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Current status of battery recycling and technology

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Current status of battery recycling and technology

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Abstract. In recent years, battery recycling has become one of the hot environmental issues in China. This paper analysis the current situation of battery recycling and the methods of recycling, and analyzes the effective means of recycling batteries under the existing conditions. The results show that the current situation of battery recycling in China is worrying, with no complete recycling industry chain and low recycling efficiency. And as the demand for batteries increases and the price of metals rises, the urgency of battery recycling is further increased. From the analysis of existing methods, pyrometallurgy is defective in many aspects and the environmental life cycle is not complete. The cost of electrolytic recycling method, although high recovery efficiency and wide range, requires adequate technology and high cost. Bioleaching method is highly efficient, low cost and produces almost no pollution. Although the technology is not mature enough and is still in the laboratory stage, the bioleaching method has a good future. This paper looks forward to exploring more appropriate recycling methods to address the current situation of battery recycling difficules in China and discusses the future prospects of these methods.

Keywords: Battery Recycling, Bioleaching, Lithium Battery.

1. Introduction

1.1. The dilemma of battery recycling in China

There is considerable pressure to recycle batteries in China

Most of the used batteries flow into informal recycling channels, and such recycling often means unsafe, environmentally unfriendly, and even serious secondary pollution. According to information from the International Energy Agency (IEA), electric and plug-in hybrid vehicles grew at an average annual rate of 56% in 2015 and 2016, with the number of these types of vehicles reaching 2 million by 2016, while in 2017 the figure was already over 3 million. [1]. This shows the increasing amount of our batteries in use. In terms of recycling, lead batteries, Just take lead battery as an example, every year China's waste Lead batteries are generated more than 2.6×10^6 tons per year, while the formal recycling rate is notto 30%.

1.2. It is difficult to form an industrial chain for battery recycling in China

Battery recycling in China is very inefficient, but if it can have an industrial effect, then it can not only have a better economic effect, also have a good impact on the ecosystem. The topic of batteries is now a very hot topic, so battery recycling will also become a concern for everyone. However, there are very few companies in the recycling industry and the technical route for recycling batteries is quite complicated. For example, when dealing with end-of-life lithium batteries, they are first pretreated, includes shell disassembly, material extraction, material crushing and recycling sorting; the plastic or scrap metal obtained after disassembly can be recycled.; then the electrode materials are subjected to various procedures such as alkaline leaching and acid leaching, and then extracted. [2] Such complex procedures and high costs discourage many recycling companies, so there is a serious gap in battery recycling treatment. The urgency of the need for minerals to produce batteries. The main components of a battery are the positive electrode, the negative electrode, the electrolyte, the plastic diaphragm and the casing, with metal being the key material for these components. In the case of lithium batteries, for example, the lithium needed for lithium batteries is actually not sufficient. Being an unsustainable mineral, once it is used up, it is gone, meaning people need to recycle the metal. Lithium ores are abundantly distributed, but partly limited by our technology not being easily exploited after mining, not all lithium-related ores meet the demand. Looking at the production and consumption Figure 1, people are now in a situation where demand is outstripping supply and people even need to import the material. Also looking at the price Figure 2, the price of lithium has been rising in recent years as the market for lithium batteries continues to open up and our consumption continues to rise. As things stand, human need to recycle and implement sustainable development [3].

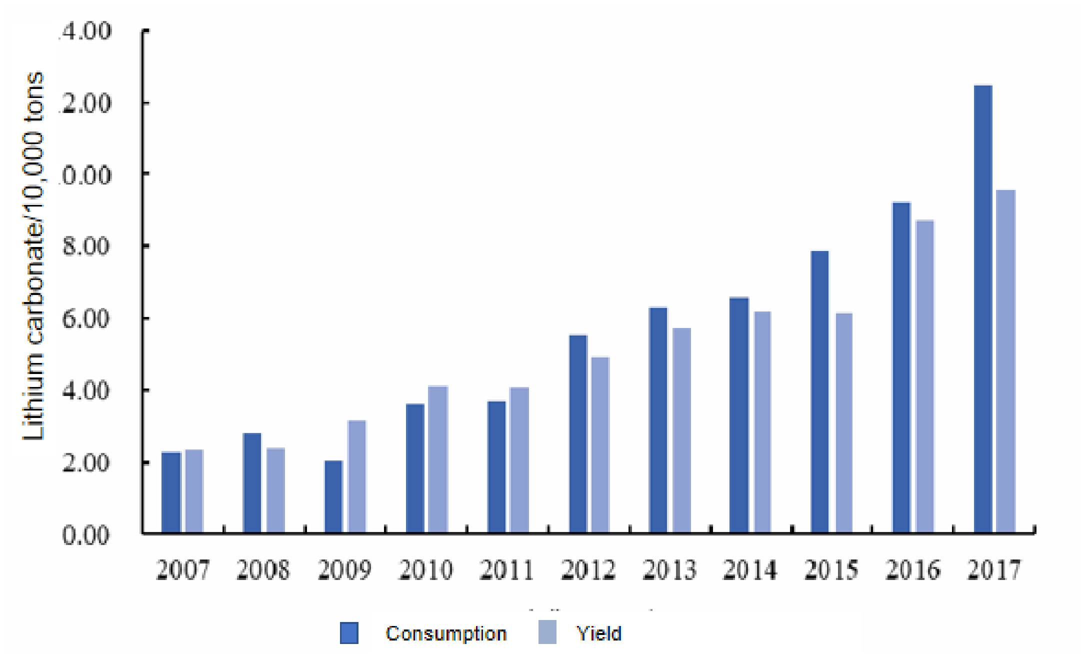

Figure 1. Lithium consumption and yield.

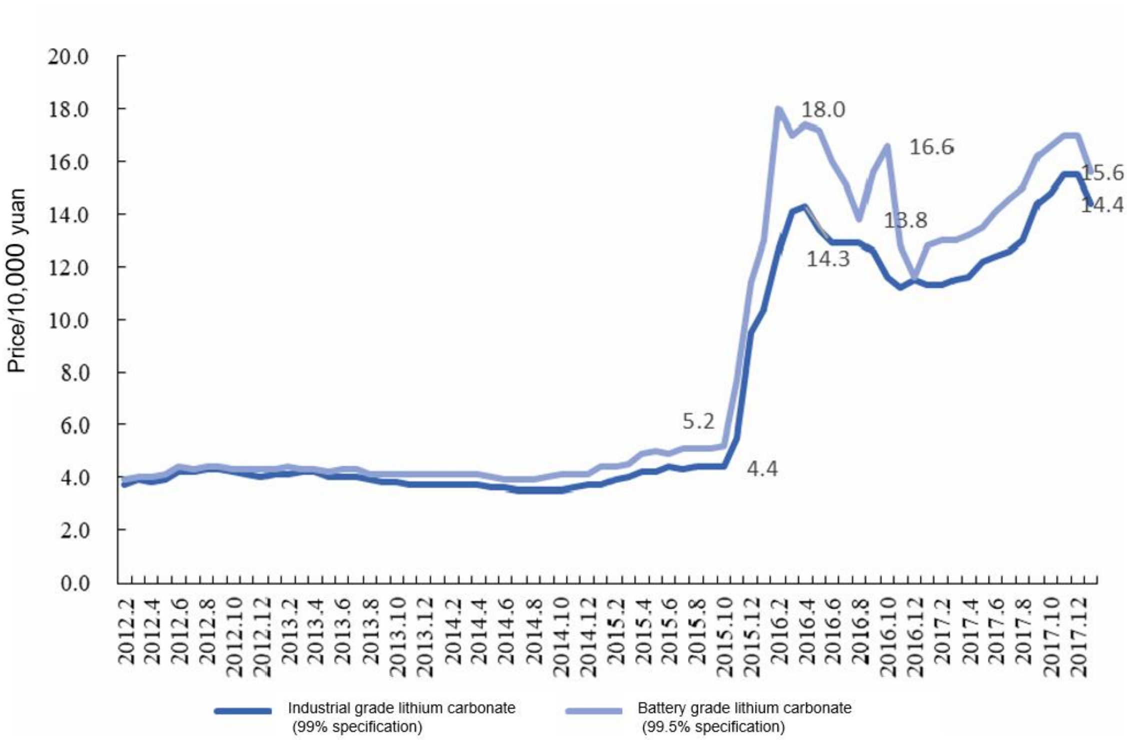

Figure 2. Lithium price.

In order to explore feasible solutions for battery recycling in China, the existing methods of battery recycling was analyzed. By discussing electrolysis, pyrometallurgy, and bioleaching methods, and further exploring the advantages and disadvantages of these methods, this paper identify possible methods and development trends for future battery recycling in China.

2. Battery recycling methods

2.1. Pyrometallurgical

Pyrometallurgy is a recycling technology that uses high temperatures to destroy the shell and recover the metallic components of the battery, and is a relatively simple and technically advanced method of recycling lithium-ion batteries. The organic binder in the electrode material is dissolved and broken down by incineration at high temperatures to separate it from the recovered metal in the battery. The high temperature causes a redox reaction of the metals or metal compounds, and then the lower boiling point metals and compounds are recovered in the form of condensation. Pyrometallurgy is a relatively simple process, and can recover metals from battery waste in large quantities and quickly. It is a common recovery method and can recover multiple metals simultaneously before separation. Figure 3 shows a descriptive flowchart for pyrometallurgical recycling of LIB, Ni-Cd, and Ni-MH batteries.

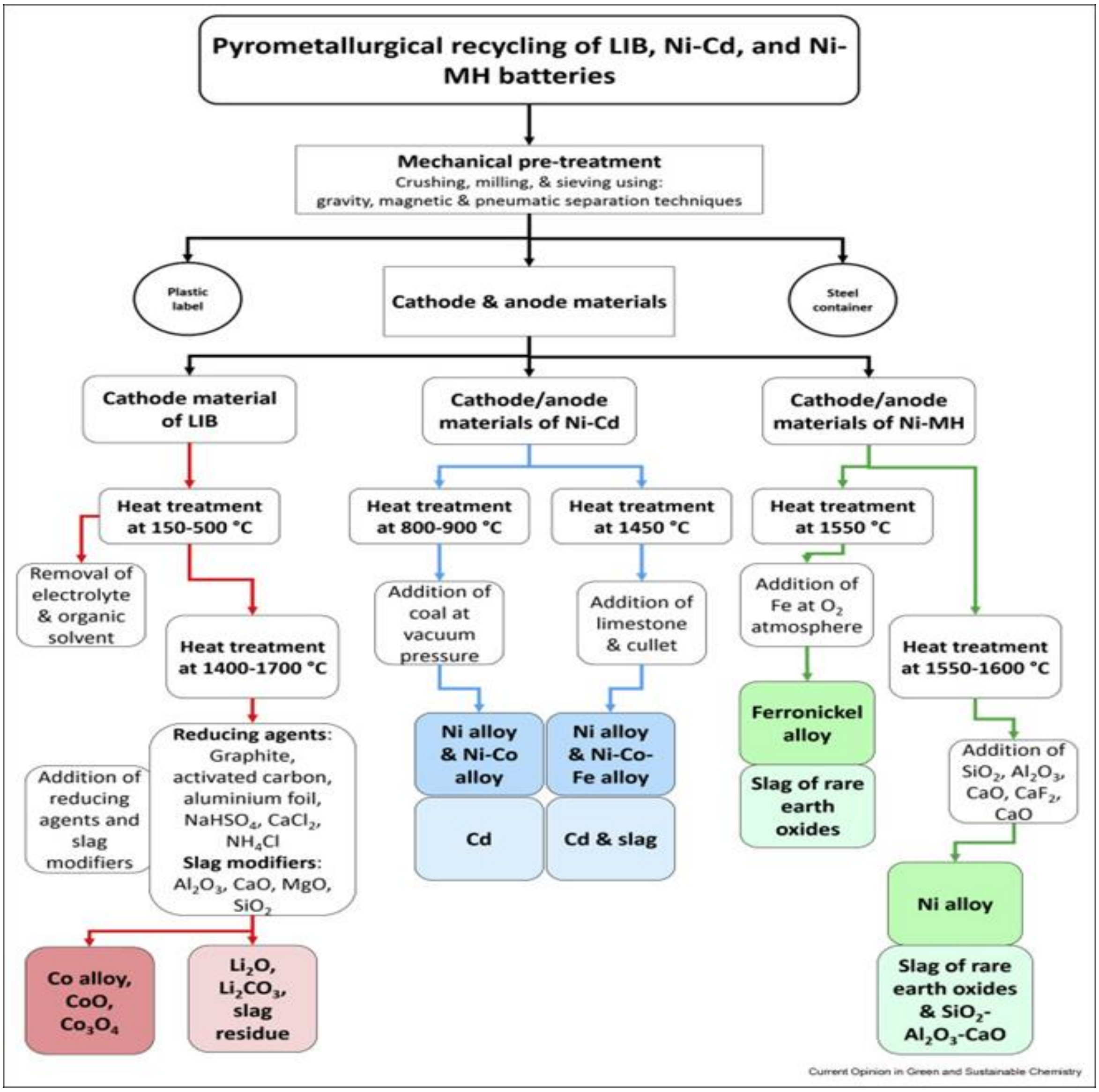

Figure 3. Battery Recycling Process.

Pyrometallurgy has certain defects and limitations, although it can recover the metal in the battery, but the recovery process will produce carbon dioxide, carbon monoxide and other polluting gases. Therefore, pyrometallurgical recycling of batteries often requires additional recycling steps and equipment, thus extending the recycling chain and finally disposing of the produced pollutant gases. Alternatively, the waste produced during the recycling of used batteries is subjected to a more stringent filtering process to bring its polluting gas emissions up to standard. After the above steps, it instead increases the technical difficulty of the work and the processing time.

Metal scrap at high temperatures remains in the reactor and generates waste metal slag in the short rotary furnace. The products of the Pb reduction process in the furnace and the harmful effects of the hazardous waste generated by the process on the environment were monitored. The main elements in the slag samples were: Fe, Na, Pb, S, C, As, Sb and Si. Most are heavy metals in the form of dust or slag [4]. Furthermore, heavy metals from slag are in most cases emitted to the atmosphere in the form of dust. Fe and Na are the main metallic elements in slag, and one of their properties is that they decompose on contact with air to form powders, which can lead to further air pollution. In recent years, existing environmental conditions in many countries have not been able to support pyrometallurgy as a mainstream means of battery recycling.

2.2. Electrochemical
Electrochemical methods are very mature and have low cost, high yield and environmental friendliness. It can be used in a wide range of different fields, with proven technology production in environmental remote sensing, material recovery and energy minerals. The most important use is the extraction/recovery of metals from different sources through electrochemical processes [5]. Electrochemical craftsmanship, such as electrodeposition or electrodialysis, can be used to recover metals of higher purity when this paper input a potential or current into an electrochemical instrument to initiate a non-spontaneous chemical reaction. Selective recovery of metals can also be achieved by changing the position of the cathode and anode or by changing the electrolyte [6]. The most basic electrochemical recovery processes used in manufacturing are the electrodeposition (electrodeposition) of metals from leaching solutions by reduction reactions, in this case, the metal ions in solution generally form a precipitate at the cathode electrode and change into solid metal form.

It was discovered that electrochemical processes that enable metal recovery can be applied in the mining industry by selective electrodeposition from natural ores to obtain the corresponding pure metals [7]. This technology soon attracted researchers who were developing sustainable recycling methods for scrap using this method to recover used lithium-ion batteries. Thus, it replaces the hazardous and costly chemical reducers, making the leaching process safer, easier to operate and more economical.

2.3. Bioleaching
Bioleaching is a green technology and a method with potential for development. This method allows the extraction of metals from used LIBs, printed circuit boards (PCBs) and other electronic waste [8.9]. This method uses microorganisms (such as bacteria, fungi and archaea) to extract metals from secondary resources such as ores, scrap iron or recycled waste, and is known as "bioleaching or biohygrometallurgy". Bioleaching technology was first developed for the recovery of metals from ores. The first commercial use was the recovery of copper using acid-producing eosinophilic bacteria [10]. After some time of research and technological development, bioleaching technology was also used in gold mining [11]. Over the years, the microorganisms used in bioleaching technology have been updated and have become more versatile in terms of their use, and it has become possible to recover metals from waste batteries. With the help of bacteria, the bioleaching process converts metal complexes from insoluble forms to water-soluble metals through biooxidation. In this process, the microorganisms rupture the metal waste, gaining energy by breaking it into its constituent metal complexes.

Compared to traditional recycling methods, bioleaching is a simpler production process, reduces investment in production materials and costs in the chain, shortens the construction time of production machines, and makes maintenance of the equipment simple and easy. Production takes place at normal atmospheric pressure and room temperature, so there is no need for temperature control equipment, alleviating manufacturing costs and reducing equipment requirements. The waste generated by bioleaching is environmentally friendly, which can also save on waste disposal costs, and bioleachate waste has few precautions and does not require an extended chain to recycle the waste generated. Finally, the bacteria used are easy to cultivate, can withstand a wide range of production conditions, and have a low water requirement, with 50 units of dissolved solids present in one unit of water. At present, the bioleaching process has been developed in a number of ways to become a more cost-effective and environmentally friendly alternative compared to the traditional process [12].

3. Sustainability and expectations of biorecycling

3.1. Recyclable substances

3.1.1. Structure of lithium battery. The original lithium battery used steel as the shell packaging, but for safety reasons, it was found that the aluminum shell mixed with Mn, Cu, Mg, Si, Fe, etc. was better than steel in weight and material structure, so the steel shell was gradually replaced by aluminum shell [13]. The cathode materials of power lithium batteries are usually lithium nickel-cobalt manganate, lithium nickel-cobalt aluminate, lithium carbonate, lithium cobaltate and lithium phosphate, and some transition metal oxides, which contain a large number of precious metals, such as Hg, Ni, Mn and Li, etc., so they are regarded as an important recyclable resource. Its negative material is also supported by copper foil, attached with binder and graphite, among which the adhesive is often some organic materials, so the recovery value is less than the positive material.

3.1.2. Precious metals in lithium batteries. The working principle of the battery is actually the REDOX reaction on the electrode [14]. In order to promote this reaction and improve the working performance of the battery, people will attach some precious metals on the carbon material as catalysts, such as Pt, Au, etc. The precious metals used as catalysts do not change with the use of the battery, so theoretically, the precious metals in these used lithium batteries can be completely recycled. This can not only reduce costs, but also reduce pollution to the environment.

3.2. Sustainability research

3.2.1. Advantages of bioleaching method. Although acid leaching is used by more people in the current recycling situation, in fact, bioleaching is less costly and does not require as much equipment. The dissolution and leaching of most precious metals in lithium batteries, such as Zn, Ag, Ni, Li and Mn, can be promoted only by some relatively special microorganisms for metabolism.

A series of relevant studies have been carried out by a lot of scholars. For example, Calvert et al. used hydrogen sulfide produced by sulfate reducing bacteria to recover metals in waste lithium battery filtrate in their experiments [15]. The results showed that the metabolism of *Vibrio desulphurization* was the best. The precipitation efficiency of Al, Ni, Co and Cu reached 99% under the action of biosulfide and NaOH solution, accounting for 96% of the total metal content in the waste lithium battery filtrate. Although the extraction rate of this process is high, it can not identify the metal. If it is to be recycled, it is necessary to carry out the subsequent supplementary process to separate the different precious metal precipitation. In this regard, some scholars make use of the uniqueness of some microorganisms to carry out targeted leaching of precious metals in waste lithium battery filtrate. Niu et al., for example, used *Bacillus aliphicylate* as SOB (sulfur oxidizing bacterium) and *Bacillus acidophilus* as IOB (iron oxidizing bacterium) respectively. In their experiment, Co and Li were extracted from waste lithium-ion batteries after 30 days of mixed culture, and mixed sulfur and pyrite were inoculated both SOB and IOB as mixed medium. The maximum extraction rates of Li and Co were 89% and 72%, respectively, when bioleached at 2% pulp concentration. These results indicate that the biological leaching method has greater development potential than the traditional chemical leaching method [16].

3.2.2. Current challenges. There are still some problems in the recycling of lithium batteries by bioleaching. Current lithium batteries still contain a certain amount of Hg, so when microbial metabolism is used for biological leaching, these Hg will often cause microbial poisoning to produce methylation, and these toxins will accumulate in the body, which is not safe for human beings for a long time.

As far as microbial culture is concerned, these special strains need to be specially cultivated, which requires harsh culture conditions and low leaching rate and processing capacity. If a large number of them are to be put into industrial biological leaching and recycling of waste lithium batteries, the problem of insufficient microbial supply needs to be solved.

3.3. Future outlook

Although bioleaching technology is superior to other traditional battery recycling technologies in terms of both cost and environmental protection, there are still some difficulties, such as longer leaching time and low leaching efficiency. In this regard, some researchers put forward the bioleaching method to improve it. Through the method of bioleaching, the experimental conditions can be changed continuously until the best leaching conditions are found. In this way, the leaching efficiency can be improved to a certain extent, and some studies even show that the leaching efficiency can be up to 90% or more. Another difficulty is the cultivation of related strains. In order to cultivate high quality strains, harsh environment is often required. Therefore, the actual cultivation effect of relevant strains is not ideal at present, and it is difficult to put into practical factory application in large quantities. In order to really use the biological leaching method to recycle a large number of waste lithium batteries, it is necessary to solve the problem of strain culture [17].

4. Conclusion

According to statistics, the consumption of lithium-ion batteries in China is huge, but the current recycling process is not perfect. Strengthening the recycling of used lithium batteries has become a hot topic in related fields. If a more mature recycling industry chain of used lithium batteries can be formed, it will bring significant economic and social benefits, and at the same time reduce the energy consumption of the whole society, it is also in line with the environmental protection concept of sustainable development. Although the recovery cost of pyrometallurgy is low and the efficiency is high, it will cause no small environmental problems. The treatment cost of electrolysis method is handed high, which is not suitable for China, as a developing country, to use on a large scale. Bioleaching method has good development prospect and does not cause pollution, and the recovery cost is not high, so it is a major direction for battery recycling in China in the future. In the future, the bacterial culture for bioleaching is the main press problem for developing this method. If different bacteria can be studied and cultured in a deeper level, and better strains can be obtained through the screening of good traits, it will promote the leaching efficiency of battery recycling to a greater extent, and promote the sustainable development of society.

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