environment, efficiency, low cost | long-term planting, which can be attacked by pollution |
| Direct recycling | low pollution, low greenhouse gas emissions, low energy consumption | it takes time to grow and sell |

Table 5. List of cell components/battery type

| Discharging | Disassembly | Crushing | Separation | Recycling methods |
|-------------|-------------|----------|------------|-------------------|
| Brine method, Ohmic, Discharge [22] | Open frame work, Cut connections, Removing, Axillary parts | Course, Shredding, Fine crushing | Sorting sieves, Floating, Ferromagnetism, Hydrophobicity | Pyro metallurgical, Hydrometallurgical, Bio-Hydrometallurgical, Direct recycling |
| EV packs | Spent LIBs | Crushed materials | Enriched materials | Co, Li, Ni, Cathode materials etc… |

3. Results and discussion

3.1. Hydrometallurgical

Hydrometallurgical reuse involves the dissolution of essential cathode elements in acids, and the disintegration of recycled metals using a melting pot. This method shows that it is best known for the large number of lithium battery particles that are used most often. Table 3 highlights the different automobile energy density of different batteries [23].
3.2. Pyro metallurgy

This cycle including in high-temperature refining is utilized to reuse and along these lines recuperation of significant metals like Ni, Co, Cu. pyro metallurgical and hydrometallurgical measures are either used in blend with other pre-medicines or post medicines or in consecutive request with different cycles. Ordinarily, during this reusing approach, spent lithium particle batteries are at first released, trailed by being destroyed through a progression of steps encouraging the recuperation of the electrolyte and division of the anodes. After electrolyte recuperation at that point, the lithium particle batteries are squashed and screened to isolate the plastics, graphite, and accordingly the metallic segments. Table 4 highlights the advantages and disadvantages of various recycling processes as summarised in literature [24].

4. Chemicals which are used in battery recycling process

4.1. Hydrogen peroxide

We locate that a peroxide arrangement added inside the electrolyte can adequately advance the deterioration of lithium hydroxide mixes at the ultralow charge potential on an impetus free Ketjen Black-based cathode [25].

4.2. Natural corrosive

Citrus extract is viable as lixiviate for metal recuperation from lithium particle batteries. > 95% Co, Li and Ni disintegration accomplished with 1.5 M corrosive at 95 °C. Expansion of H2O2 as reluctant essentially expanded filtering rates [26].

4.3. Methane sulfonic corrosive

It is utilized as a corrosive impetus in natural responses since it’s a non-unstable, solid corrosive that is dissolvable in natural solvents. It’s advantageous for modern applications since its fluid at surrounding temperature, while the firmly related p-toluene sulphuric corrosive (PTSA) is strong [27].

4.4. Li salt arrangement

Waterless electrolytes used for lithium-particle battery typical lithium hexafluorophosphate are divided into a mixture of ethylene carbonate containing dimethyl carbonate, propylene carbonate, diethyl carbonate, or ethyl methyl carbonate [28].

4.5. Inorganic acids

Most usually explored filtering specialists, likewise at the underlying phases of hydrometallurgical advancement of metal recuperation from spent Li-particle batteries, are inorganic acids mainly hostility (H2SO4), yet additionally corrosive (HCl), water forties (HNO3), and orthophosphoric corrosive (H3PO4) [29].

4.6. Gel type polymer

Polymers like polyethylene oxide, polyacrylonitrile, poly vinylidene fluoride, poly methyl-methacrylate are among the very much examined materials. Negative cathode which comprises of Li or Li-C intercalation compound [30].
5. Conclusion

- To reuse the lithium-particle battery we utilize various techniques to reuse the lithium particle battery and some of the time contain among other valuable metals high-grade copper and accordingly the aluminum furthermore to relying on the dynamic material progress metals like cobalt and nickel besides as uncommon earths materials.
- The expansion of EVs, energy stockpiling and progressively eager for power electronic gadgets presents difficulties for end-of-life battery the executives.
- The reusing lithium particle battery is basic to help natural, assets and financial matters by and large, and maintainability to close the circle on battery materials and diagram a feasible round economy for lithium particle batteries.
- Many benefits of reusing lithium battery batteries are available, but special ones, combinations, costs, and control parameters must be addressed.
- The cycle of extracting key metal components took place in the model of the contracting center and was constrained by ground-based responses; this cycle took place with those metals filtered from cathode material powder.
- Preventing the absence of cobalt (Cu), nickel (Ni), and lithium (Li) and enabling a life-saving way of those new products, also requires cycles of reuse of lithium batteries.
- These cycles need to regenerate not only Cobalt, nickel, copper, which is why aluminum is used in battery cells, but in addition it contains a large amount of lithium.
- Another significant and recyclable material is graphite and manganese. Moreover, today's recycling methods recover around 30% to 95% of the material from a lithium particle cell battery cell, depending on the separation phase to achieve this goal, and the type of development is integrated into complex chains, especially i think with the task of restoring a high level of priorities in relation to security issues.
These means are

- Deactivation or releasing of the lithium particle battery particularly if there should arise an occurrence of batteries from the electric vehicle
- Disassembly of battery frameworks
- Mechanical processes like crushing, sorting, and sieving processes
- Electrolyte recovery
- Hydrometallurgical processes
- Pyro metallurgical process

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**ACKNOWLEDGEMENT**

The work is carried at the School of Mechanical Engineering, Lovely Professional University. The Author would like to thank the guiding efforts of all faculties and staff in contributing towards this work.