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Identifying the environmental aspects of recycling used batteries(Case study: Parsian Part Industrial Complex, Pasargad)

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Abstract
One of the most prominent applications of lead is in the production of lead-acid batteries. Lead-acid batteries are used in most industries. They are small assemblies for storing energy through the controlled use of chemical reactions. Despite the existence of many advantages of batteries in industries, due to their high level of poisoning and threat to the health of humans and the environment and to preserve primary resources, their recycling is mandatory. Recycling used lead batteries can have effects on the environment. Melting lead components produces hazardous lead fumes. Lead fumes and dust released during the recycling process can become airborne to deposit on soil, water bodies, and other surfaces and contaminate the vicinity of recycling plants. Waste materials from lead processing also pollute land and water. Therefore, in the current research, the environmental effects of recycling lead-acid batteries on the natural environment, including soil, water, and air, were discussed, and then reduction solutions and corrective measures were pointed out

Keywords: :“ Battery” , “lead” , “recycling” , “pollution

Introduction

Heavy metals are among the most significant and well-documented environmental pollutants, with their introduction into ecosystems leading to various health disorders. Consequently, the imperative to monitor and control pollution stemming from these metals has grown increasingly urgent [2]. Among heavy metals, lead has garnered particular attention due to its extensive use in diverse industries, including battery manufacturing, military applications, alloy production, and fuel additives [1]. The battery manufacturing sector is a major global consumer of lead, with estimates indicating that approximately 80 percent of the lead used as raw material in this industry, particularly in developing nations [2].

Lead, a heavy metal, is primarily utilized in the form of lead oxide paste within the battery manufacturing industry. Lead-acid batteries [3] serve as essential energy storage devices. In these batteries, lead, a naturally occurring element in the Earth's crust, undergoes extraction, processing, and utilization across various countries. However, due to its toxicity, lead poses significant dangers, adversely affecting both environmental integrity and human health [3]. Given its extensive range of applications, lead contamination can occur in geological formations, soil, and even water bodies. Lead and its compounds can infiltrate the human body through respiratory pathways, subsequently entering systemic circulation and affecting various organs. Notably, organic lead compounds are also capable of transdermal absorption [2].

Despite the widespread industrial applications and benefits of batteries, their potential toxicity and associated health and environmental risks are considerable. Consequently, the presence of hazardous and toxic substances, including various heavy metals in battery production, necessitates strict adherence to environmental and health regulations, as well as the adoption of advanced technologies in the collection and recycling processes. According to a global ranking, the recycling of lead-acid batteries is among the most hazardous industrial processes. As previously noted, lead-acid batteries pose numerous environmental challenges, underscoring the need for their recycling to be conducted under stringent guidelines. The collection, transportation, and recycling of these batteries must be managed in a manner that minimizes associated risks. It is noteworthy that lead-acid batteries are classified as hazardous waste upon reaching the end of their service life. Recycling lead batteries offers multiple benefits, including reducing environmental pollution, conserving natural resources, saving energy, and creating employment opportunities. Given the profound impact of recycling used batteries on the natural environment, this study seeks to evaluate the effects of battery recycling on water, soil, and air pollution and proposes measures to mitigate these impacts.

Methodology

Environmental Status of the Study Area

Qom Province is situated in the central region of Iran. It is bordered to the north by Tehran Province, to the east by Semnan Province, to the south by Isfahan

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Province, and to the west by Markazi Province. Additionally, it lies to the west of the Salt Lake. Covering an area of 11,238 square kilometers, Qom Province is geographically positioned between longitudes 50 degrees, 4 minutes, and 40 seconds to 51 degrees, 58 minutes, and 10 seconds east, and latitudes 34 degrees, 9 minutes, and 28 seconds to 35 degrees, 13 minutes, and 15 seconds north.

As of 2019, Qom Province is administratively divided into one county, five districts [4], six cities [4], and nine rural districts [5]. The province includes 367 villages, with 224 inhabited and 137 uninhabited. The Salafchegan District, located within Qom County, has a population of approximately 10,000 and is situated 40 kilometers from the county center. This district comprises two rural districts: Rahjerd and Nizar [6].

The project area covers 150,000 square meters [5] and is located within Qom Province, Qom County, Salafchegan District, and Nizar Rural District

Parsian Part Pasargad Industrial Complex

Established in 2006, the Parsian Part Pasargad Industrial Complex was founded with the primary aim of recycling used lead-acid batteries in Iran. The complex, which began operations in 2009, emerged after the transfer of technology from Italy and the subsequent construction and installation of specialized machinery. Its core operations involve the production of various types of pure and alloyed lead ingots.

The Parsian Part Pasargad Industrial Complex not only caters to the Iranian market but also extends its reach to Asia, the Middle East, and Europe. In addition to its primary focus on lead production for battery manufacturing, the complex also engages in the production of two additional products: sodium sulfate, utilized in the detergent and tissue paper industries, and polypropylene granules, which are employed in the production of polymeric goods.

Methodology

The production of lead-acid batteries constitutes approximately 85% of the global demand for refined lead. This demand is predominantly met through recycled lead, with used lead-acid batteries serving as the primary source of this recycled material. However, the recycling process for lead-acid batteries is associated with significant environmental pollution and poses substantial risks of human exposure to heavy metals, particularly lead, which can have serious and long-term health effects [6].

Lead can be released at various stages throughout the recycling process. For instance, the discharge or leakage of lead-contaminated electrolytes can result in contamination of soil and water. Mechanical or manual disassembly of batteries can release lead particles and contaminated dust [7]. The smelting of lead components generates hazardous fumes, which can disperse into the air and settle on soil, water bodies, and other surfaces, thereby contaminating the areas surrounding recycling facilities [7].

During the collection and transportation phases, sulfuric acid electrolytes are sometimes discharged to reduce the weight of batteries or because higher prices are offered for discharged batteries. If discharge does not occur at this stage, the electrolyte may be released at the recycling site [8]. Additionally, electrolytes may leak from damaged batteries during storage and transport [8]. Inadequate precautions to prevent skin contact with acids can result in corrosive damage. If lead-containing electrolytes leak instead of being collected in appropriate containers or if they spill onto the ground, lead can infiltrate soil particles, subsequently becoming a source of lead dust.

Given the substantial environmental pollution associated with lead-acid battery recycling, it is crucial to investigate off-site pollution around these facilities. Potential environmental impacts of lead exposure include soil and dust contamination, air pollution, water contamination, and risks to food safety. Therefore, this study aims to assess and analyze the environmental factors related to the recycling process, considering the nature of the project and the effects of its various stages.

Analysis of Environmental Pollutants and Their Sources in the Project

Air Pollutants

1. **Emissions from Combustion**: A significant source of air pollution in lead-acid battery recycling facilities arises from emissions related to furnace operations. In the current project, the furnaces are fueled by gas and oxygen, with diesel utilized during emergencies to maintain furnace operation. As a result, potential emissions include hydrocarbons, sulfur oxides, carbon monoxide, and nitrogen oxides. However, it is noteworthy that at the Parsian Part Pasargad facility, sulfur oxides are mitigated through a sulfur removal process from stack emissions, thereby excluding them as a pollutant of concern for this project.
2. **Emissions from Transportation**: Air pollution is also contributed by the transportation of personnel, batteries, and final products. This transportation is predominantly conducted using diesel-powered vehicles. Diesel vehicles are known to be major sources of hydrocarbons, particulate matter, carbon monoxide, and nitrogen oxides, which can significantly affect air quality in the vicinity of the project site and surrounding areas. The impact of these pollutants on air quality is influenced not only by their concentration but also by factors such as the air's capacity to disperse them, as well as environmental conditions like wind, temperature, and precipitation. While some vehicle and industrial emissions

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may not pose immediate health risks under normal conditions, their effects can be exacerbated during atmospheric inversions, which hinder the dispersion of pollutants.

3. Process-Related Emissions: Various stages of the recycling process can lead to the emission of smoke, lead particles, and other pollutants into the air. Research indicates that in lead-acid battery recycling facilities, there is a risk of exposure to elevated levels of airborne lead, which is associated with increased lead concentrations in workers' blood [9]. Furthermore, airborne lead eventually settles, contaminating surrounding surfaces. The movement of battery components within the recycling facility and the sieving of mixed plastic waste for lead particle recovery can also release lead dust. Additionally, other toxic substances, such as arsenic, antimony, barium, cadmium, and sulfur dioxide, may be emitted during the recycling process [9]. As lead components are transported within the facility, such as on open conveyor belts or when introduced into the furnace, lead particles and dust are released into the air. Lead fumes are particularly hazardous because their fine particle size allows for inhalation and absorption into the lower respiratory tract [9]. These fumes eventually settle as lead particles on surrounding surfaces and soil, contributing to lead dust that can be inhaled. The dispersion of lead from these sources can be considerable and presents significant challenges for control.

Water and Wastewater

During the separation process in lead-acid battery recycling, water utilized in automated systems for separating lead from other components becomes significantly contaminated with lead compounds. If this water leaks or is not properly treated before disposal, it can lead to soil contamination. As the water evaporates, residual fine lead dust may remain and could be dispersed by wind. Key sources impacting the quality of surface and groundwater in this phase include:

1. Water Contaminated with Lead Particles
2. Pollution from Accidental Leaks, Such as from Storage Tanks
3. Sanitary Wastewater from Employee Activities

Soil Pollutants

Beyond air pollution, lead-acid battery recycling facilities are recognized as significant sources of lead contamination in soil, contributing to soil and dust pollution. For instance, numerous cases of lead poisoning associated with soil contamination from battery recycling have been documented around recycling facilities in various countries [10]. Additionally, studies have found elevated blood lead levels in children residing near these facilities [10]. Contaminated dry soil can also lead to the dispersion of lead dust throughout the community, posing risks of inhalation or direct contact [11]. Lead, a toxic heavy metal, poses substantial risks to human health, wildlife, and natural habitats, as heavy metals do not decompose and thus accumulate in the soil. Lead contamination in soil and its transfer through the biological food chain [12] can result in chronic health issues for humans and other organisms. Lead exposure can occur through inhalation, ingestion of contaminated food or water, and contact with lead dust or fumes. It is a cumulative toxin that gradually accumulates in the body, causing serious long-term health problems, predominantly storing in bones and teeth. Some of the absorbed lead that is not excreted exchanges with blood and soft tissues, including the liver, kidneys, lungs, brain, spleen, muscles, and heart [13].

The principal soil pollutants in this context are attributable to the following factors:

1. Processes Involving Mechanical Breaking
2. Leaks from Solvent Storage Tanks
3. Improper Management of Acidic Drainage
4. Diesel Leaks from Storage Containers
5. Spills and Leaks from Waste Transport Vehicles

Waste

Plastic waste generated from the battery recycling process constitutes a significant byproduct at these facilities. Such waste may contain lead particles or other hazardous metals, which, if not managed properly, can result in the release of pollutants into the air, water, and soil, thereby adversely affecting both the environment and human health [11]. Field observations indicate that approximately 50 kilograms of plastic mix are produced per ton of batteries processed. Over 14 years of operation, a considerable volume of this plastic mix has been generated and inadequately stored on-site. This waste contains lead and other dangerous heavy metals, contributing to pollution of the air and soil. Additionally, other waste types, such as temporarily stored plastic pellets intended for reuse and lead slag reserved for sale to authorized companies, are also present on-site. The current practices for the temporary storage of these materials are associated with environmental contamination.

Noise Pollution

The primary sources of noise pollution in lead-acid battery recycling facilities include the operation of machinery such as hammers and crushers for breaking batteries, transportation of batteries and products, conveyor systems, and the production of battery casings. The adverse effects of noise pollution from

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various industrial processes can be mitigated through effective noise management strategies within the facility [12]. Moreover, personnel working in these environments should be protected from high noise levels by using appropriate personal protective equipment, such as earplugs. To minimize lead emissions and environmental pollution, it is essential that recycling processes be conducted in facilities equipped with engineering controls designed to limit lead release. These controls include fully automated and enclosed operations, air filtration systems, and wastewater treatment facilities. Additionally, workers at recycling centers should receive proper training and be provided with suitable personal protective equipment and facilities for changing into clean clothing [14].

Discussion and Conclusion

Lead battery recycling provides substantial environmental benefits; however, it also poses significant environmental risks. The recycling process for lead batteries can release lead particles into the atmosphere, contributing to air pollution. Additionally, toxic gases such as sulfur dioxide and carbon monoxide may be emitted during this process. If wastewater generated from lead recycling is not adequately treated, it can contaminate groundwater and surface water, which may adversely affect aquatic flora and fauna. Improper management of recycled lead can lead to soil contamination, which can further impact the health of plants and animals inhabiting the soil [12].

Sabouhi et al. [13] examined heavy metal contamination in battery recycling workshops in Yazd, identifying significant environmental impacts associated with these pollutants. Their study revealed that high concentrations of heavy metals in these workshops result from interactions between heavy metal components in waste products, such as electronic waste and batteries, and dust, which is anthropogenic in nature. Notter et al. [15] explored the environmental impacts of lithium-ion batteries used in electronic devices and concluded that the overall environmental impact of batteries is approximately 15%, primarily due to the use of aluminum and copper in the production of battery anodes and cathodes. Van der Kuijp et al. [15] investigated the health risks associated with lead-acid battery manufacturing in China over a seven-year period and found that blood lead levels in children exposed to this industry exceeded 100 micrograms per mole. This finding indicates substantial lead contamination resulting from the production, repair, and use of lead-acid batteries in China. Gao et al. [15] assessed the environmental risks near a typical lead-acid battery recycling plant in China and found that concentrations of lead and arsenic in ambient air and vegetables near the plant were above standard limits. Their health risk assessment indicated that daily exposure to hazardous materials poses a greater risk to children compared to adults.

Recommendations and Corrective Actions

The implementation of any national project, while offering substantial economic and social benefits to the region, also entails potential negative impacts. These impacts can be identified, assessed, and managed through appropriate measures. Corrective actions, mitigation strategies, and enhancement plans are essential for addressing and reducing environmental impacts through engineering and environmental management practices. It is important to recognize that complete eradication of negative impacts is not feasible; however, their intensity and scope can be significantly diminished [14]. The primary activities necessary to mitigate the adverse environmental impacts of the project are outlined as follows:

Air Pollutant Reduction Program:

- Fabric Filters: Install fabric filters in the granulation unit to capture vapors and mists [15].
- **Baghouses:** Utilize four baghouses to collect dust, lead particles, and kiln gases, including two in the kiln, one in the refining unit, and one in the secondary refining unit.
- Scrubbers: Implement scrubbers in the crushing unit [15].
- Online Monitoring: Establish an online monitoring system for stack emissions [15].
- **Ventilation:** Ensure proper ventilation in the battery bush production unit.

Soil Pollutant Reduction Program:

1. Physical Removal of Contaminated Soil: Physical removal of contaminated soil represents the simplest method for treating lead-contaminated soil, involving excavation and disposal at secure landfills. Key challenges with this method include the potential for pollutants to migrate from the landfill to other areas, complicating stabilization efforts. Pollutants should ideally have minimal solubility or volatilization potential to facilitate control at the disposal site. Techniques such as surface capping, barriers, and vertical filters can be employed to prevent horizontal and vertical migration of contaminants. Additional concerns include air, surface water, groundwater pollution, and noise pollution from excessive machinery traffic. This method can be effective for large areas of heavily contaminated soil in industrial sites, provided the contamination is not excessively widespread or deep. It may also be applicable in scenarios involving the demolition of structures and clearing entire blocks [16].

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2. Stabilization or Solidification: Solidification and stabilization technologies aim to reduce the solubility of contaminants and isolate polluted soil from the surrounding environment using impermeable layers. This approach involves the use of solidifiers and stabilizing agents such as Portland cement, lime, silicates, clays, and polymers to stabilize the soil at its original location. The success of this method depends on forming bonds between the solidifying agents and the contaminants. Essentially, contaminated soil is mixed with binding materials to immobilize lead and reduce the risk of leaching [16].
3. Bioremediation: Bioremediation employs microorganisms, such as bacteria, fungi, and algae, which can degrade or transform toxic compounds into less harmful substances, to remediate soil and water contaminants. Soil microorganisms can produce enzymes that convert lead into less toxic forms, thereby reducing its solubility and toxicity. A key mechanism involves the production of organic acids by bacteria, which dissolve lead-bearing minerals in the soil and convert them into soluble lead complexes. These complexes are then absorbed by bacteria and transformed into elemental lead or less toxic forms. Additionally, bacteria can produce extracellular polymeric substances [17] that create a protective coating around lead particles, reducing plant uptake. EPS also serves as a source of energy and nutrients for bacteria, promoting their growth and activity in the soil. Bioremediation utilizes naturally occurring microbial populations, and when their numbers are insufficient, the process may be slow. This approach may require the addition of nutrients or other amendments to support microbial growth and activity [16].

Water Pollutant Reduction Program:
In the studied project, operating within a closed system with no wastewater discharge, the only wastewater produced is human wastewater from personnel activities, which is disposed of via a soak pit. In addition to wastewater, factors contributing to soil and water pollution include leaks and infiltration of diesel and acids. These issues have been addressed through proper concrete flooring in these areas, as observed during field inspections. Additional measures include:

- Runoff Prevention: Install drainage systems on-site to prevent runoff [18].
- Monitoring Wells: Establish monitoring wells to control leakage of contaminants from storage areas [18].
- **Waste Disposal Management:** Monitor and control the stability and erosion of waste disposal areas through regular inspections and observations.

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