Development of novel methods for treatment of E-waste

Deepika Yadav[1], Prof. Tanu chaturvadi [2]
[1]Post Graduate Student, Dept. of Civil Engineering, SATI Vidisha (M.P) India
[1]Assistant Professor, Dept. of Civil Engineering, SATI Vidisha (M.P) India

Abstract- *The electronics industry is the world's biggest and most rapidly developing manufacturing sector. Leads to consumer-oriented growth, along with rising product obsolescence and technical advancements, has resulted in new environmental issues. Obsolete electronic equipment's are growing as a source of e-waste. The given the volume of e-waste created and the concentration on both harmful and beneficial elements, it is both an expanding concern and a growing commercial opportunity. PCBs, for example, are made up of many important heavy metals like copper (Cu) extraction of 3.15 percent, tin (Sn) 42.4 percent, zinc (Zn) 1.16 percent, lead (Pb) 27.81 percent, and others 25.48 percent (Ni, Fe, Br, Mn, Mg...). The current work focuses on recovering heavy metals from PCBs using aqua regia as a two-stage leaching agent (the first stage uses HCl and HNO_3 and the second stage uses HCl and H_2SO_4), as well as optimizing different operational parameters. leaching with optimal parameters 900℃ of temperature, 0.05mm of thickness, 2 hours of contacting time, 60rpm shaking speed. The metal recovery rate improved in the tests, reaching 98% for copper, 95.8% for tin, 97.3% for lead, and 93.5 percent for zinc. Furthermore, When the experimental and anticipated values are compared, the desirability for PCB heavy metal leaching is determined to be 0.761. RSM's best answer is identical to the experimental response. The recovery percentages for metals Zn, Cu, and Pb were 96 percent, 97 percent, and 96 percent, respectively, using chemical leaching.*

Keywords: - ***Printed Circuit Boards, Metal leaching, Extraction of Elements, Chemical Leaching, Chemical Characterization.***

1. Introduction

Electronic waste, often known as e-waste, refers to waste disposal systems that are designed for re-use, recycling, resale, or disposal. Technology advancements, business expansion, economic advance, and the short-term Electrical and Electronic Equipment (EEE) sector have all contributed to significant trash increase. Printed Circuit Boards (PCBs) are the most important component of electronic equipment, and they typically comprise 40% metal, 30% ceramic, and 30% plastic (Yang et al. 2019 & Wei and Liu 2018). A great bulk of the metal composition is filled by the 10-30% Cu of metals and other metals such as Sn, Zn, Pb, Br, Ni, Fe, Ag, Cd, Au, etc. from PCB sources (Bari et al. 2020).

According to studies, the average rate of PCB creation has grown by 8.7% in recent years due to technological developments. As a consequence, environmental problems have emerged, necessitating the need for a remedy (Huang et al., 2016). In a comparative case study of standard desktop personal computer boards weighing 60 lbs.', E-waste production rates in tones per year (TPA) were reported as Switzerland 66,042 TPA, Germany 1,100,000 TPA, UK 915,000 TPA, USA 2,124,400 TPA, Taiwan 14,036 TPA, and Thailand 60,000 TPA. Figure 1.1 shows PCBs as garbage from electronic machines such as television boards, CD players, and cell phones. The survey also found that the ongoing rise in E-waste creation rates is related to the country's population and technological advancements. According to the survey, each person produces around 5,173 kg of e-waste every year. On the other hand, the analysis covers 2025 and shows that DKI Jakarta produces roughly 124,568,613.3 kg per year (Rimantho and Nasution 2016). Increased use of new electrical and electronic equipment will result in the disposal of old equipment, resulting in a significant increase of E-waste for all sorts of technology in this country, including personal computers (PCs), mobile phones, inputs, and output currencies. The harmful and dangerous products produced worldwide have a substantial negative impact on the ecosystem.

According to the findings, the metal content in cell phone PCBs is over 80% by weight. Handling this E-waste, which is projected to reach 8 Mt every year, has become one of the world's most pressing issues (Cherukuri et al. 2020). According to Lakshmi et al. (209), India generates an estimated 50 million Tonnes of E-waste each year. About 24% of e-waste is generated in India, with Chennai (2%), Bangalore (21%), Mumbai (10%), and Delhi (10.1%) accounting for the majority (9.1 percent). This analysis demonstrates a consistent upward trend in each year, as illustrated in Figure 1.2. India generates roughly 12.5 million tonnes of e-waste every year (Kumar and Karishma 2016). E-waste is produced in significant quantities all around the world every year. PCBs commonly contain the most dangerous heavy metals (lead, tin, zinc, and copper). As a result, an effective treatment procedure for metal recovery from PCBs is required. The choice of a good recovery strategy will determine how effective PCB therapy is. Developing a new technique for recovering harmful heavy metal ions from waste PCBs is still a primary scientific goal. As an alternative to chemical leaching, microbial leaching could be a better option for extracting important metals from PCBs. It is a low-cost, easy-to-manage operation for recovering heavy metals from PCBs under ambient settings. However, most microbial leaching studies published in the literature are on a laboratory scale, and further research is needed to determine the impact of various parameters on microbial leaching.

The study's key goals are as follows to prepare suitable chemical and microbiological leaching agents and optimize operating parameters such as concentration, temperature, shaking speed, leaching time, and bulk density to extract metal ions such as Copper, Zinc, Tin, and lead from PCBs. Using EDXs, determine the stability of the prepared leaching media by looking at the recovery rate. A response surface methodology-based multi-response optimization process is used. The goal of the optimization tasks has been to maximize the amount of heavy metal recovered. Using adsorption, recover the harmful heavy metal ions (Copper, Lead, Tin, and Zinc) from chemical and microbially leached PCB solutions (Bent and peanut shell).

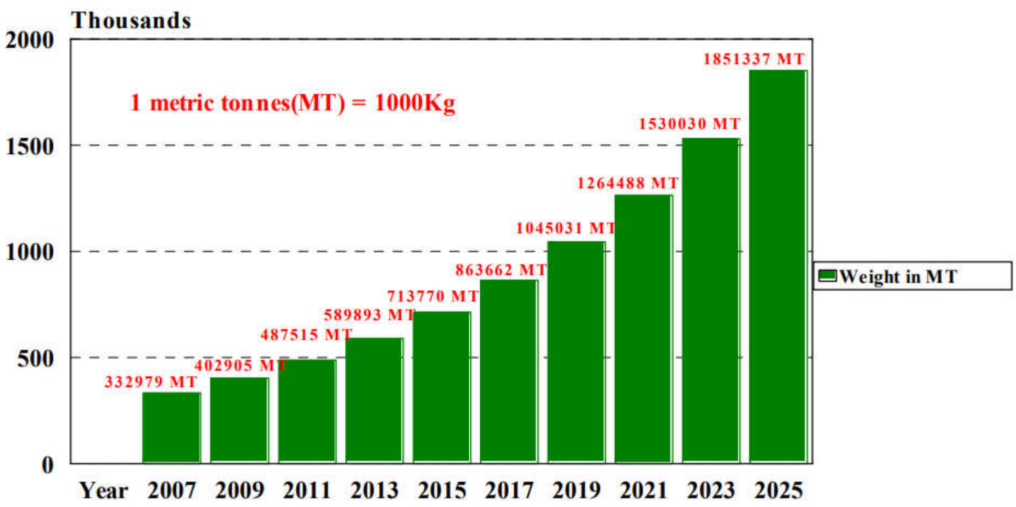

Figure 1 Depicts Schematic Illustration of E-waste generation in India.

2. Methodology

The garbage PCBs come from an Indian e-waste disposal facility. First, the sample was cleaned manually with an Air Blower to eliminate dust particles. Later, mechanical tools (saw metal cutter, sheet cutter, metal lathe cutting tool, cutting pliers, and materials separation toolkit) were used to separate other elements such as capacitors, resistors, integrated circuits, diodes, and transistors. Electronic components such as a capacitor, diode, resistor, transistors, and others are dismantled and heated to 700-900ºC in a muffle furnace (Masavetas et al., 2009; Tripathi et al. 2012). After that, the samples are compressed in a crusher to lower the particle size. The crushed PCBs are then crushed and subjected to a milling operation for additional size reduction using a ball mill, with particles of various mesh sizes being examined.

Fig. (A) Computer PCBs. **(B) Computer Random Access Memory PCBs.**

(C) Mobile PCBs **(D) TV PCBs**

Figure 2 E-waste collected from various sources

2.1 Sample collection and preparation

The resulting crushed sample is processed into powder form by a pulverizer since the reduction size enhances the rate of recovery of metal ions (Frazzoli et al., 2010). The weight fraction of the bottom products (Sieves from 52 B.S.S. to pan) is enhanced, but it is still insufficient for the projected recovery. As a result, P.C.B. powder is pulverized and processed in a ball mill. Since the samples received from the ball mill ranged in size from 5 mm to 3 mm, they did not fulfill the stipulated size requirements, and an assembled printed circuit board contains many components. During crushing, the components may generate heat. These P.C.B.s are then heated at 900°C in a muffle furnace to improve their flexibility and crushing capabilities (Tripathi et al., 2012), followed by 2 hours of size reduction operations in a drop weight crusher, pulverizer, and ball mill. The crushed sample was transformed into powdered form with the help of a pulverizer. The powdered samples are screened through various mesh sizes, and the weight fraction of bottom products (sieves from 52 B.S.S. to pan) increased, but not enough to recover the expected amount.

The pulverized P.C.B. powders were processed in a ball mill, resulting in significant size reduction and the highest weight fractions at the lowest sieves. Each sieve's weight fractions were collected separately and subjected to a leaching procedure. The particle sizes that were obtained ranged from 2 mm to 0.05 mm (Kumar et al. 2013; Pant et al. 2012). As a result, (Figure 3.1 and Table 3.1) show that Primary Raw P.C.B.s are subjected to progressive size reduction during mechanical operations (Jaw crusher, roll crusher, thermal heater, and pulverized mills produced small sizes between 2 mm-0.05 mm). The sample obtained from the ball mill has several fractions of weight in the pan with a size less than 0.05 mm, according to the sieve analysis data of each operation. Various investigations have employed shredded samples with a size of less than 0.5 mm, resulting in a high rate of heavy metal recovery (Ping et al., 2009). The current study involves leaching with a particle size of 0.05 mm, with the sample remaining just above the pan.

2.2 Analysis for metals.

Analytical techniques such as SEM with EDX were used to determine the prepared samples' morphology and metallic elemental analysis (SEM-FEI-Quanta FEG 200F). The beam current typically has a 100Na energy, a Schottky emitter with a voltage range of (-200v–30kv), magnifications of 12X–105X, and a resolution of 2 nm (Gold Nano-particles suspended on carbon substrate). The fundamental structure of the size decreased sample (0.05 mm) was revealed by SEM examination, with granular structures belonging to PCB particles that are spherical and have a rough surface.

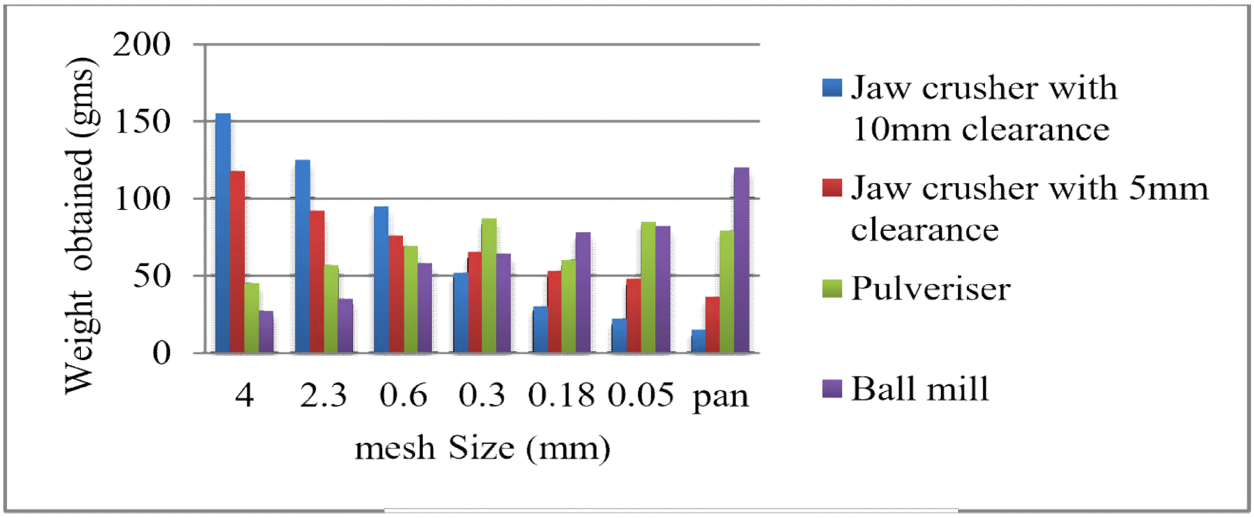

Figure 3 Graphical representation of size reduction in multiple processes.

3. Results

EDX examination revealed several most substantial spectrum peaks of heavy metal elements like Cu, Sn, Zn, Pb, and other metals like Fe, Ti, Mg, Cd, Ni, Ca, and Br, as well as other metals like Fe, Ti, Mg, Cd, Ni, Ca, and Br (Figure 3.2). The table shows that various metals by weight percent were obtained (Table. 3.2). Cu was found to be 3.15%, Sn 42.40 %, Pb 27.81%, Zn 1.16 %, and miscellaneous metals 25.48%.

Table 1 Initial Concentration of metal ions obtained from PCB.

S. NO	Heavy metals	Weight (%) at initial
1	Cu	3.15
2	Sn	42.40
3	Pb	27.81
4	Zn	1.16
5	Others	25.48
	Total	100

The fundamental structure of the size decreased sample (0.05 mm) was revealed by SEM examination, with granular structures belonging to PCB particles that are spherical and have a rough surface (Figure 3.3a).

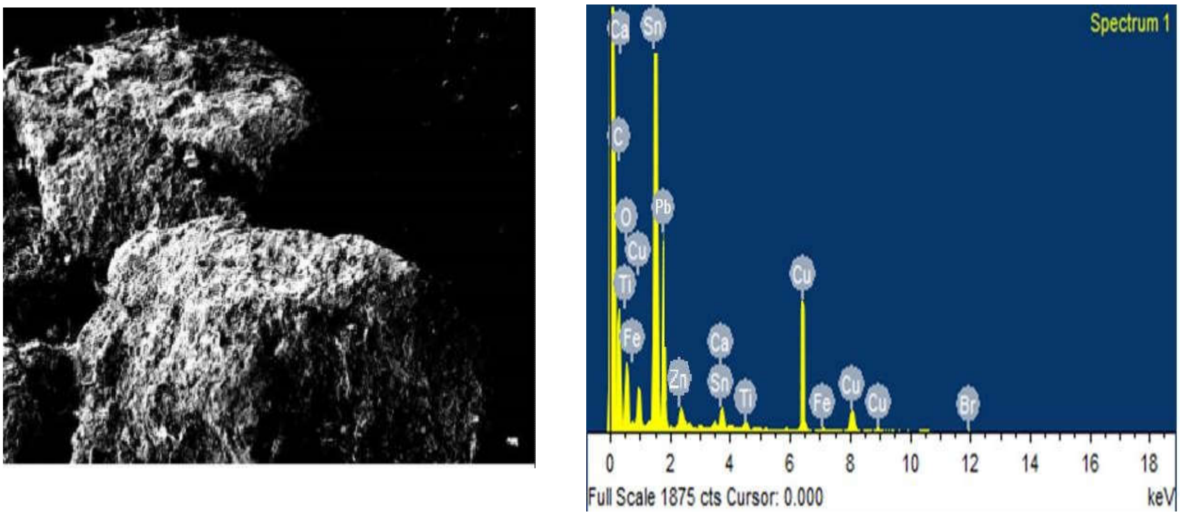

Figure 4 (a) Schematic diagram of SEM images of metal present in PCBs sample. (b) metallic composition of PCBs at initial stage.

3.1 Recovery of metals

The recovery of hazardous metals from PCBs is considerably more visible. Prior investigations have focused on Cu, Pb metals, Sn, Cr, Ni, Zn, Au, and Fe leaching in diverse media. As a result, the concentrations of the leached solution varied depending on the leaching agent, resulting in exceedingly challenging concentrated metal separations due to the various metallic components. Several researchers in different nations have used the Informal Metal Recovery method for valuable metal separation methods that are judged unsafe due to toxic emissions, non-technical procedures, environmental consequences, and human health implications, depending on the type of metal recovery process.

As a result, the limitations of this study are addressed. It begins by optimizing various operational parameters while recovering heavy metals from PCBs using aqua regia as a leaching reagent in two phases (the first stage is HCl and HNO_3, and the second stage is HCl and H2SO4).

Experiments using Response Surface Methodology (RSM) are also being carried out to determine the recovery of heavy metal ions by Central Composite Design (CCD).

Electro-winning, electro-refining, and ion exchange procedures are now used to recover leached metals, although these methods have drawbacks. As a result, this study adsorption strategy is recommended to address environmental problems and other disadvantages. This study used pure materials such as Bentonite Clay (Bent) and Peanut Shell Carbon (PSC). Adsorbents with thermally and chemically active formulations were utilized to recover heavy metals from the leached solution.

3.2 Parameters influencing recovery of metals from PCBs

The experiments were conducted in a conical flask with a temperature-controlled shaker. To get a standard recovery rate, primary analyses were carried out under specific conditions. 20 g of PCB samples are allowed to react with 0.5 litters of leaching media within a conical flask at 800C for 3 hours before being shaken at 120 rpm in a mechanical shaker. The shaker was turned off at the end of the effective contact period. The solutions in the conical flask were filtered with filter paper (Glass fiber Whatman 42 filter paper which had 2.5-micrometer pore size, 200-micrometer thickness). It is well-suited to treat strong acids to recover heavy metals while also offering great wet strength and chemical resistance. Figure 5 shows the metal composition after complete filtering, as measured by Energy-dispersive X-ray Spectroscopy EDXs.

Figure 5 SEM scans of metals found in powdered PCBs.

Various shaking speeds were used to test metal recovery. Initially, vibrating speed enhances the recovery rate, but samples with higher shaking speeds have lower recovery rates. Metal ionic dissociation is influenced by the acid retention duration on the sample's surface.

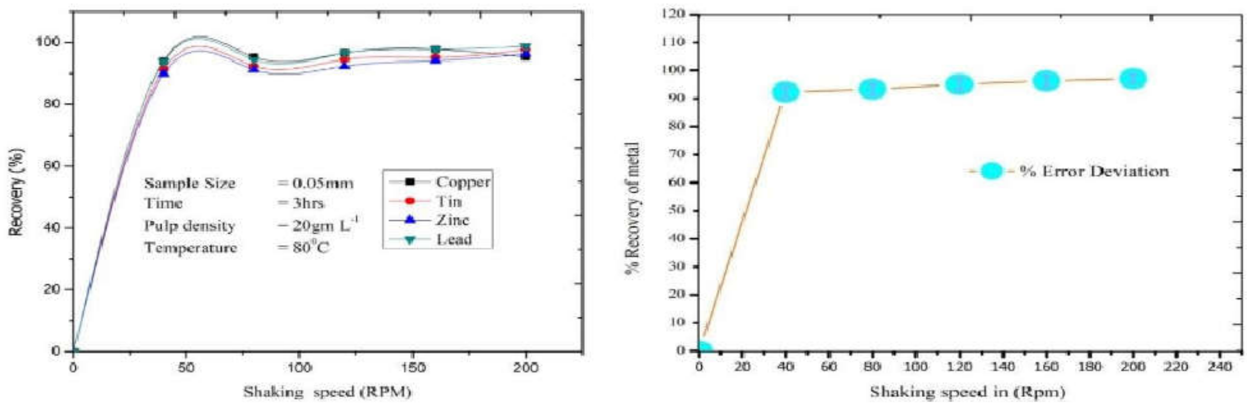

Figure 6. Graphical Representation of a) Metal recovery percent as a function of shaking speed; b) error deviation of metal recovery concerning shaking speed.

As the contact time between the metal surfaces and the leaching media decreases, there will not be enough time to remove the ions from the surface of the metals if the speed is raised. The test reveals complete metal recovery at a rate of 60 rpm. When leached at a 60rpm shaking speed, it recovers 95.35 percent, 97.76 percent, 96.39 percent, and 98.76 percent of Cu, Sn, Zn, and Lead, respectively. At a 60rpm shaking speed, the error deviation plot (Figure 3.5b) shows a minimum deviation of 1.5 percent.

After 2 hours of shaking at 80 rpm at 900°C, the solutions in each conical flask are filtered individually. The filters are dried in the sun, and their metal properties are studied. Table 3.5 shows the metal composition. The sieve particles are leached with aqua regia to determine the fraction of the weight of the metallic components. The smallest PCB sample size had the highest recovery rate (3.6a)

(0.05 mm). Copper, nickel, zinc, and lead recovery percentages are 95.79, 93.59, 92.56, and 97.84 percent. Because of this, metal recovery rates vary modestly with sample size (4.3mm), and variations are 1.03, 1.27, 1.21, 1.88, and 1.56%. Figure 3.6b shows it.

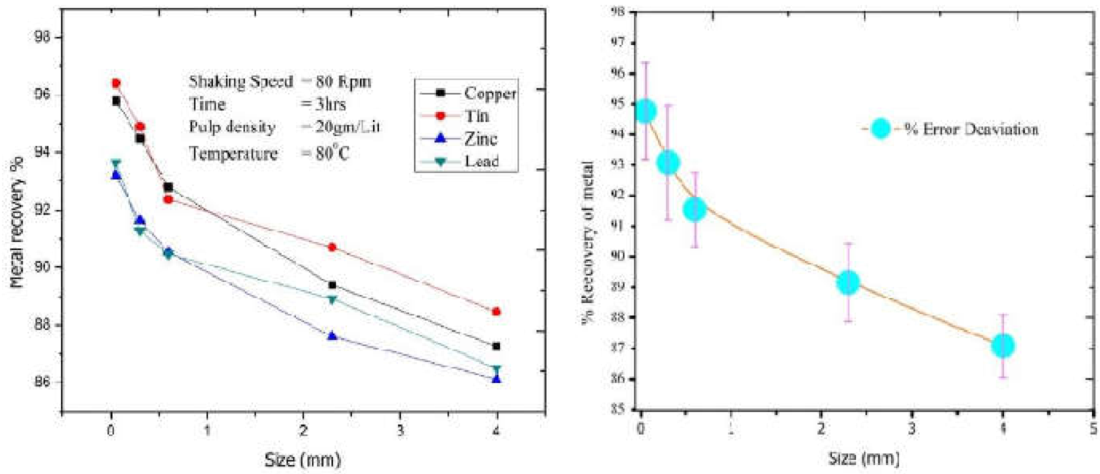

Figure 6 Graphical representation of (a) Percentage recovery of metals with sample size in mm. (b) Metal recovery error deviation plotted against sample size.

4. Conclusion.

During the two-stage leaching processes, heavy metals in waste PCBs were leached into appropriate reagents, and the heavy metals were recovered. In this study, the efficacy of two leaching media (HCl; HNO3, H2SO4; HCl) for the separation of heavy metals during the treatment of PCBs was assessed. The study demonstrates the dependence of the rate of recovery on the conditions, which were done arbitrarily in the study.

Copper and lead have the highest recovery rates of metals discovered in the first stage, but other metals such as tin and zinc have the lowest recovery rates. Adsorption was used to address the metal ions leached from the leaked solution. Heavy metal ions (Zn2+, Sn2+, Cu2+, and Pb2+) from PCBs were recovered using activated and non-activated adsorbents (Bent and peanut shell), which were studied using a variety of relevant factors. As a result of the research, it was determined that the combination of aqua regia leaching with bent adsorption is a viable and cost-effective method for recovering heavy metals from PCBs. The existence of harmful compounds, on the other hand, means that it has certain drawbacks. As a result, it is important to use a different way to get metal that doesn't harm the environment.

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