Design of a Sustainable Storage Power Medium's Recycling Method for Automobiles

S. Rumi, M. Hassan, and A. Rashid

Department of Mechanical and Production Engineering (MPE)

Islamic University of Technology (IUT), Board Bazar, Gazipur 1704,

Dhaka, Bangladesh.

Email: rashidarmh@gmail.com

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, storage power, recycling, automobiles, battery.

INTRODUCTION

Automobile storage power recycling for automobile is vital to stay the car in the running condition. Battery recycling is aimportant activity that aims to reduce the number of batteries being disposed of as municipal solid waste. Like many other things batteries contain a variety of things that are harmful for environment like heavy metals and toxic chemicals. Therefore disposing them as regular trash has raised concerns over soil contamination and water pollution [1]. Recycling old batteries reduces waste and impact on environment. Besides, up to 99 percent of a lead-acid battery is recyclable [2]. It also reduces the necessity to use new raw materials and components. Rather than keeping your old battery, make certain it gets recycled by leaving it with the counterperson once 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 once you purchase a replacement 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 that the earliest kind of rechargeable battery. Despite having a really low energy-to-weight ratio and a coffee energy-to-volume ratio, its ability to provide high surge currents implies that the cells have a comparatively large power-to-weight ratio. These features, alongside their low cost, make them attractive to be used in motor vehicles to supply 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 isn't important and other designs could provide higher energy densities. In 1999 lead-acid battery sales accounted for 40–45% of the worth from batteries sold worldwide (excluding China and Russia), worth of a manufacturing market price of about $15 billion.[3] Large-format lead-acid designs are widely used for storage in backup power supplies in mobile phone towers, high-availability settings like hospitals, and stand-alone power systems. For these roles, modified versions of the quality cell could also be wont to improve storage times and reduce maintenance requirements. Gel-cells and absorbed glass-mat batteries are common in these roles, collectively referred to as VRLA (valve-regulated lead–acid) batteries.

In the charged state, the energy of the battery is stored within the potential difference between the pure lead at the negative side and therefore the PbO2 on the positive side, plus the aqueous vitriol. The electricity produced by a discharging lead–acid battery may be attributed to the energy released when the strong chemical bonds of water (H2O) molecules are formed from H+ ions of the acid and O2− ions of PbO2.[4] Conversely, during charging the battery acts as a water-splitting device.

Most sorts of batteries may be recycled. However, some batteries are recycled more readily than others, like lead–acid automotive batteries (nearly 90% are recycled) and button cells (because of the worth and toxicity of their chemicals)[5]. Rechargeable nickel–cadmium (Ni-Cd), nickel-metal hydride (Ni-MH), lithium-ion (Li-ion) and nickel–zinc (Ni-Zn), may also be recycled. There is currently no cost-neutral recycling option available for disposable alkaline batteries, though consumer disposal guidelines vary by region[6].

LITERATURE REVIEW

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 lately sustainable development (e.g., triple bottom line, multi-faceted accountability for both public and private sectors)[7,8]. In today's global economy, the practice of sustainable development is of particular importance to the handling of toxic materials like lead in order to encourage industrial organizations and its stakeholders to take a vigorous role in maximizing human and environmental health.

The focus of this study is on lead and lead compounds. It has been found to be major hazardous waste around the world. In the USA, it makes up the biggest hazardous waste stream in the US according to the Toxic Release Inventory. Currently, there is limited information on recycling rates for lead-acid batteries within the published literature. The recycling rates for recovering lead from spent LAB is approaching 99.2% for the 1999 to 2003 period of time [9]. Although very encouraging, such rates appear to be significantly above those reported for other countries. for instance ,the recycling rate for LAB is 85% in Western Europe, (there are not any other sources comparing recycling rates over the same time period) [9]. Therefore, the present state of recycling efforts within the US has been unclear so on determine the strategies for maximum lead recovery and recycling within the face of serious demands for LAB particularly within the auto industry.

Before 1900s lead within 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 [10]. Within the early 1900s, lead uses expanded to incorporate bearing metals, cable covering, caulking lead, solders and sort metal. By the mid-1900s, the expansion in lead use was derived from the assembly of public and private motor vehicles and associated use of starting-lighting-ignition (SLI) lead-acid storage batteries and metal for gas tanks. Additionally, the utilization of lead was drawn from radiation shielding in medical analysis, video display equipment, and gasoline additive [11].

By the late 1900s, the utilization of lead was significantly reduced or eliminated in non-battery products, including gasoline, paints, solders, and water systems. because the use of lead in no- lead battery products has continued to say no , 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 entire demand for lead in all sorts of lead-acid storage batteries represented 88% of apparent US lead consumption. Other prominent uses were found in ammunition (3%), oxides in glass and ceramics (3%), casting metals (2%) and sheet lead (1%). the rest (b1%) was consumed in solders, bearing metals, brass and bronze billets, covering for cable, caulking lead, and extruded products.

RESEARCH GAP AND OBJECTIVES

From the literature review, it could be seen that for developing countries that could not invest a good amount of money to install large plant and therefore may research on innovative storage medium. So this research was focused on this development and its objectives were as follows:

- 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 - Land filling will also cause plastic pollution. This process also aims to reduce plastic pollution.

SUSTAINABLE STORAGE METHODS

Among the various storage methods, lead acid battery was selected for its different features and advantages for developing countries. 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 could 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 utilized in a range of applications, including new batteries.

The lead in a lead–acid battery has been recycled for decades. Elemental lead is toxic. Therefore, it should be kept out of the waste stream. Many places of the world 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 the recycling of old batteries rather than abandonment or disposal with household waste. Within the U.S., about 99% of lead from used batteries is reclaimed [2].

Businesses that sell new car batteries might 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 against in exchange for a new battery. Most battery shops and recycling centers buy scrap batteries. This could be a lucrative business, enticing especially to risk-takers due to the wild fluctuations within the value of scrap lead that may occur overnight. It is noted that 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 the various components. The plastic in lead-acid batteries is generally polypropylene (also referred to as PP or by the resin code #5), which features a high heat tolerance. It is often recycled. The lead within the batteries is sold to companies that make new batteries [5].

The lead-acid accumulator gains its environmental edge from its closed-loop system cycle. the standard 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 recycling facility. Then the lead and plastic are reclaimed under strict environmental regulations and sent to a new battery manufacturer. The recycling cycle goes on indefinitely. It implies that the lead and plastic within the lead-acid batteries will still be recycled repeatedly over.

In a recycling facility, 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 therefore the plastic floats. At this time, the polypropylene pieces are scooped away and therefore the liquids are drawn off, leaving the lead and heavy metals. Each of the materials is separated and goes into a different recycling “stream”. Here, the various materials of the lead acid batteries are extracted as follows:

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 consistent size. The pellets are replaced into manufacturing battery cases and therefore the process begins again.

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

Sulfuric Acid - Old battery acid can be handled in the two ways:

I. The acid is neutralized with an industrial compound almost like household baking soda. Neutralization turns the acid into water. The water is then treated, cleaned, tested during a waste water treatment plant to make certain it meets clean water standards.
II. The acid is processed and converted to sodium sulfate, an odorless white powder that’s utilized in laundry detergent, glass, and textile manufacturing.

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

DESIGN AND FABRICATION

Following tools and materials were used in the fabrication of sustainable lead acid battery recycling:

(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:

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:

Power drill was used for making holes in the battery. Before crushing the battery, holes were made at the corners. It was used to separate 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 as shown in Figure 1. 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 01: Baking Soda

Distilled water:

Sulfuric acid is used in the battery as the electrolyte of a specific concentration. During the charging and discharging cycles, a part of the water gets lost and therefore the concentration of the acid increases. the ability of the battery to charge and provides the current decreases with this and therefore the battery can get damaged if the concentration of the acid increases unchecked. To bring the concentration to the desired 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 of this research was to recycle lead-acid batteries in a small scale. It is known that automobile factories use furnaces for crushing batteries. Putting the batteries in furnaces was not in line of the goal of the research. Instead of using furnace, hammers were used to crush the used lead acid batteries. Here grinders can be used too. Before crushing the batteries it is to be made sure the acid is neutralized.

Hydro-separator:

In our research we used a hydro-separator for separating the extracted lead from other impurities as shown in Figure 2. 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.

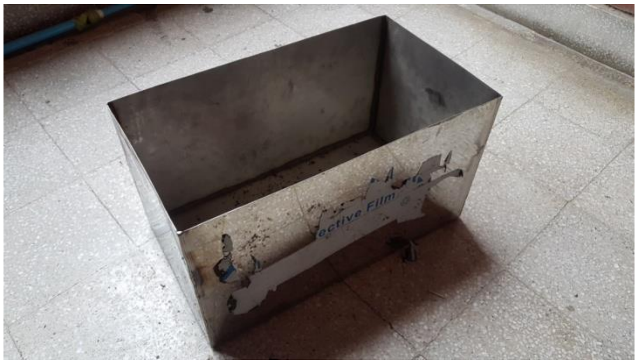

Figure 02: Stainless-steel Hydro-separator

WORKING PROCEDURES

The research 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. The working procedures of the sustainable recycling method are elaborately described as follows:

Step 1 - Acid Neutralization

Sulfuric acid (H_2SO_4) is the electrolyte in all lead / acid cell batteries, which is also referred to as Battery Acid. Usually, it is at a concentration of between 15% and 35%. At this concentration, sulfuric acid reacts with nearly everything especially organic material including human flesh and therefore is extremely dangerous.

Battery acid must be neutralized earlier than it is disposed of. Battery acid, although very dangerous, can be safely neutralized yielding harmless salts. The pH neutralization of vitriol or any concentrated acid is a hazardous task. However, the risks are often controlled. The heat liberated from the neutralization of sulfuric acid (battery acid) is extremely high and may end in a temperature rise of over 100^0C (212^0F).

If extreme care is not exercised the energy released during the neutralization cycle can be explosive. At a minimum, it would be sufficient to melt all thermoplastics. Digital Analysis makes use of a unique process for the neutralization of battery acid. Here 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 set point, 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:

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

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.

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 as shown in Figure 3.

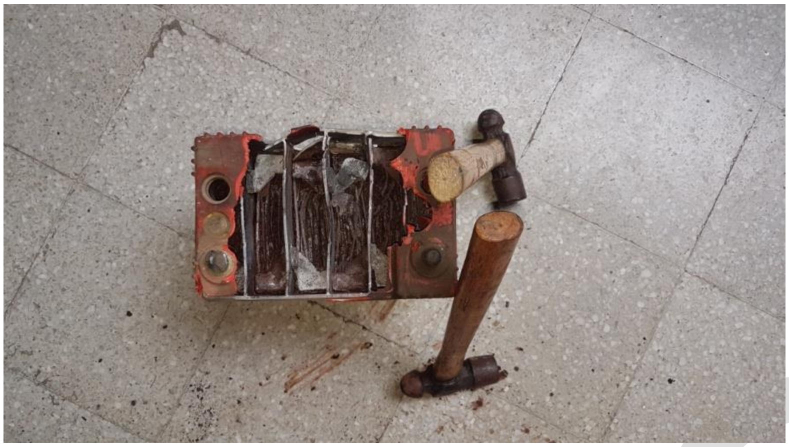

Figure 03: The battery being crushed using hammers

Step 4 - Hydro Separation

The hydro-separation process was carried out inside a separator made of stainless steel as shown in Figure 4 to Figure 7. 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.

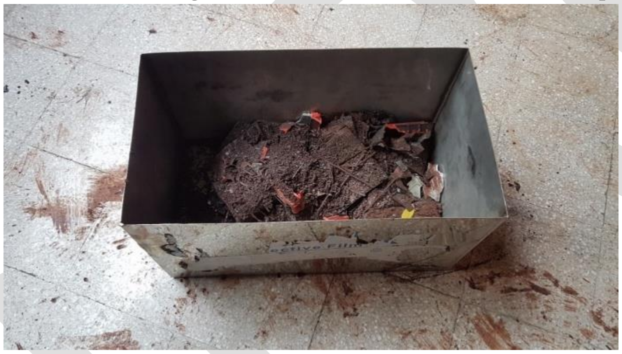

Figure 04: Crushed battery bits inside the hydro-separator

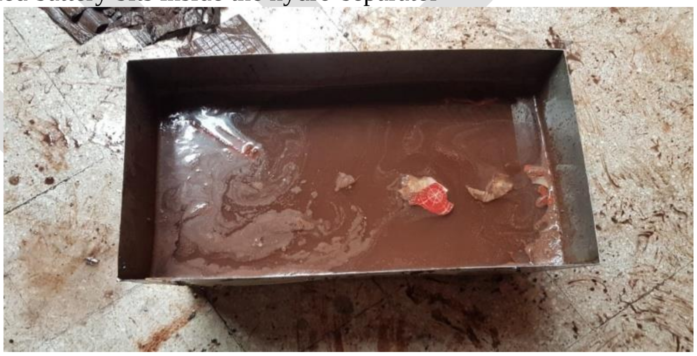

Figure 05: Hydro-separator filled with water and plastic bits floating up

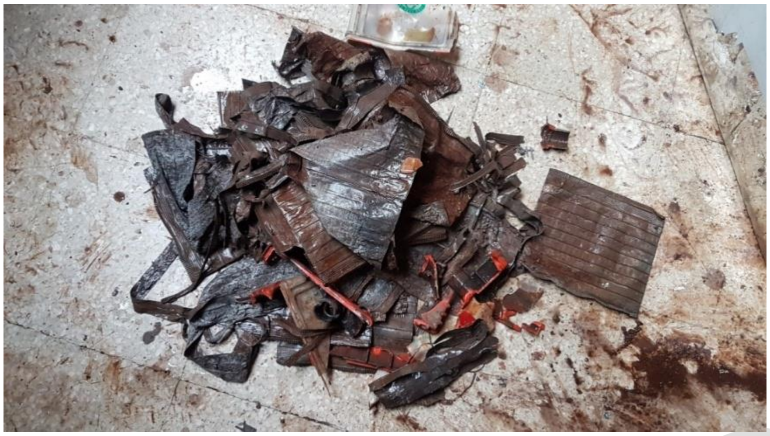

Figure 06: Separated plastic and other wastes

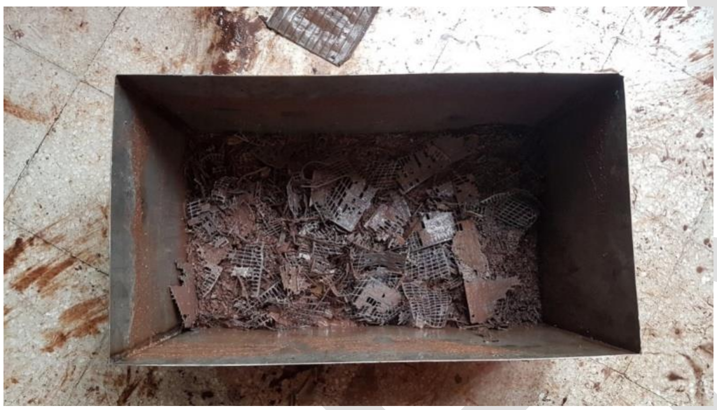

Figure 07: Sedimented lead along with some impurities and waste

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.

FINDINGS FROM TEST RUNS

In this experiment we 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% [12].

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 as shown in Table 2 and comparison is given in Table 3.

Table 2: Extracted materials in smelting process [13]

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 3: 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.

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.

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.

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