Life Cycle Assessment (LCA)-based study of the lead-acid battery industry

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Abstract. Lead-acid batteries are the most widely used type of secondary batteries in the world. Every step in the life cycle of lead-acid batteries may have negative impact on the environment, and the assessment of the impact on the environment from production to disposal can provide scientific support for the formulation of effective management policies. A study was conducted on a lead-acid battery company using the life-cycle assessment method. The evaluation method of CML2001Dec07 provided by Gabi5 software was used to calculate and analyze the list, and the results showed that the environmental impact of the final assembly and formation stage was the greatest, among which, the most important type of environmental impact was the contribution of non-living resource consumption.

1. Introduction

Lead-acid batteries are a widely used chemical power source in the world at present, with the advantages of stable voltage, safety and reliability, low price, wide application range and high recycling rate. If the acid of lead-acid batteries is improperly disposed of, it will cause serious environmental pollution, and there is a shortage of resources, high energy consumption and serious pollution problems in the industry [1]. Using LCA in the lead battery industry, we can identify the environmental impact caused by the production process of lead batteries from the perspective of life cycle, and identify the key factors causing the environmental impact, so as to reduce the environmental pollution in the battery industry. Provide theoretical guidance.

Life Cycle Assessment (LCA) is a tool for evaluating the energy consumption and environmental impact of products, processes and services throughout their life cycle, from raw material collection to production, transportation, use and final disposal (generally referred to as cradle-to-grave). There are four sections relating to scoping, inventory analysis, impact assessment and interpretation of results.

Foreign researchers used the LCA method to assess the potential environmental impact of lead-acid battery regeneration plants that use the fire smelting process to regenerate lead, identified key pollution-producing links, and recommended that companies achieve low emissions through improved processes and better management in order to minimize the environmental impact [2]. Chen Yan et al. and Yu Yajuan used the Eco-indicator 99 system to compare the life cycle environmental impact of lead-acid, nickel-cadmium and lithium-ion batteries, and the environmental impact index was: lithium-ion < lead-acid < nickel-tin[3]. This paper takes a provincial lead-acid battery company as the main object of study, and uses the life cycle assessment method to determine the audit priorities and propose a cleaner production plan.
2. Basic situation of the enterprise
In this paper, a lead-acid battery manufacturer is selected as a research object, which has an annual output of 1.1 million KVAH lead-acid batteries. The production process is mainly divided into three processes: the preparation of raw materials, plate casting and final assembly and formation. At this stage, the main raw materials are plates and lead parts, and the main energy comes from raw coal and electric energy. According to the production process statistics of the enterprise, alloy lead and electrolytic lead in the raw material preparation process are taken as the starting point of production. In the raw material preparation process, the preparation of 1Kg of lead powder consumes 18.704Kg of electrolytic lead, the preparation of 1Kg of lead parts consumes 1Kg of alloy lead, in the pole casting process, the production of 1t of pole plate consumes 1.01t of alloy lead and 0.317t of acid. In the process of assembly and packaging, 0.36t of electrode plate is consumed to produce 1t of battery.

3. LCA implementation process

3.1. Purpose of evaluation
According to the principle of clean production audit and the actual situation of enterprises, considering the use and emission of lead in the production process of lead storage battery industry is the focus, through setting quantitative indicators, setting clean production targets and implementing clean production audit, the enterprise can achieve the goal of energy saving, consumption reduction, pollution reduction and efficiency enhancement [4]. In this paper, the production of 1t lead batteries is taken as the functional unit of the study.

3.2. System boundary
The process of lead battery in this enterprise is mainly divided into three parts: raw material preparation process, plate casting process and final assembly and formation process, therefore, three study scope boundary diagrams can be identified.

(1) The system boundary of the raw material preparation process is shown in Figure 1.

![Figure 1. Process system boundary for raw material preparation](image-url)
3.3. Inventory analysis

Data input and output statistics are calculated for the three main processes of lead-acid battery production: raw material preparation, plate casting, and final assembly and formation. This part of the data needs to be borrowed from the China Life Cycle Basic Database (CLCD).

The main pollutants produced by the enterprise are lead powder preparation, lead plate casting, lead parts manufacturing, battery assembly and formation and battery cleaning, etc. The main pollutants can be divided into waste water, waste gas (lead dust and lead fume) and solid waste (domestic garbage, waste lead slag, etc.), and the noise generated by the equipment operation is negligible. The list of
material consumption and pollutant emission of each process of producing 1t lead-acid battery is shown in Table 1.

**Table 1. Inventory of substance consumption and pollutant emissions by process.**

| Names               | Raw Material Preparation | Plate Casting | Final Assembly |
|---------------------|--------------------------|---------------|----------------|
| import resource     |                          |               |                |
| alloy lead (t/d)    | 0.036000                 | 0.360000      | —              |
| electrolytic lead (t/d) | 0.614000          | 0.000033      | —              |
| lead dust (t/d)     | —                        | 0.001550      | —              |
| barium sulphate (t/d) | —                        | 0.114000      | —              |
| Sulphate (t/d)      | —                        | 0.001500      | —              |
| sodium sulphate (t/d) | —                        | —              | —              |
| arctic plate (t/d)  | —                        | —              | 0.360000       |
| lead parts (t/d)    | —                        | —              | 0.036000       |
| Water (t/d)         | 2.340000                 | 3.920000      | 4.580000       |
| power source        | Electricity (kwh/d)      | 0.003000      | 0.006000       | 0.003300       |
| products            |                          |               |                |
| lead dust (t/d)     | 0.032827                 | —              | —              |
| lead parts (t/d)    | 0.036000                 | —              | —              |
| arctic plate (t/d)  | —                        | —              | 0.360000       |
| Batteries (t/d)     | —                        | —              | 1.000000       |
| output              |                          |               |                |
| environmental emissions |                        |               |                |
| lead fume (t/d)     | 0.000050                 | 0.000700      | 0.000062       |
| lead dust (t/d)     | 0.000040                 | —              | —              |
| Exahusts (t/d)      | —                        | 0.000010      | —              |
| Wastewater (t/d)    | —                        | 0.003150      | 0.003900       |
| lead slag (t/d)     | —                        | 0.004400      | —              |
| waste electrode (t/d) | —                        | 0.004600      | —              |
| waste battery (t/d) | —                        | —              | 0.003040       |

3.4. Environmental impact assessment software analysis process

The process of conversion into comparable environmental impact indicators through three steps: classification, characterization and normalization. In this paper, the life cycle assessment software Gabi5.0 was used for modelling and calculations, and the assessment model was the CML2001 characterization model developed by the Centre for Environmental Science at Leiden University, the Netherlands [5].

3.4.1. Type of impact classification. The types of effects in this paper include abiotic resource depletion (ADP), greenhouse effect (GWP), human potential toxicity (HTP), acidification (AP), and photochemical toxicity (POCP) [6]. The environmental emissions that cause the greenhouse effect are CO₂, those that cause the acidification effect are SO₂ and NOₓ, while human health damage involves the emission of SO₂ and NOₓ, and the formation of photochemical smog is related to the emission of NOₓ.

3.4.2. Characterization. Characterisation is the multiplication of the characterisation factor by the amount of pollutants emitted to obtain the size of the environmental impact potential (EIP), which converts the substances emitted during the production of lead-acid batteries into a uniform impact value of the standard reference material.

3.4.3. Normalisation. In order to better evaluate the relative magnitude of the results of each impact type parameter in the production process of 1t lead-acid batteries, it is necessary to represent the benchmark values of the selected type parameters. In this paper, the normalized benchmarks for 2000 global abiotic resource consumption, greenhouse effect, potential human toxicity, acidification and photochemical toxicity were selected using the default values from Gabi5.0 software, and the calculation and statistical results are shown in Table 2.
3.5. Life cycle outcome analysis studies

From Table 2, it can be seen that the most serious environmental impacts in the life cycle of lead-acid batteries are greenhouse gases, followed by potential human toxicity, acidification, photochemical smog and consumption of non-living resources. In order to further study the main sources of environmental problems in each process of lead-acid battery production, the impact of different types of environment in each process is analyzed.

According to the data, the environmental impact potential of the final assembly and formation process accounted for 66.442% of all production stages, the plate casting process accounted for 18.208%, and the raw material manufacturing process accounted for 15.350%. From these results, it can be seen that the environmental impact of the final assembly formation process is the largest in the production of lead battery industry, and is therefore considered the primary target of clean production. Among them, the consumption of non-living resources contributes the most, which is the main type of environmental impact of the final assembly process. Cleaner production can be achieved by adopting effective technologies to reduce the consumption of non-living resources.

At the formation stage, a large number of acid injection and battery charging and discharging processes are required, which consume a large amount of energy. So the process technology should be improved to save resources. The analysis shows that the second most important environmental impact of the production process is solid waste, therefore, the clean production audit process needs to focus on reducing the environmental impact of these two parts. In addition, the resource and energy consumption of lead battery production is also large, the audit process should pay attention to the source of production to reduce energy and material consumption, recycling of solid waste, in order to achieve the purpose of clean production.

4. Conclusion

(1) Using the life cycle assessment method, the data in the life cycle of lead-acid batteries were screened and calculated, and then assessed and analyzed by the CML2001 model to obtain the life cycle assessment results. The results showed that the normalized results for the consumption of non-living resources, potential human toxicity, greenhouse gas, acidification and photochemical toxicity of environmental emissions from the production of 1t lead-acid batteries were $9.11 \times 10^{-10}$, $6.85 \times 10^{-5}$, $2.07 \times 10^{-3}$, $2.97 \times 10^{-6}$, $2.21 \times 10^{-7}$.

(2) The environmental impact potential of the final assembly and formation process accounts for 66.442% of the environmental impact potential of all production stages, the plate casting process accounts for 18.208%, and the raw material manufacturing process accounts for 15.350%. From these results, it can be seen that the environmental impact of the final assembly formation process is the largest in the production of lead battery industry, so it is considered as the focus of clean production audit. Among the environmental impacts of the assembly and formation processes, the consumption of non-living resources contributes the largest proportion and is the main type of environmental impact of the assembly and formation processes.
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