ISLAMIC UNIVERSITY OF TECHNOLOGY
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Study of Automotive Battery Recycling and Development of a Sustainable Method

BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

November 2019

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CERTIFICATE OF RESEARCH

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DECLARATION

I hereby declare that this thesis entitled "Study of Automotive Battery Recycling and Development of a Sustainable Method" is an authentic report of our study carried *out as requirement for the award of degree B.Sc. (Mechanical Engineering) at Islamic University of Technology, Gazipur, Dhaka, under the supervision of Dr. A.R.M. Harunur Rashid, MPE, IUT during January 2019 to November 2019.*

The matter embodied in this thesis has not been submitted in part or full to any other institute for award of any degree.

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Acknowledgments

We would like to express our sincere gratitude to our advisor, Dr. A.R.M. Harunur Rashid for the continuous support of our Undergraduate study and research, for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped us throughout the span of our research and eventually writing of this thesis.

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Abstract

Lead-acid batteries are most widely used automobile batteries all over the world. Many waste batteries are thrown away every year. But the fact is that lead is only found in nature and therefore it has limited supply. Also, thrown away lead can cause lead pollution to animals and plants which can be fatal. So, the best option is to recycle the battery. In this research, existing factory process of lead-acid battery recycling are analyzed and a sustainable method is proposed. This research is beneficial to least developed countries where there are not enough recycling factories and recycling cost is higher.

Keywords: Industrial engineering, environmental pollution, sustainable design.

Chapter 1: Introduction

Battery recycling is a recycling activity that aims to reduce the number of batteries being disposed as municipal solid waste. Batteries contain a number of heavy metals and toxic chemicals and disposing of them by the same process as regular trash has raised concerns over soil contamination and water pollution.[1] Recycling old batteries reduces waste, and since up to 99 percent of a lead-acid battery is recyclable, it also reduces the need to use new raw materials and components. Instead of keeping your old battery, be sure it gets recycled by leaving it with the counterperson when you purchase a replacement, or by dropping it off at any local battery retailer. Automotive retailers will usually provide a credit for your used battery when you purchase a new one. Follow all safety precautions when handling your old battery.

The lead–acid battery was invented in 1859 by French physicist Gaston Planté and is the earliest type of rechargeable battery. Despite having a very low energy-to-weight ratio and a low energy-to-volume ratio, its ability to supply high surge currents means that the cells have a relatively large power-to-weight ratio. These features, along with their low cost, make them attractive for use in motor vehicles to provide the high current required by automobile starter motors.

As they are inexpensive compared to newer technologies, lead–acid batteries are widely used even when surge current is not important and other designs could provide higher energy densities. In 1999 lead–acid battery sales accounted for 40–45% of the value from batteries sold worldwide (excluding China and Russia), equivalent to a manufacturing market value of about $15 billion.[2] Large-format lead–acid designs are widely used for storage in backup power supplies in cell phone towers, high-availability settings like hospitals, and stand-alone power systems. For these roles, modified versions of the standard cell may be used to improve storage times and reduce maintenance requirements. *Gel-cells* and *absorbed glass-mat* batteries are common in these roles, collectively known as VRLA (valve-regulated lead–acid) batteries.

In the charged state, the chemical energy of the battery is stored in the potential difference between the pure lead at the negative side and the PbO_2 on the positive side, plus the aqueous sulphuric acid. The electrical energy produced by a discharging lead–acid battery can be attributed to the energy released when the strong chemical bonds of water (H_2O) molecules are formed from H^+ ions of the acid and O^{2-} ions of PbO_2.[3] Conversely, during charging the battery acts as a water-splitting device.

Battery Recycling by Type: Most types of batteries can be recycled. However, some batteries are recycled more readily than others, such as lead–acid automotive batteries (nearly 90% are recycled) and button cells (because of the value and toxicity of their chemicals).[4] Rechargeable nickel–cadmium (Ni-Cd), nickel metal hydride (Ni-MH), lithium-ion (Li-ion) and nickel–zinc (Ni-Zn), can also be recycled. There is currently no cost-neutral recycling option available for disposable alkaline batteries, though consumer disposal guidelines vary by region.[5]

Chapter 2: Previous Work

The past five decades have witnessed the evolution of environmental technologies and management practices from end of pipe treatment (e.g., reactive, driven by regulations, no regard for resource consumption, limited accountability), to pollution prevention (e.g., reduce, reuse, recycle), to design for environment (e.g., proactive, beyond compliance, lifecycle analyses, ISO 14000), to most recently sustainable development (e.g., triple bottom line, multi-faceted accountability for both public and private sectors)[6]. In today's global economy, the practice of sustainable development is of particular importance to the handling of toxic materials such as lead in order to encourage industrial organizations and its stakeholders to take an active role in maximizing human and environmental health.

The focus of this study is on lead and lead compounds as they make up the largest hazardous waste stream in the US according to the Toxic Release Inventory. We adopt an evidence-based approach to explore strategies for maximum lead recovery and recycling so as to encourage the designated US stakeholders to promote their social responsibility via sustainable development with the goal to greatly eliminate unused scrap and waste along the product lifecycle which makes use of lead or any of its compounds. In this study, we will concentrate on the lead acid battery product as evident from statistics shown in the next section. Currently, there is limited information on recycling rates for lead-acid batteries in the published literature. The recycling rates for recovering lead from spent LAB is approaching 99.2% for the 1999 to 2003 time period [7]. Although very encouraging, such rates appear to be significantly higher than those reported for other countries. For example, the recycling rate for LAB is 85% in Western Europe, (there are no other sources comparing recycling rates over the same time period) [8]. Therefore, the current state of recycling efforts in the US has been unclear so as to determine the strategies for maximum lead recovery and recycling in the face of significant demands for LAB particularly in the auto industry.

Prior to 1900s lead in the US was primarily used for ammunition, brass, burial vault liners, ceramic glazes, leaded glass and crystal, paints or other protective coatings, pewter, and water lines and pipes [9]. In the early 1900s, lead uses expanded to include bearing metals, cable covering, caulking lead, solders and type metal. By the mid-1900s, the growth in lead use was derived from the production of public and private motorized vehicles and associated use of starting-lighting-ignition (SLI) lead-acid storage batteries and metal for gas tanks. In addition, the use of lead was drawn from radiation shielding in medical analysis, video display equipment, and gasoline additive.

By the late 1900s, the use of lead was significantly reduced or eliminated in non-battery products, including gasoline, paints, solders, and water systems. As the use of lead in nonlead battery products has continued to decline, the demand of lead has continued to grow in SLI and non-SLI LAB applications (e.g., motive sources of power for industrial forklifts, mining equipment, airport ground equipment, uninterruptible power systems in telecommunication networks). In the early 2000s, the total demand for lead in all types of lead-acid storage batteries represented 88% of apparent US lead consumption. Other significant uses included ammunition (3%), oxides in glass and ceramics (3%), casting metals (2%) and sheet lead (1%). The remainder (b1%) was consumed in solders, bearing metals, brass and bronze billets, covering for cable, caulking lead, and extruded products.

Chapter 3: Objectives

- To recycle lead-acid batteries in a small scale - This process is targeted for developing countries where there are not enough or no recycling plants. One spent battery was recycled using a moderated version of existing recycling process.

- To reduce recycling cost - This process aims to reduce cost per battery using manual labor.

- To minimize lead pollution - Developing countries without proper recycling facilities might tend to landfilling which would cause massive lead pollution. Our research targets to reduce the lead pollution in those countries.

- To minimize plastic pollution - Landfilling will also cause plastic pollution. This process also aims to reduce plastic pollution.

Chapter 4: Theory

Lead-acid batteries include but are not limited to: car batteries, golf cart batteries, UPS batteries, industrial fork-lift batteries, motorcycle batteries, and commercial batteries. These can be regular lead–acid, sealed lead–acid, gel type, or absorbent glass mat batteries. These are recycled by grinding them, neutralizing the acid, and separating the polymers from the lead. The recovered materials are used in a variety of applications, including new batteries.

The lead in a lead–acid battery can be recycled. Elemental lead is toxic and should therefore be kept out of the waste stream.

Many cities offer battery recycling services for lead–acid batteries. In some jurisdictions, including U.S. states and Canadian provinces, a refundable deposit is paid on batteries. This encourages recycling of old batteries instead of abandonment or disposal with household waste. In the United States, about 99% of lead from used batteries is reclaimed.[10]

Businesses that sell new car batteries may also collect used batteries (or be required to do so by law) for recycling. Some businesses accept old batteries on a "walk-in" basis, as opposed to in exchange for a new battery. Most battery shops and recycling centers pay for scrap batteries. This can be a lucrative business, enticing especially to risk-takers because of the wild fluctuations in the value of scrap lead that can occur overnight. When lead prices go up, scrap batteries become targets for thieves.

According to the U.S. Environmental Protection Agency, specialized lead-acid battery recyclers crush old batteries into nickel-sized pieces and separate out the different components. The plastic in lead-acid batteries is mostly polypropylene (also known as PP or by the resin code #5), which has a high heat tolerance. It can be recycled. The lead in the batteries is sold to companies that make new batteries.

The lead-acid battery gains its environmental edge from its closed loop cycle. The typical new lead-acid battery contains 60 to 80 percent recycled lead and plastic. When a spent battery is collected, it is sent to a permitted recycler, where under strict environmental regulations, the lead and plastic are reclaimed and sent to a new battery manufacturer. The recycling cycle goes on indefinitely. That means the lead and plastic in the lead-acid batteries have been and will continue to be recycled many times over.

In a recycling plant, the battery is broken apart in a hammer mill, a machine that hammers the battery into pieces. The broken battery pieces are then placed into a vat, where the lead and heavy materials fall to the bottom and the plastic floats. At this point, the polypropylene pieces are scooped away and the liquids are drawn off, leaving the lead and heavy metals. Each of the materials goes into a different recycling "stream".

Plastic - Polypropylene pieces are washed, blown dry and sent to a plastic recycler where the pieces are melted together into an almost liquid state. The molten plastic is put through an extruder that produces small plastic pellets of a uniform size. The pellets are put back into manufacturing battery cases and the process begins again.

Lead - Lead grids, lead oxide and other lead parts are cleaned and heated within smelting furnaces. The molten melted lead is then poured into ingot molds. After a few minutes, the impurities float to the top of the still molten lead in the ingot molds. These impurities are scraped away and the ingots are left to cool. When the ingots are cool, they're removed from the molds and sent to battery manufacturers, where they are re-melted and used in the production of new batteries.

Sulfuric Acid - Old battery acid can be handled in two ways: 1. The acid is neutralized with an industrial compound similar to household baking soda. Neutralization turns the acid into water. The water is then treated, cleaned, tested in a waste water treatment plant to be sure it meets clean water standards. 2. The acid is processed and converted to sodium sulfate, an odorless white powder that's used in laundry detergent, glass and textile manufacturing.

Lead acid batteries are closed-loop recycled, meaning each part the old batteries is recycled into a new battery. It is estimated that 98% of all lead acid batteries are recycled.

The research we performed involved a moderated version of this process. The process was conducted manually. One spent battery was used for the experiment. This process was targeted for developing countries where there are not enough or no recycling plants. We used power drills to drill holes in the battery to open it up for acid neutralization reaction. Distilled water was used to wash up the battery. It was crushed using grinders and hammers. The broken battery was put in a hydro-separator made of stainless steel. To conduct the separation process, the separator was filled with water which caused the lead to sediment below and the plastic to float up. The plastic was withdrawn from above. The water was then drained leaving the lead and some impurities inside the separator. The process had to be stopped there due to unavailability of a furnace nearby.

Chapter 5: EQUIPMENT

Following equipment were used in the research:

(1) Lucas 12v lead-acid battery

(2) Power drill

(3) $NAHCO_3$ (Baking soda)

(4) Distilled water

(5) Grinder and hammer

(6) Hydro-separator made of stainless steel

Lucas 12V Lead-acid Battery:

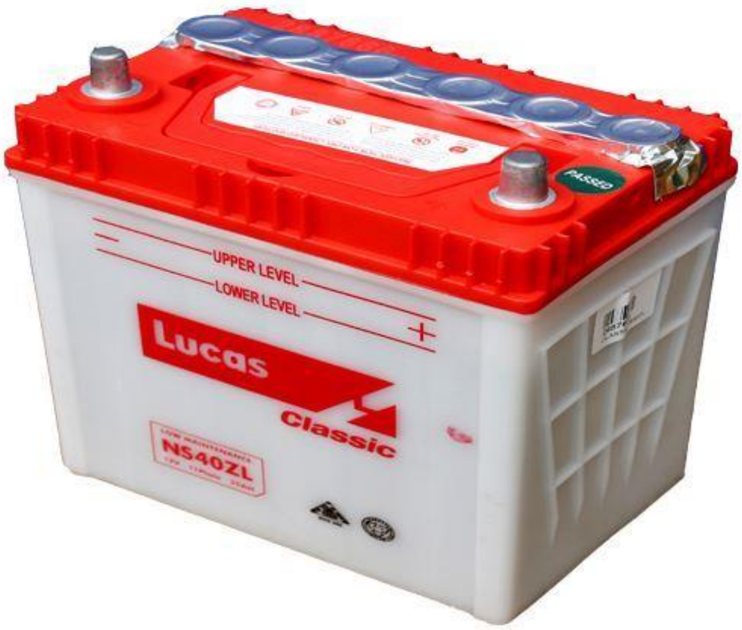

Figure 01: Lucas 12V Lead-acid Battery

The specifications of the used battery are:

Brand: TVS LUCAS

Voltage: 12V

Warranty: 48 months

Weight: 12.6 kg

Battery capacity: 45 Ah

Power Drill:

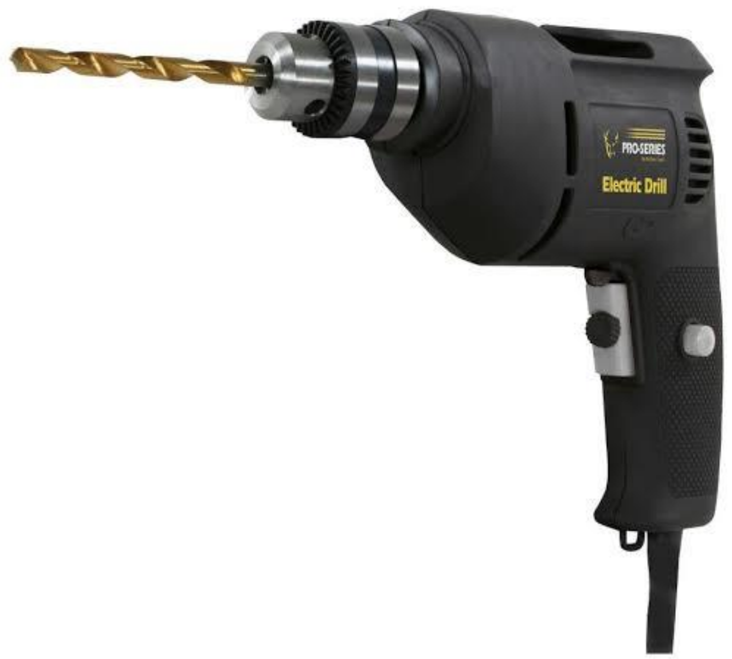

Figure 02: Power Drill

Power drill was used for making holes in the battery. Before crushing the battery, holes were made at the corners. It was done for separating the upper plastic part in order to crush the battery properly.

$NaHCO_3$ (Baking Soda):

Vehicle batteries contain some amount of acid, so we had to neutralize the acid first before crushing the batteries. Because acid can burn the skin. Here we used baking soda as a neutralizer. A hidden talent of sodium bicarbonate better known as baking soda is neutralizing acids, including strong varieties such as hydrochloric acid. When baking soda is mixed, a mild base with acids, a chemical reaction turns the acids into harmless byproducts, such as salt and carbon dioxide. It effectively neutralized the corrosive nature of battery acid.

Figure 03: Baking Soda

Distilled water:

A battery uses sulfuric acid as the electrolyte of a specific concentration. During the charging and discharging cycles, part of the water gets lost and the concentration of the acid increases. The ability of the battery to charge and give the current decreases with this and the battery can get damaged if the concentration of the acid increases unchecked. To bring the concentration to the required levels, water is added. If ordinary tap water is used, the impurities in the water like metal ions react with the acid. To avoid this, we used distilled water which is free of impurities.

Hammer:

Our one of the main objectives was recycle lead-acid batteries in a small scale. As we know automobile factories use furnaces for crushing batteries. Putting the batteries in furnaces was not our goal. Instead of using furnace we used hammers, grinders can be used too. Before crushing the batteries make sure the acid is neutralized.

Hydro-separator:

In our research we used a hydro-separator for separating the extracted lead from other impurities. We used a tub which was made of stainless steel. Stainless steel is mostly inert and it is much stronger because of its excessive strength. The tub we used was 18 inches in length, 12 inches in width and 10 inches in height. The volume of this tub was 2160 cubic inches.

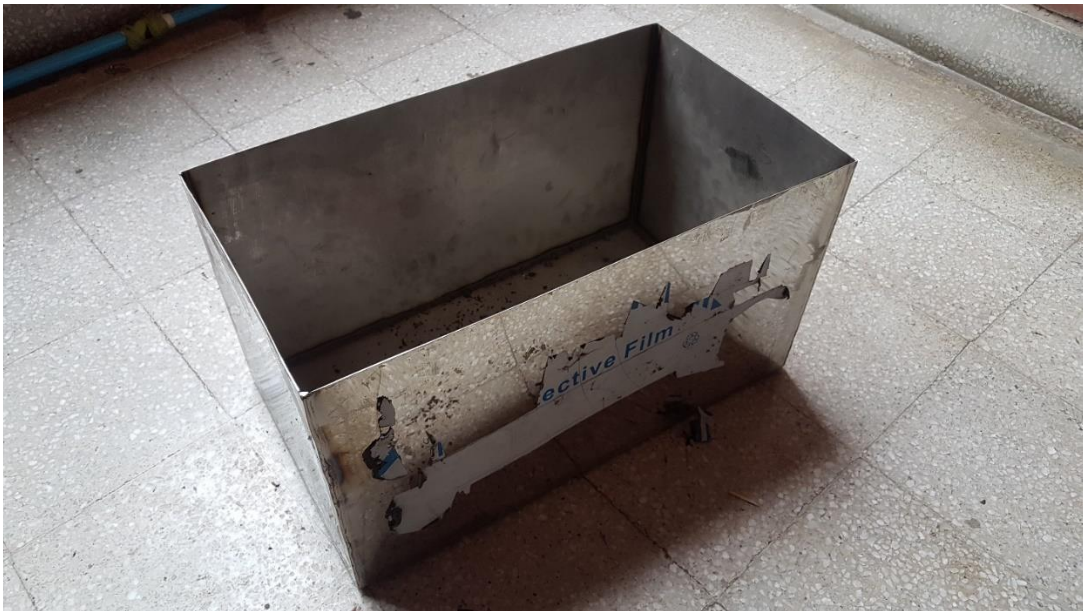

Figure 04: Stainless-steel Hydro-separator

Chapter 6: Methodology

6.1 Step 1 - Acid Neutralization

Battery Acid, the electrolyte in all lead / acid cell batteries, is sulfuric acid (H_2SO_4) at a concentration of between 15% and 35%. At this concentration sulfuric acid is very dangerous and will react with almost everything especially organic material including human flesh.

Battery acid must be neutralized before it is disposed of and battery acid, although very dangerous, can be safely neutralized yielding harmless salts. The pH neutralization of sulfuric acid or any concentrated acid is a hazardous task, however, the risks can be controlled. The heat liberated from the neutralization of sulfuric acid (battery acid) is very high and can result in a temperature rise of over 100^0C (212^0F). In the lab we have measured temperatures as high as 250^0F.

If extreme care is not exercised the energy released during the neutralization cycle can be explosive and, at a minimum, be sufficient to melt all thermoplastics. Digital Analysis utilizes a unique process for the neutralization of battery acid one in which the rate of reaction is constantly controlled and is limited by temperature. As the temperature of the process rises and begins to approach a field defined setpoint the rate of reaction is slowed or even halted as is dictated by the rate of rise. Additionally, cooling water can be added in the event that the temperature rises beyond a safe level.

As a spent battery was used, the remaining acid was not powerful enough to cause damage. Still the neutralization process was carried out in order to eliminate any risk factor. The reaction was carried out inside the battery chamber after drilling holes on top using power drills. Sodium bicarbonate ($NaHCO_3$), commonly known as baking soda was used as the neutralizer. The chemical equation of the reaction:

H_2SO_4 (*aq*) + $2NaHCO_3$ (*aq*) = Na_2SO_4 (*aq*) + $2CO_2$ (*g*) + $2H_2O$ (*l*)

6.2 Step 2 - Washing the Battery

After the neutralization reaction salt, water and carbon dioxide were produced. Carbon Dioxide was in gaseous form and it left the battery chamber with wind. Salt and water remained inside the battery chamber. Before crushing the battery, these products had to be washed out. So, distilled water was used to wash up the battery. Distilled water was inserted into the battery through the same hole that was made using power drills for Sodium bicarbonate solution to enter the battery chamber for neutralization reaction. The battery was shaken properly and then drained with proper caution. Then the battery was again rinsed with distilled water to clean it up properly. The washed battery was left out to air dry.

6.3 Step 3 - Crushing the Battery

The washed-up battery was held in place using vice. A hand-grinder was used to open up the battery from different sides. Hammers were used to crush the battery.

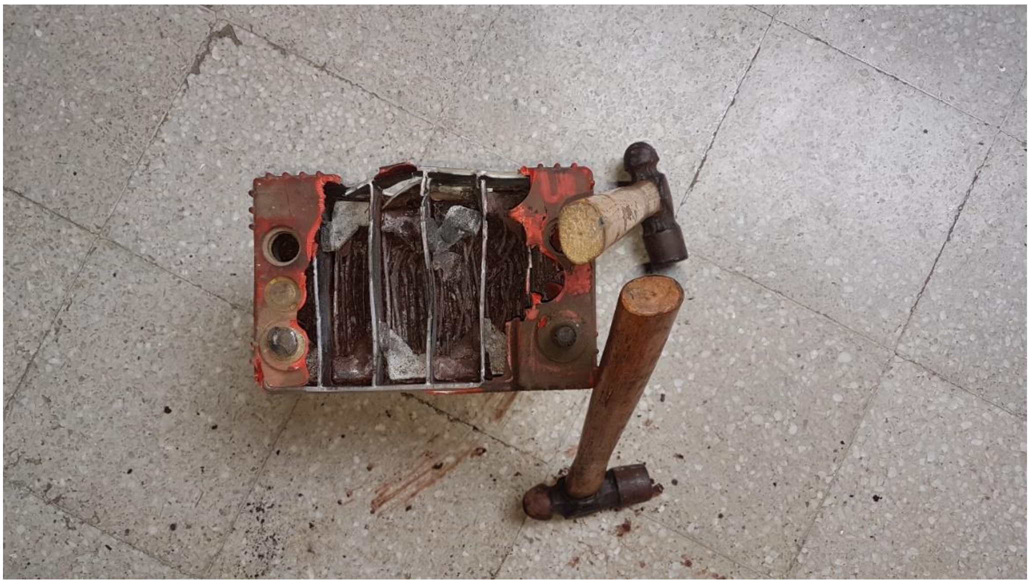

Figure 05: The battery being crushed using hammers

6.4 Step 4 - Hydro Separation

The hydro-separation process was carried out inside a separator made of stainless steel. The crushed battery bits were put inside the separator. Then the separator was filled with enough water. After leaving it for a while, the plastic bits floated up as they were lighter than water. Lead sedimented below as lead is heavier than water. Plastic and some other floating wastes were extracted from the top using a strainer. Then the water was drained leaving the lead inside the separator. There were some impurities and wastes along with the lead which could later be separated.

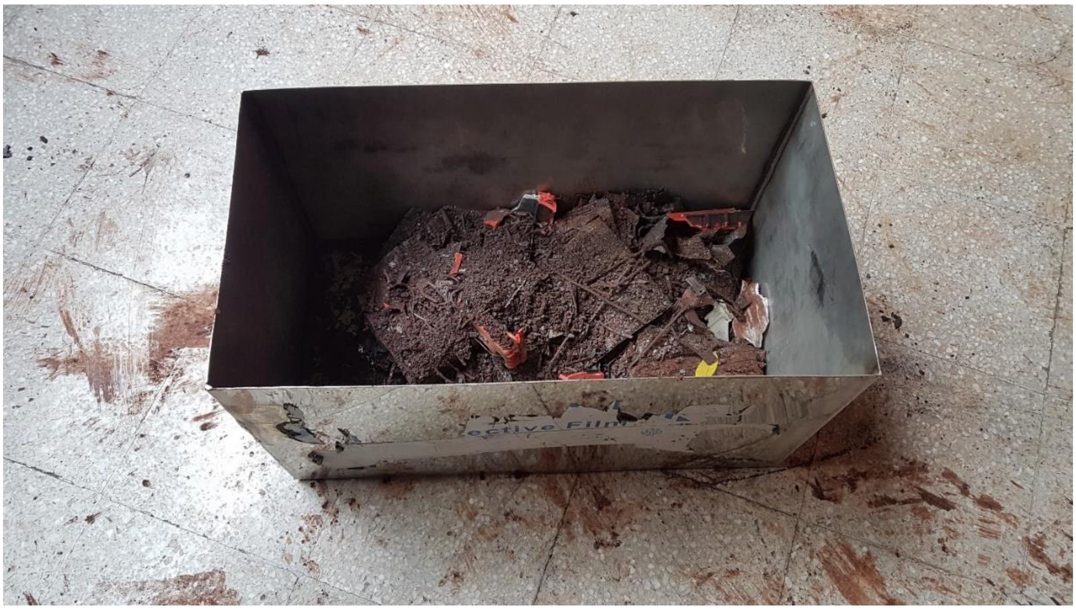

Figure 06: Crushed battery bits inside the hydro-separator

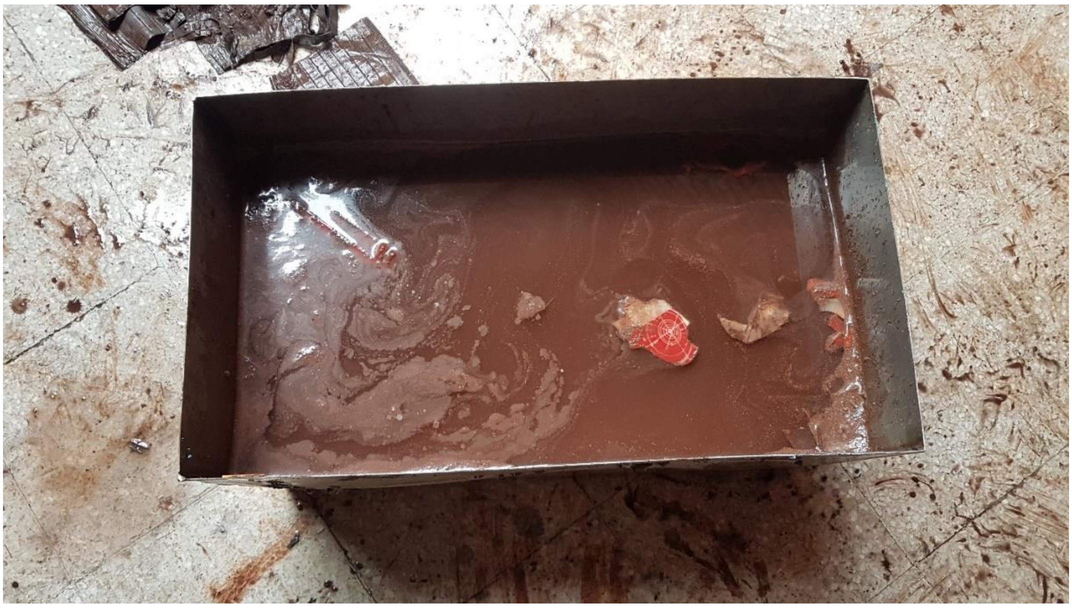

Figure 07: Hydro-separator filled with water and plastic bits floating up

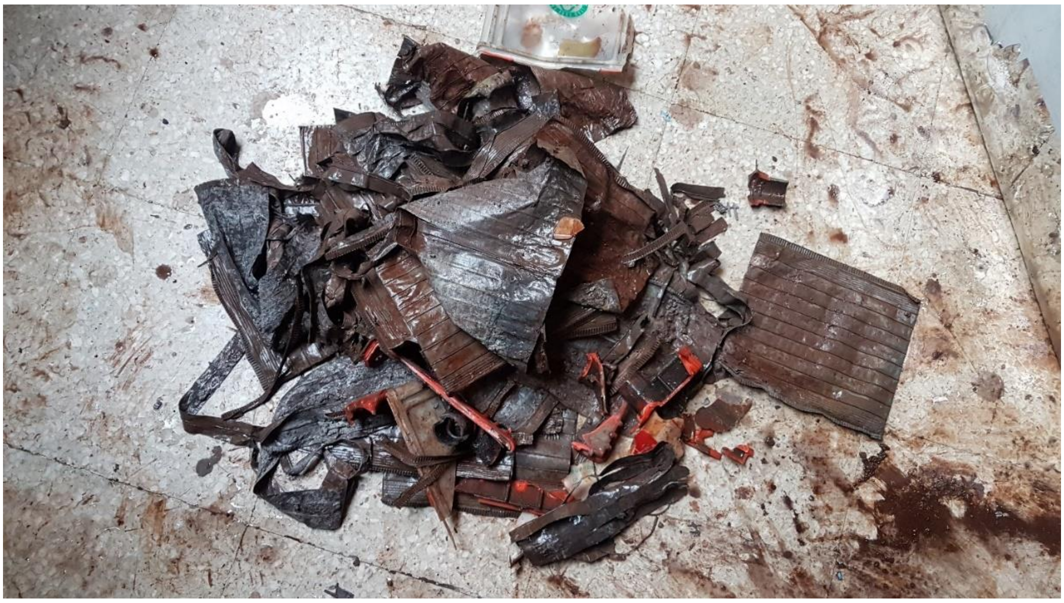

Figure 08: Separated plastic and other wastes

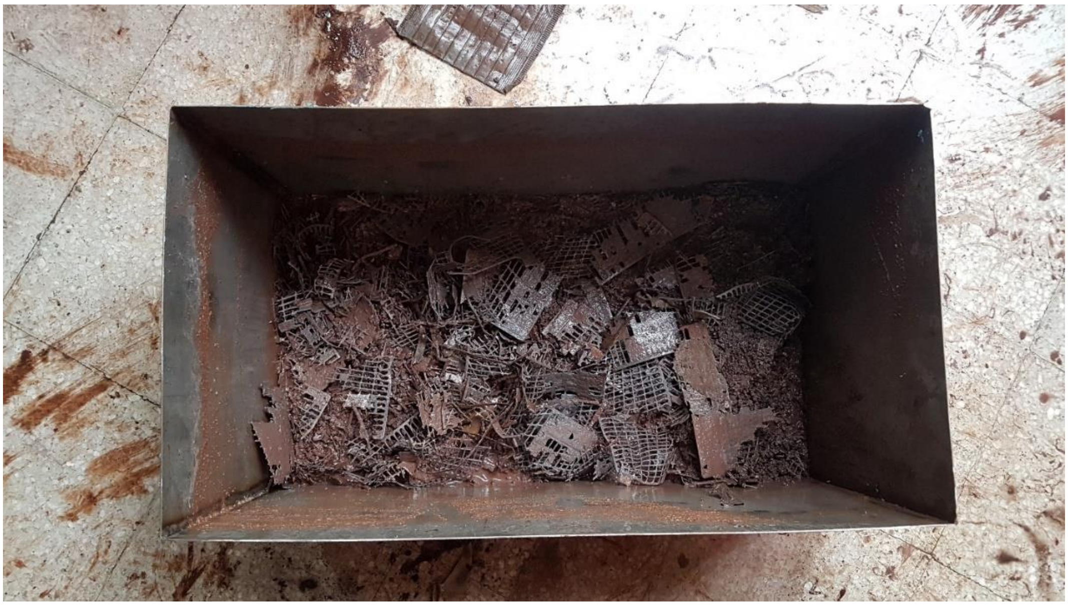

Figure 09: Sedimented lead along with some impurities and waste

6.5 Step 5 - Storage and Transportation of Lead

Lead is toxic to environment when dumped openly. But storage of lead is not much of a problem. It can be safely stored in a plastic or stainless-steel container. The extracted lead can be transported using any vehicle to the nearest furnace to melt them and turn them into blocks which can later be supplied to battery manufacturers.

Chapter 7: Result

In this experiment we have used an electronic weighing machine to measure the weight of different materials we have got. After breaking the battery, we have collected the different materials in different pots and weighing them in weighing machine we have got the following data.

Table1: Extracted materials from the lead acid battery.

Extracted materials	Amount (kg)
Lead	5.738
Plastic	1.148
Salt	0.948
Dust and other impurities	4.584

Total weight of a lead acid battery was approximately 12.6 kg and the amount of lead is usually 60% of the total weight of a battery which makes around 7.56 kg of lead in a battery.

So, the lead recovery rate becomes = (5.738/7.56) *100%=75.9 or 76%

As the process is done by hands the recovery rate is quiet low. If the process is done in an automated machine the recovery rate can be up to 99%.

The purity of the lead from the extraction can be up to 99.97% [11].

Table2: Percent composition of extracted lead.

Element	Symbol	Composition in %
Antimony	Sb	0.001(max)
Arsenic	As	0.001(max)
Tin	Sn	0.001(max)
Copper	Cu	0.001(max)
Bismuth	Bi	0.025(max)
Iron	Fe	0.025(max)
Nickel	Ni	0.001(max)
Silver	Ag	0.001(max)
Arsenic	As	0.003(max)
Zinc	Zn	0.001(max)
Calcium	Ca	0.0005(max)
Sulphur	S	0.0005(max)
Aluminum	Al	0.0005(max)
Selenium	Se	0.0005(max)
Cadmium	Cd	0.0005(max)
Tellurium	Te	0.001(max)
Lead	Pb	99.970(max)

This is the composition of the lead that is found in this extraction process. The quality of the extracted lead is usually very good as the impurities that found in the process is removed in the furnace.

Here in Bangladesh the hydro-separation process not being performed due to its high initial cost rather the different lead recycling plant uses the smelting process to recycle the extracted lead.

Table3: Extracted materials in smelting process [12].

Battery type	Total weight (kg)	Metal content(kg)	Plastic content(kg)	Ash (kg)
1	12.75	2.9	2.4	5.4
2	12.85	2.45	2.55	5.75

The amount of ash is very high in smelting process so another ash handling process is required to maximize the outcome of the system. But it costs higher. Usually the recovery rate of lead in smelting process is from 60 to 70 percent. For a medium scale plant, we have set the lead limit up to 150 ton per month. We have considered different amount of recovery rate for both the processes to compare between the existing and the desired processes. And the value of lead per ton is considered 90000 taka and the value of 1 dollar is considered as 84.78 taka.

Table 4: comparison of performance of Smelting and Hydro-separation process.

Process	Lead used for recovery per month (in ton)	Recovery rate	Recovered lead per month (in ton)	Recovered lead per year (in ton)	Price of lead per ton	Price in taka(crore)	Price in USD (million)
Smelting	150	70%	105	1260	90000	11.34	1.338
Smelting	150	65%	97.5	1170	90000	10.53	1.2423
Smelting	150	60%	90	1080	90000	9.72	1.147
Hydro-separation	150	85%	127.5	1530	90000	13.77	1.624
Hydro-separation	150	80%	120	1440	90000	12.96	1.5287
Hydro-separation	150	76%	114	1368	90000	12.312	1.4526

Smelting process has less recovery rate than the hydro-separation process so the amount of recovery lead will be less than the hydro-separation process.

For the smelting process,

At the recovery rate of 70%,

Total amount of lead was 150 ton

So, the recovered lead is (150 of .70) ton or, 105 ton per month

The yearly recovered lead becomes =105*12=1260 ton.

Price of lead =1260*90000=11.34 crore taka.

The amount is 1.338 million U.S.D

At the recovery rate of 65%,

Total amount of lead was 150 ton

So, the recovered lead is (150 of .65) ton or, 97.5 ton per month

The yearly recovered lead becomes =97.5*12=1170 ton.

Price of lead =1170*90000=10.53 crore taka.

The amount is 1.2423 million U.S.D

At the recovery rate of 60%,

Total amount of lead was 150 ton

So, the recovered lead is (150 of .60) ton or, 90 ton per month

The yearly recovered lead becomes =90*12=1080 ton.

Price of lead =1080*90000=9.72 crore taka.

The amount is 1.147 million U.S.D

For Hydro-separation process,

At the recovery rate of 85%,

Total amount of lead was 150 ton

So, the recovered lead is (150 of .85) ton or, 127.5 ton per month

The yearly recovered lead becomes =127.5*12=1530 ton.

Price of lead =1530*90000=13.77 crore taka.

The amount is 1.624 million U.S.D

At the recovery rate of 80%,

Total amount of lead was 150 ton

So, the recovered lead is (150 of .80) ton or, 120 ton per month

The yearly recovered lead becomes =120*12=1440 ton.

Price of lead =1440*90000=12.96 crore taka.

The amount is 1.5287 million U.S.D

At the recovery rate of 76%,

Total amount of lead was 150 ton

So, the recovered lead is (150 of .76) ton or, 114 ton per month

The yearly recovered lead becomes =114*12=1368 ton.

Price of lead =1368*90000=12.312 crore taka.

The amount is 1.4526 million U.S.D

So, Hydro-separation process can save up to 2 crore taka per year at the minimum recovery rate.

Chapter 8: Future Work

The process we followed is a moderated version of an existing process of automobile battery recycling which is used in USA. We conducted the process in a small scale in order to test if it is applicable where there are not enough recycling plants, specifically in developing countries. We successfully extracted the lead from waste batteries with minimum expenditure and the plant can save a huge amount of money following the Hydro-separation process. This extracted lead can later be melted in furnaces and made into blocks. It was a successful research as the outcome we got was more than we expected. We believe our research will be beneficial in keeping the environment safe and reuse the leads in lead-acid batteries in developing countries. And further work can be done based upon the plant layout and design.

Chapter 9: Conclusion

Lead is toxic to the environment. So, recycling the lead batteries prevent the lead from being discharged in the environment. Lead is only found in nature. If not recycled, we will run out of lead in next 40 years. Also, recycling helps with making new batteries. It also prevents the waste battery from causing any health hazard. We think our research was a successful research as we got more amount of lead than we expected. We believe this process will be efficient for battery recycling in developing countries.

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