© 2019 IJSRSET | Volume 6 | Issue 4 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section : Engineering and Technology
DOI : https://doi.org/10.32628/IJSRSET196444

Industrial Facilities for Recycling Lead Acid Batteries (LABS)

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ABSTRACT

This document provides some minimal guidelines (and requirements) for writing a research paper. Issues related to Batteries in the modern world have become ubiquitous in large quantities, in the sense that they provide energy for a wide range of products used in all parts of everyday life, from households to large industrial enterprises that have high energy requirements. Nowadays, more and more countries, collect and recycle lead batteries. However, the recycling process is quite dangerous if not properly controlled. The appropriate design of industrial facilities will minimize the hazards of the process, allowing a smooth development of materials and services, with higher added value, at minimum cost. This paper refers to a recycling batteries facility, where three mainly sectors positively contribute to the conservation of natural resources, energy savings, as well as the reduction of toxic gases and emissions.

Keywords : Industrial, Factory, Lead, Recycling, Battery, Anti-Pollution Technology

I. INTRODUCTION

The recent years, many countries showing an interest on low carbon footprint, while recycling, is the new trend of turning a trash into new product. But, before start looking for the recycling process, three things must be considered, plant location, the class of recyclable material will be recycled, and the placement of the facilities in the plant area. These three parameters often have a significant impact upon manufacturing costs, work in process, lead times and productivity. A land permission is also required from the local host city or country, which must comply with the environmental protection legislation of the respective state.

During this period new directives have been published especially in Europe [**1**]. The manufacturing and recycling of lead-acid batteries is practiced worldwide in both regulated industries and unregulated, informal establishments [**2**]. It is well known, that a battery converts chemical energy to electrical energy (**Fig. 1**).

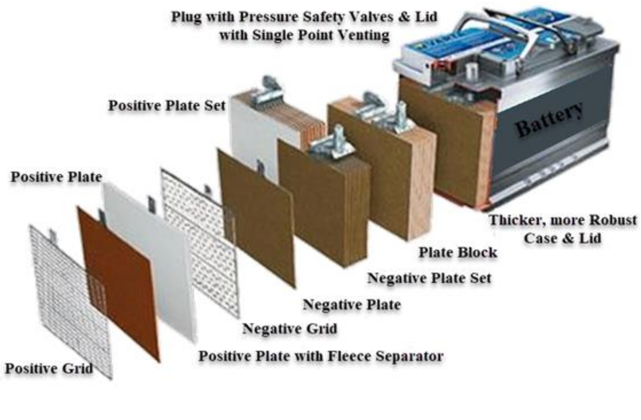

Figure 1. Structure of a lead acid battery according to [**3**].

Potentially hazardous components of batteries include apart from Pb materials such as mercury, copper, zinc, cadmium, nickel, cadmium and lithium [**4**]. When batteries are not properly disposed the casing may disintegrate and these toxic chemicals may leach into the surrounding environment. The leaking material is responsible for contamination soil and water while most of these elements can accumulate in wildlife and humans. Industrial waste management is another interesting sector for any business, because of the significant amount of waste that produces. If the waste disposal management is not the appropriate one, both employees and the environment may be at risk [**5-7**]. Therefore, implementation of recycling or proper disposal of any waste materials is necessary [**8**]. Recycling is the recovery of material from waste created in manufacturing and consumption, for reuse in the production of new items [**9**]. It is well known that lead is a highly toxic metal, and is quite dangerous, especially for young children. A small or high amount of exposure can cause many problems, such as reading impairments, psychological disturbances, and mental retardation [**10**], as well as, damage to brain and kidney, and other associated problems. It has been written that more than 3 million die each year due to lead contamination [**11**].

Increase in population and consequently increase in amount of consumed materials, has caused (large quantities of wastes generated) serious crisis in human societies [**12, 13**]. Nowadays, China is the largest exporter and consumer of lead acid batteries [**14**]. The next decades is likely to see batteries investments approaching the $548 billion, as costs falls [**15**]. It has been also reported, that 1,288 gigawatts of new batteries will be commissioned by 2050 [**16**] while in year 2000, in Europe only 5 billion units of batteries were produced [**17**]. Advanced recycling facilities must be developed. Besides, recycling benefits everyone. It enables the reuse of materials that would otherwise be used and discarded. The cost of energy, the raw materials, the type of transportation to be used, and the availability of labor all depend on the plant site. In this paper, a recycling lead battery facility is discussed, which involves collection and storage, battery crushing and separation, smelting refining and pollution control equipment for the fumes and gases generated during operation of the above furnaces.

II. LEAD-ACID RECYCLING INDUSTRIES TARGETS

The main objectives of a lead-acid recycling industry are to protect the environment, and to decrease energy consumption as well as to protect the employees. Despite this interest, chemicals and heavy metals, contaminates water and soil. Moreover, other recycling processes, includes the mineral processing techniques, pyrometallurgical [**19-21**] and hydrometallurgical [**22**] treatment. Energy efficiency is also an important objective for industries, by reducing as much as possible the global greenhouse gas emissions [**23**]. However, this is a very difficult task. A serious weakness is that the lack of capital for investments and others [**24**]. Systematic analysis and optimization are undergoing a revolution in terms of reducing the energy consumption of industrial enterprises.

New methods can increase the productivity and the safety of the workers from several kinds of hazards. Workers should be informed, instructed and trained by the technical engineers of the company [**25**]. Nowadays, many reports have shown that lead (Pb) exposure continues to be a major public health problem worldwide [**26-28**]. Lead (Pb) is a neurotoxicant and could produce alterations in many organs and has the capability to interfere with many biochemical events, especially in children and adolescents [**29, 30**]. Generally, Pb is responsible for a range of illnesses [**31-35**]. Furthermore, it is well known, that the consumption of Pb is in the manufacture process of Pb batteries [**36**]. The assessment of human exposure to toxic metals in the environment through measurement of those chemicals or their meta- bolites in human specimens is termed biomonitoring [**37**]. However, industry goals can be as broad or as specific as the administration wants them to be. Continuous growth and improvement create new jobs, where residents will be able to work [**38**].

III. PLANT CONFIGURATION AND DESIGN

A. Location of a lead-acid recycling battery factory

One of the most important strategic decisions for any company is the site selection, since it affects long-term profits and costs. Some locations may offer competitive advantage and may contribute to the success of an enterprise [**39**]. Such factories, mainly constructed in industrial areas (zones), where often possess strong government support, a legal and regulation framework, with a significant economic and social returns.

The cost of land where a factory is being built is a key factor to determine its success. For instance, accessibility to railroads, commercial ports, airports and roads are necessary for the transportation of raw materials and final products to and from the factory [**40**] (**Fig. 2**).

The plant size depends on the cost of energy, raw materials, the type of transportation to be used, and the availability of labor. It will be useful, the (suppliers)-markets to be close to the factory, in order to minimize the transportation time of the raw materials. The parameter "labor" plays also an important role. Industries that are far away from cities usually must pay higher wages to attract workers. Workers are always attracted by other facilities, such as schools, hospitals, housing, recreation clubs and more so on [**41**].

Figure 2. Batteries recycling facilities in industrial area.

Moreover, fuel, power and water are indispensable for industries. In a lead-acid factory, a substantial amount of power is required. Industrial areas provide a developed infrastructures network. For instance, industrial area offers electric power or electricity, water supply network, drainage and sewerage network, natural gas, fire brigade and wastewater treatment [**42**].

Extreme dry or humid climate would be catastrophic for battery industries. Locations with relatively stable climate allow batteries to be stored with lower cost and more safely than extreme humid and dry climates, where batteries could provoke a fire, if not stored under specific conditions. A typical legal requirement is storage of batteries raw materials in an enclosed indoor space. Another interesting thing is the wind direction which will determine the general location of vessels. Extreme caution must be taken for the equipment which spills flammable materials. All this equipment's must be located on the downwind side of the factory.

Government laws and policies could increase the cost of such industry. Different countries provide industries with different benefits, tax collections and subsidies. It should be mentioned that changing a location decision is a very difficult and expensive process [**43**]. Government laws and policies could increase the cost of such industry. Different countries provide industries with different benefits, tax collections and subsidies. It should be mentioned that changing a location decision is a very difficult and expensive decision [**44**]. However, a recycling plant is typically divided mainly into three sectors, raw storage materials (1), processing sector (2) and lead ingots sector (3) (**Fig. 3**).

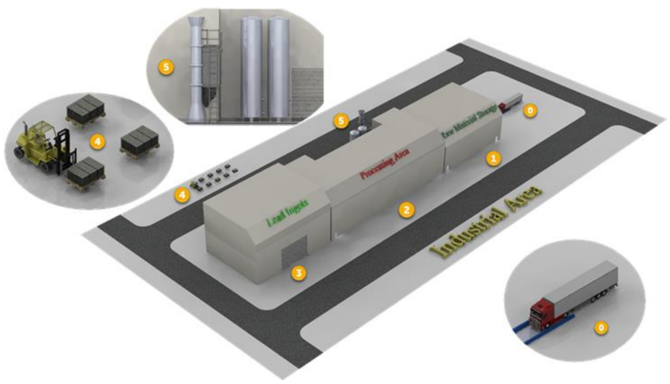

Figure 3. Lead acid recycling factory.

Recommended font sizes are shown in Table 1.

B. Collection of raw materials and transportation

It is well known, that all used lead acid batteries (ULAB) are recyclable. However, such batteries must be packaged and transported separately from other battery types. Batteries should not be drained at the collection point. They should be stored securely and sheltered from the extreme dry and humid conditions. A weak point in a collecting system of ULAB runs on purely economic criteria, which means that without a central and proper control there is a higher risk of leakage of the sulfuric acid from the disposed batteries into the environment [**45**]. That means, lead acid batteries and spent lead acid batteries shall be stored in compliance with all local, state and federal regulations to prevent contamination or injury from acid spillage or leakage. The collection of batteries could involve a variety of vehicles including vans, box trailers or whatever is available to the collectors. Usually, the raw materials arrive at recycling factories by trucks or ships (containers), if a commercial port is accessible (**figure 3, No. 2 and 3**) [**46**]. Before the raw material being stored, each truck must be weighed by a truck scale. A *truck scale* is a significant investment for any industry. Significantly, truck scales are used to ensure the incoming and outcoming weight, respectively.

Another important reason that trucks must be weighed is safety (**figure 2, No. 0**). The raw material storage (**sector 1, No. 1, figure 2**), should be well ventilated and the ground should be coated with acid-resistant concrete or other resistant material. Leaking batteries should be placed in acid-resistant containers. The number of stored batteries should be numbered, which means that the storage sectors must be large enough. A recycling plant should never shut down, under normal circumstances, because of a lack of raw materials. On the other hand, the product storage (**sector 3, No. 3 and 4, figure 2**) must be large enough that it does not impede production process. It is not very economical to shut a plant down because the warehouses are full. It should be noted, that the storage size increases with the plant size.

A. Process zone in a lead acid recycling plant

In order to facilitate recycling of used ULAB, five steps are involved, collection, crushing, sorting, sieving and pyrometallurgy and hydrometallurgy processes. Desulfurization process of paste produced is an advanced technique that modern facilities utililize. The target is to reduce Sulfur content as low as possible, in order to facilitate the operation of foundry – furnace, meaning much less additives used, and slag produced. These last two processes are applied in association with pretreatment of spent LABs. Reviewing subsequent and more recent literature, hydrogen peroxide is used to dissolved copper (hydrometallurgical process), while in order to control slag quantity, a carbon/alkali borate flux at 1150–1300°C should be melted (pyrometallurgical process). A flow diagram is presented in Appendix I (**figure 4**), while a typical modern recycling plant facility is presented in Appendix II (**figure 5**). Moreover, metals such as lead and tin are leached under hot conditions, by hydrochloric acid. Other observations indicate that the above metals and copper, can be recovered by thermal reduction.

According to the flow diagram, the batteries are brought in the receiving area (**Fig. 4a-Fig. 5 Sector 1**). In this area the batteries are grouped and separated. Only the lead-acid batteries continue to the second step of the process, because ion-lithium batteries are considered to be highly hazardous, flammable and could cause a significant problem to the production process [**47**]. Crushing is the next step. On reaching the recycling facility, the battery is broken apart in a hammer mill. Batteries are smashed into little pieces and the weak electrolyte – sulfuric acid (H_2SO_4) is separated from the plastic, metal and lead pieces (**Fig. 4a-Fig. 6 Sector 1**). Liquids and solids follow a different processing scheme.

The electrolyte is neutralized by a strong base in a desulphurization-neutralization reactor, usually with NaOH or CaOH, or Sodium Carbonate Na_2CO_3 and salt is produced. The salt is then distilled, nano-filtrated, crystallized in order to produce sodium sulphate. The remaining liquid, including water, from the distillation process could be reused in the factory after a quality control. In other words, that sodium sulphate (salt) can then be sold in many manufacturing processes, like detergent and glasswork (**Fig. 4b-Fig. 6 Sector 1**).

From the above process, the resulting plastic pieces, such as polypropylene, are cleaned using water and dried (**Fig. 4c-Fig. 6 Sector 2**). Then they are transported to another factory where further processing (melting and pellet making). Resulting lead pieces are being also cleaned with water and filtered; two main lead materials is the resulting form batteries crushing: lead paste as Pb oxides and lead grids as metallic Pb. Slag is produced after the furnace treatment (**Fig. 4d**). Lead parts are being molten inside a furnace (**Figure 4d-Fig. 6 Sector 2**) [**48, 49**]. Inside a rotating furnace, the lead is created by adding additives, such as anthracite, cast iron and soda ash.

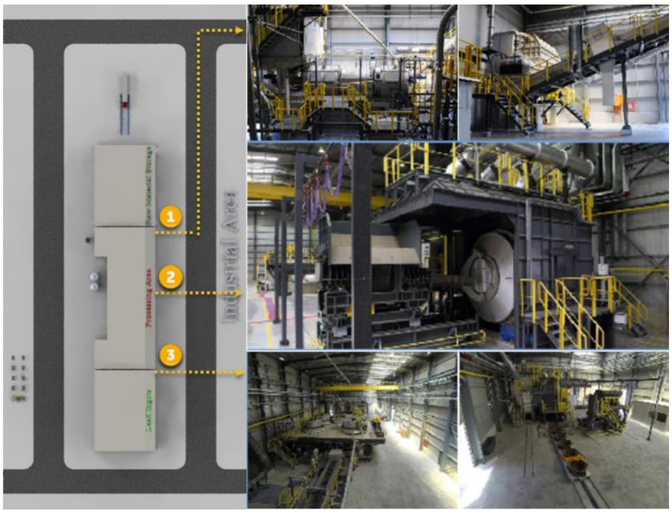

Figure 6. Lead acid recycling factory sectors.

Metal grids and lead plates are created by solidification of the molten lead into molds. (**fig. 6, sector 3**). By following the above process, a new battery can be produced by using recycled materials. These batteries must be controlled and shipped after charging for 30-40hours (**Fig. 4e**).

B. Equipment list

In a recycling factory (as it happens in any industry) the process equipment is defined directly from the detailed flow sheet. Each equipment is placed according to the layout to minimize, (1) damage to persons; (2) maintenance costs; (3) the number of people required to operate the plant; (4) construction costs; and (5) the cost of the planned future expansion.

Equip. List	A.	B.	C.	D.
a	20-60	20-40	25-30	48,58-62
b	50-100	30-50	1	49,58-62
c	30-60	30-40	1-3	50,58-62
d	40-80	35-45	11-15	51,58-62
e	50-100	20-35	15-21	52,58-62
f	70-140	30-40	2.5-7.5	53,58-62
g	90-150	20-40	17-25	54,58-62
h	100-160	40-60	7.5-12.5	55,58-62
i	30-80	40-60	1-2	56,58-62
j	15-40	60-70	1	57,58-62

Table 1. The main characteristics of the equipment units. The energy consumption for each unit is given as the percentage of the total energy consumption (*).

Note 1: A: Cost (103) $, B: Efficiency (%), C: Energy consumption (%), D: References

Note 2: a: Hammer crusher, b: Sink/Float separation tank, c: Desulphurization reactor, d: Nano filtration, e: Plastic melting machine, f: Molding plastic machine, g: Rotating lead smelting furnace, h: Lead casting molding machine, i: Rotating sieve, j: Electrolyte filling machine.

Obviously, all these goals cannot be met. In order to increase factory productivity, the appropriate size equipment must be selected.

For instance, keeping large machinery clean and having a maintenance and repair schedule can increase productivity and reduce risks. Another, interesting parameter is the hours of operation and the cost of purchasing and installing of each piece of equipment. The operating hours usually varies from 7,900 (small plants with new technology) up 8,760 hours (large plants), while the equipment is either difficult to operate or very expensive, it is desirable to specify equipment large enough to handle the expansion. Equipment units can have a rectangular or irregular shape. In this study, the main equipment units are, the hammer crusher, the sink/float separation tank, the desulphurization reactor, the nano-filtration-crystallization system, the plastic melting machine, the molding plastic machine, the rotating lead smelting furnace, the refining kettles, the lead casting molding machine, the rotating sieve and the electrolyte filling machine. In order to increase productivity, the machines are automatic. One of the major advantages to exploiting this automation systems are sensors, PLCs and motor drives.

For instance, sensors would monitor and measure (pressure, temperature, pH and weight). The main characteristics (cost, efficiency, energy consumption) of each equipment are given in table 1. These values vary according to capacity.

C. Control room and laboratory

The control center [**63, 64, 65**] and the electrical switching room in a recycling factory is always located in an enclosed building. By having a control room enables, quickly access mission-critical processes applications, supports faster alarm resolution, integrate control access across multiple systems, and so on. Such services provided safety in the case of emergency.

Control room operators control material and energy flows, which are made to interact with and transform each other. Such transformations (physical or chemical), incorporates the continuous and batch processing of materials and energy in their operations [**66**]. This confirms that, quality control laboratories are a necessary part of any plant. The main priority of the lab is to optimize the process and monitor the quality of the products by testing. All tests are provided, in order to keep the national (DIN), international, company and group standards.

IV. POLLUTION CONTROL TECHNOLOGY AND IMPACTS

In a recycling lead acid batteries factory, all sectors (mining/concentrating,smelting/refining, manufacturing, and recycling) release gaseous and particulate emissions, either as point sources through stacks or as fugitive emissions [67]. Other pollutants such as SO2, NOx and trace quantities of arsenic or volatile organic compounds (VOCs) are monitored in particular locations, depending on local air quality requirements. Wastewater treatment is another critical issue, while is known that battery wastewater is characterized by its pH, BOD, TDS, COD, Sulphate, Chlorine and others [68].

Environmental engineers must ensure environmental performance. Environmental considerations need to incorporate into engineering in order to assure, (1) zero discharge of liquid waste into the environment; (2) zero liquid toxic waste and air pollutants. Moreover, the appropriate selection of best available techniques and antipollution technology, could reduce (a) the production of solid waste (slag) and (b) reduce lead emissions through installation of dedusting baghouses [**46**].

China was found to be the leader of lead emissions in Asia [**69, 70**]. In order to minimize air emissions, different equipment's could be installed such as electrostatic precipitators, fabric filters or bughouse and wet scrubbers [**71**]. Such technologies can reduce the concentration of substances in process off-gas [**72**]. It is written, that in a lead acid battery industry, the bughouse technology provides 90% efficiency to separate air pollutant like acid mist, leady fumes and particulate matters (**figure 6, No. 1**).

Furthermore, in lead acid battery industries (manufacturing or recycling process) contains mainly sulfuric acid (H2SO4) at a pH of 1.2 - 3 and soluble Pb2 + ions at a concentration of 5 -15 mg L^{-1}. Alkaline substances such as sodium hydroxide, sodium carbonate can adjust pH in the appropriate range (5.5-9). This process (neutralization) cannot reduce the Pb concentrations. Macchi et. al. [**73**], propose a mixed precipitation/coagulation process based on $Fe(OH)_3$ co-precipitation. The acidic property of the air increases because of SO_2, SO_3, during electrolytic process, which is very harmful for the environment. For instance, acid rain absorbs aluminum from the soil, which might be harmful to plants as well as animals. Also, acid rain removes minerals and nutrients from the soil that trees need to grow and might strip nutrients from trees foliage. On the other hand, dry acidic particles of acid rain which are made from nitric and sulfuric acid, can land on all metal or concrete structures, causing damage to their surfaces.

The acidic particles corrode metal and dirty the surfaces of buildings and other structures such as monuments [**74**]. Usually, the main parts of fume neutralizer tank consist of four elements, (a) blower; (b) neutralizing tank; (c) NaOH dozing tank; and exhaust chimney (**figure 6, No. 2**).

Moreover, materials such as glass plastic scrape, and pastes (leady and its oxides) are treated as hazardous waste [**75**]. Leady paste generated from effluent treatment plant (ETP) and dry lead from air treatment plant (ATP) which are sent for recycling of lead. It has been found that this kind of treatments, has not any direct ill effect to worker. What's more, the lead oxide pastes, and the discarded plastic scrapes are sent for recycling.

V. CONCLUSION

This paper gives a brief overview for a lead battery recycling factory which involves four basic steps, collection, crushing, sieving, and processes (hydrometallurgical or pyrometallurgical).

Unfortunately, such businesses are small compared to the vast of quantities of batteries. It is well known, nowadays, only lead acid can be recycled profitably. However, a battery recycling factory, is also a great source of significant emissions. On the other hand, recycling saves, (1) natural resources; (2) energy; (3) landfill space; and (4) money. Equipment's such as, electrostatic precipitators, fabric filters or bughouse and wet scrubbers ensures the effective control of gases and fumes. Every battery recycling business must follow all the appropriate environmental practices.

The most critical and difficult process is to select the site for an industrial recycling plant. It is mainly governed by considerations, such as the economic analysis of the costs. These factors for the site selection are the (a) location of raw materials; (b) location of markets; (c) transportation; (d) water quality; (e) climatic conditions; (f) labor; (g) taxes; (h) construction and utilities costs; and (i) pollution requirements.

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Cite this article as :

Panagiotis J. Charitidis, Savvas Symeonidis, Stefanos Dimitriadis, Christos Manolis, Savvas Chavianidis, Christos Dimitriadis, "Industrial Facilities for Recycling Lead Acid Batteries (LABS)", International Journal of Scientific Research in Science, Engineering and Technology (IJSRSET), Online ISSN : 2394-4099, Print ISSN : 2395-1990, Volume 6 Issue 4, pp. 331-340, July-August 2019. Available at doi : https://doi.org/10.32628/IJSRSET196444

Journal URL : http://ijsrset.com/IJSRSET196444