Key Indicators - 3.4 Research Publications and Awards

		Title of the book/chapters published	Title of the paper	Title of the proceedings of the conference		Name of the conference	National / international	Year of publication	ISBN/ISSN number of the proceeding	Affiliating Institute at the time of publication	Name of the publisher
3.4.4	Number of books and chapters in edited volumes / books published per teacher during the year: File Description • Upload any additional information • Paste link for additional information	Data Science	-	-	-	-	-	2021	9789391987282	Excel Engineering College	Dr.S.Sreethar

R&D Coordinator

HOD

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Dr Sheik Saidhbi, earned her doctorate from Bharathiar University, Coimbatore, Master Degree in Computer Science and Engineering from Andhra University, Visakhapatnam. She is currently working as an Associate Professor in the Department of Computer Science, Samara University, Samara, Ethiopia
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She has received "Best Faculty Award 2021" from International Scientist Awards. She has professional memberships of CSI, ISTE, CRSI, IACSIT, UACEE and CSTA and Red cross society . She has completed 45 online certification courses from reputed universities and organizations like Coursera, edx, saylor etc. Apart from research, administration She has implemented number of community service projects ethiopia. Her research interests are Cryptography, Cloud Computing, Bigdata Analytics and Multi Media, Machine learning.

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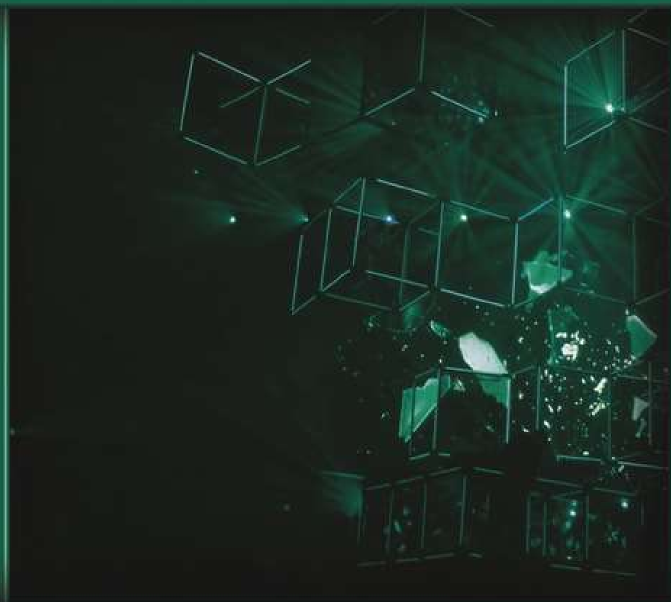

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ECE Department

(Academic year 2021-22)

3.4.4 Number of volumes / books published per teacher duringtheyear:

Title of the book/chapter published	Title of the paper	Title of the proceedings of the conference	National /international	Year of publication	Affiliating Institute at the time of publication	Name of thepublisher
Embedded and real time systems	-	-	National	2022	Excel Engineering college	Scientific international publisher

J. Jayanthi
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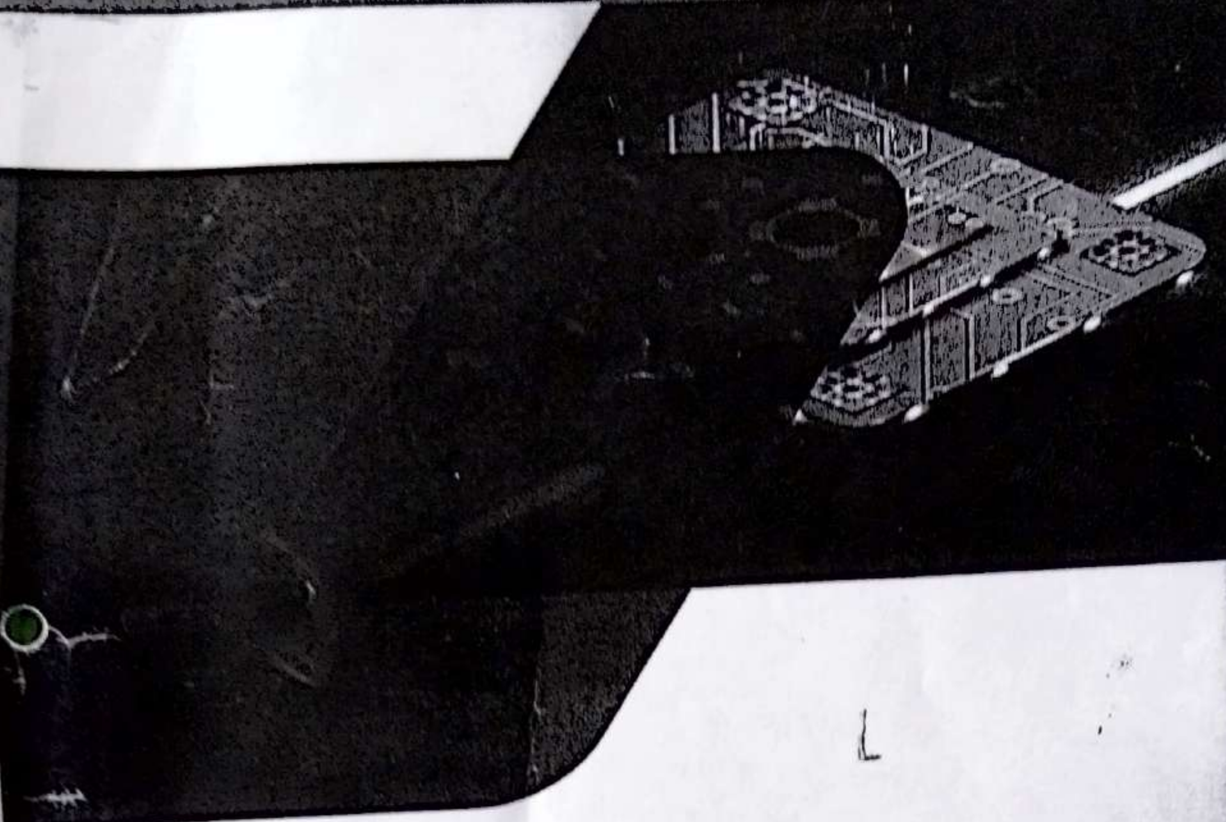

EMBEDDED AND REAL –TIME SYSTEMS

Dr. A.VASANTHARAJ

Dr. MAHENDRA PRATAP SWAIN

Mrs. CHHAYA SURYABHAN DULE

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Department of Food Technology
IQAC- Criterion III – Research, Innovations and Extension
NAAC Accreditation Academic Year – 2021-22
Food Technology

Metric No : 3.4.4

Details of books and chapters in edited volumes / books per teacher during the year : 1

Sl. No.	Name of the Teacher	Title of the Book published	Title of the Chapter published	Title of the proceedings of the conference	Name of the conference	National / International	Year and month of publication	ISBN of the Book/Conference Proceeding	Affiliating Institute of the teacher at the time of publication	Name of the Publisher
1	Dr. M P. Murugesan	Leaching Technology for Precious Heavy Metal Recapture through (HCl+HNO3) and (HC+H2SO4) from e-Waste, Heavy metals.,	Environmental Impact and Remediation of Heavy Metals	-	-	International	Dec-2021	ISBN978-1-80355-526-3	Excel Engineering College	Intechopen Limited, Prinnces Gate Court, London, UK

Faculty In charge

HOD

Head of the Department
Department of Food Technology,
Excel Engineering College,
Namakkal District - 638 183.

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Chapter

Leaching Technology for Precious Heavy Metal Recapture through (HCI + HNO_3) and (HCI + H_2SO_4) from E-Waste

Murugesan Manikkampatti Palanisamy, Akilamudhan Palaniappan, VenkataRatnam Myneni, Padmapriya Veerappan and Minar Mohamed Lebba

Abstract

The rapid growth of information technology and industrialization are the key components for the development of electronic equipment, and their inevitable role in human day-to-day life has an important stint in the generation of electronic waste (e-waste). This waste has far-reaching environmental and health consequences. One such e-waste printed circuit board (PCB) contains significant amounts of valuable heavy metals such as copper (Cu), lead (Pb), zinc (Zn), nickel (Ni), and others that can be extracted through various metallurgical routes. Recovery and recycle of heavy metal ions is a major challenge to prevent environmental contamination. The present study discusses the current e-waste scenario, health impacts and treatment methods in detail, and also presents experimental results of recovery of heavy metals from printed circuit boards (PCBs) by leaching using aqua regia (HCI + HNO_3 and HCI + H_2SO_4). Under varying conditions such as specified conditions of 80°C, 0.05 mm of thickness, 3 hrs of contacttime, 80rpm shaking speed, and concentration of PCB sample of 0.5 g ml^{-1}, it results in the composition of extracted heavy metal ions in such a way that 97.59% of copper, 96.59% of lead, 94.66% of tin, and 96.64% of zinc, respectively. The recovery of heavy metal ions from PCBs has an important leading contribution in electronic waste management and the result shows a higher rate.

Keywords: e-waste, printed circuit board, leaching, aqua regia, heavy metals, optimization

1. Introduction

The electronics industry is the largest and fastest-growing manufacturing sector in the world. The PCBs are waste sources from electronic machines such as television boards, CD players, and cell phones. Researchers have reported that in recent years, the average rate of PCB development has risen by 8.7% due to technological progress. The studies observed that the continuous increase in e-waste generation rates is due to the nation's population and technological growth. The studies predict that each individual would produce approximately 5173 kg of e-waste per year. The metallic composition consists primarily of 10–30% of copper (Cu) and other metals such as tin (Sn), zinc (Zn), lead (Pb), nickel (Ni), iron (Fe), silver (Ag), cadmium (Cd), gold (Au) and others, depending on the sources of printed circuit boards (PCB) [1–3]. A sample PCB is shown in **Figure 1**. Informal processing of e-waste in developing countries can lead to adverse effects on human health and environmental pollution. In 2016, 44.7 million metric tons of e-waste were generated globally [4, 5]. Health symptoms like headaches, dizziness, irritation in the eyes, nose, mouth, etc. are caused by exposure to Cu, which is present in landfills [6–8]. The methods that can be used to recover metals from PCBs are essentially physical, mechanical and chemical separations. Several studies on the feasibility of metal recovery from PCBs have been investigated in the last decade. Hydrometallurgical procedures, such as leaching, are very intentional in these studies.

1.1 Health hazards caused by informal disposal of e-waste

E-waste not only includes household and industrial electrical appliances but also includes their components such as batteries, capacitors, castings, etc. Recycling of such waste has been carried out both formally and informally in several countries like China, India, Ghana, Thailand, Vietnam, etc. [9]. Traditional recycling techniques are well developed techniques to ensure safe and efficient separation, but are highly expensive to install and run. So such techniques are not taken into consideration and cheap informal techniques are to be implemented. This may cause the release of several pollutants into the environment, which can lead to a variety of health problems [8–10]. The metals present in the PCBs are highly toxic and hazardous to living bodies. These metals follow media such as dust, air, water, and soil to reach the human frame. Exposure to metals such as lead (Pb) and cadmium (Cd) affects reproductive health, growth, and mental instability and damages human DNA [11–13]. Health symptoms like headaches, dizziness, irritation in the eyes, nose, mouth, etc. are caused by the exposure to copper (Cu) which is present in landfills [14–16]. The different e-waste sources, heavy metals, and effects are explained in **Figure 1**.

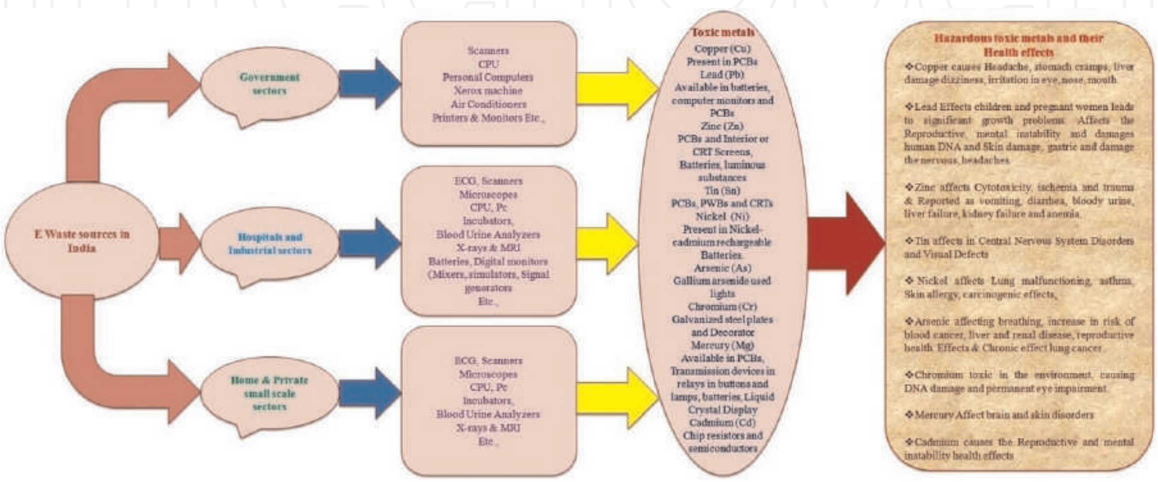

Figure 1.
Diagram of e-waste sources in various aspects and health effects.

Informal treatment strategies as well as innovative metal recovery approaches based on the material composition present in PCBs are accompanied by management and sustainable treatment techniques involving the reduction of waste circuit boards in developing countries. There are two techniques used to dispose of and extract heavy metals from PCBs. Incineration was used as a primary method through high-temperature PCB melting and is very hazardous as it releases strong toxic metal vapors such as polycyclic aromatic hydrocarbons and dioxins due to the emission of possible contaminants during incineration [17, 18], and the secondary method was followed at low temperature by hydrometallurgical techniques with the help of chemical reagents [19–21].

1.2 Pyrometallurgical method

Pyrometallurgical processing is the most common method used for the separation of heavy metals from PCBs. The smelting process consists of the melting of waste PCBs in a high-temperature furnace (up to 1500°C) and is primarily used for the recovery of copper from used waste circuit boards. The limitations of this process are relatively low performance, high energy consumption, and difficulty in distinguishing metallic and non-metallic components [19, 22]. The pyrometallurgy process involves the heating of e-waste at a high temperature to recover precious metals. This treatment leads to the release of dangerous gases into the air, which must be extracted from the air by the flue gas cleaning system [23]. The limitations of this process are:

- Pyrometallurgical techniques have a greater environmental impact due to the gaseous emissions from incineration.
- Plastic recovery is not possible due to the replacement of plastics by coke as a source of energy.
- Hazardous emissions such as dioxins are generated during the smelting of feed materials which have halogenated flame retardants and polyvinyl chloride (PVC), which lead to dioxins in the form of dioxins. Therefore, special installations (emission controls) are required to minimize environmental pollution.
- It is very difficult to separate all the metals.
- Low metals are recovered only by a fraction of metals.
- The process has high energy consumption.

1.3 Hydrometallurgical method

The hydrometallurgical method includes the application of aqueous solution leaching media, such as strong acid or base, oxidizing agents, and complexion agents, for the recovery of heavy metal separations. Previous studies have employed various leaching media such as strong acids (sulfuric acid, nitric acid), bases (sodium hydroxide, sodium hypochlorite), and complexing agents (cyanide, thiosulphate). This treatment approach has advantages over pyrometallurgical processes such as reduced pollution, radioactive contaminants, and moderately toxic chemicals for environmental effects. Therefore, these various recovery methods used for the treatment of used PCBs need to be reconsidered due to the enormous amount of flammable, toxic, and corrosive reagents used and the large volume of effluents and other solid waste produced [24]. In hydrometallurgical procedures, the following steps are widely used: leaching and extraction, purification, and concentration of liquefied solutions, as well as the recovery of heavy metals. Four operations are typically implemented in these recovery operations, as shown in previous studies. The hydrometallurgical procedure, such as leaching, has shown a great deal of strength in several studies. Several leaching reagents demonstrate major improvements in metal recovery. When treated with different acidic media, aq.HNO_3, aq.HCI, and aq.H_2SO_4, PCBs were cut to remove Cu^{2+} ions and the recovery percentage of Cu^{2+} was 97.5, 65, and 76.5%, respectively [20]. Only trace quantities of other metals can be extracted through this targeted extraction of copper. While using HCI as a leaching agent under specified conditions, the PCB sample size of 4×4 cm results in the separation of Cu, Zn, Sn, and Pb with a composition of 117.33, 28.97, 10.41, and 9.34 mg g^{-1}, respectively [23].

The amount of Zn and Pb leached was very small when compared to the typical PCB metal content. The recoveries for Cu, Pb, Zn, and Sn were 16, 2.0, 1, and 1%, respectively, when leaching was done in crushed PCBs (size between 0.43 and 3.33 mm) using sodium cyanide solution [25]. It has the least compositional value compared to the average weight of the total metals found in it. After 480 min, various metals leached from PCB waste, such as H_2SO_4 and H_2O_2, provide 76% Zn, 85% Cu, 82% Fe, 77% Al, and 70% Ni recovery [26]. Other valuable metals are retained in the leaching solution as residue. The effective treatment of PCBs will depend on choosing the suitable recovery method. The development of new technology for the recovery of toxic heavy metal ions from waste PCBs remains an important scientific endeavor. The literature study shows the more stable and effective metal ion recovery will be achieved by two-stage chemical leaching with adsorption from waste PCBs. However, a suitable carrier has to be selected for the selective recovery of heavy metals in an effective manner.

This chapter presents an overview of current e-waste scenario, its impacts and treatment methods. The experimental studies are carried out for the the extraction of copper (Cu), tin (Sn), zinc (Zn) and lead (Pb) from PCBs by leaching using aqua regia (a mixture of HCI and HNO_3 and HCI and H_2SO_4) for varying conditions of temperature, size of sample, contact time and shaking speed.

The main objectives of the present study are:

- To prepare the suitable leaching agents in chemicals and optimize the operational parameters like concentration, temperature, shaking speed, time of leaching, and bulk density for the recovery of metal ions such as copper, zinc, tin, and lead separate from PCBs.

- To determine the stability of the prepared leaching media by the recovery rate with the help of EDXs.

2. Materials and methods

2.1 Electronic waste collection

The waste PCBs are obtained from the e-waste disposal unit in India. The sample was initially cleaned manually to remove dust particles by the air blower. Later, other elements such as capacitors, resisters, integrated circuits, diodes, transistors, etc., were detached with the help of mechanical tools (saw metal cutter, sheet metal cutter, metal lathe cutting tool, cutting pliers, and materials separation toolkit). This separation is not as simple due to the difference in the physical characteristics of metals and non-metals. Hence, different separation methods, such as pneumatic separation, magnetic separation, filtering, eddy current separation, electrostatic separation, etc., are used to enrich metals and non-metals [10, 14, 23, 27].

The crushed PCBs obtained from the crusher are then pulverized and further exposed to milling operations for better size reduction using a ball mill, and particles of different mesh sizes are analyzed. The weight fraction of crushed PCBs obtained from the lower screens of jaw crushers with a capacity of 80 kg $hr.^{-1}$ and a clearance of 10 mm is much lower, making better ion recovery impossible. Thus, it is subjected to 5 mm of clearance in the same jaw crusher, yielding samples weighing 65, 53, 48, and 36 grams for sieves with mesh sizes of 0.3, 0.18, 0.05 mm, and pan, respectively, when screened using a rotary sieve shaker at a speed of 60 rpm with a power of 0.25 HP and a single-phase 80 volt supply. As the reduction in size increases the rate of recovery of metal ions [16], the resulting crushed samples are processed into powder form using a pulverizer with a disk diameter of 175 mm operated by a 3-phase motor at 1400 rpm in a 225–445 V supply (**Figure 2** and **Table 1**).

2.2 Chemical leaching experimentation with aqua regia

2.3 Leaching mediaPreparation

The leaching media is an important factor that should be considered while extracting heavy metals from PCBs. Various sorts of leaching agents show different leaching rates with respect to the type of metals present in PCBs. H_2SO_4, HCI, NaCl,

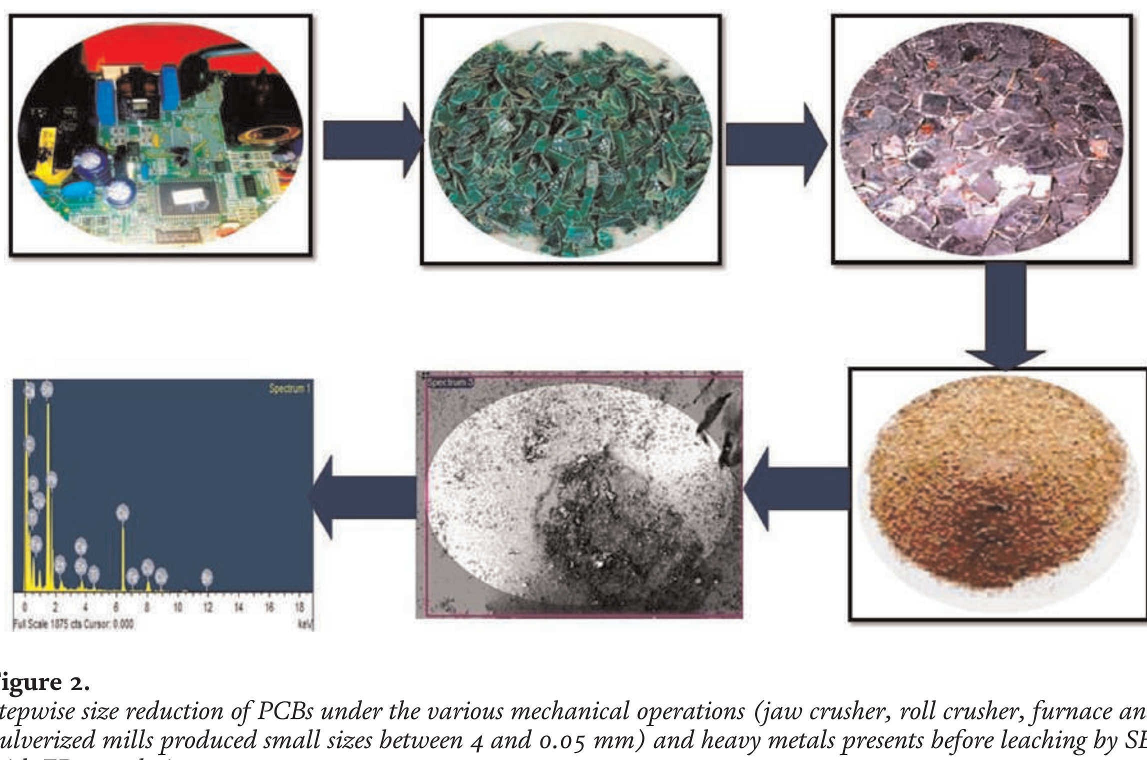

Figure 2.
Stepwise size reduction of PCBs under the various mechanical operations (jaw crusher, roll crusher, furnace and pulverized mills produced small sizes between 4 and 0.05 mm) and heavy metals presents before leaching by SEM with EDx analysis.

Mesh size		Weight fraction (grams)			
		Jaw crusher		Pulveriser	Ball mill
B.S.S	(mm)	Clearance 10 mm	Clearance 5 mm	Feed size 6 mm	Ball weight 500 g
4	4	155	118	45	27
7	2.3	125	92	57	35
25	0.6	95	76	69	58
52	0.3	52	65	87	64
85	0.18	30	53	60	78
300	0.05	22	48	85	82
pan	_	15	36	79	120

Table 1.
Analysis of PCB size reduction.

HNO_3, $Na_2S_2O_3$,etc. are commonly used leaching media for the extraction of heavy metals from PCBs. Aqua regia, which is a mixture of hydrochloric acid and nitric acid, is used as a leaching agent in this study. It is prepared by mixing HCI and HNO_3 in a 3:1 ratio under specified conditions of temperature, time, and surrounding conditions. Different leaching agents show different rates of recovery and metal extracted with respect to the nature of the leaching media, rate of ion exchange, degree of dissociation of ions and various parameters such as time, temperature, concentration etc. When remaining constraints are held constant, metal ions such as Cu^+, Zn^+, Pb^+, and Sn^+, among others, exhibit different ionic properties with acid medium. Even though the above studies result in significant metal recovery, they also possess demerits, such as the targeted extraction of a specific metal leads to the loss of several other valuable metals. By using aqua regia as a leaching reagent, heavy metals such as Cu, Sn, Pb, and Zn can be extracted from PCBs with a high recovery rate. Aqua regia preparation involves the mixing of strong acids. It produces heat and toxic gases, so it is necessary to follow safety protocols while preparing and handling this solution. In this experiment, HNO_3 is added to HCI contained in a beaker, which is placed in a water bath in order to reduce the fume generation. The two concentrated acids are mixed in the ratio of 3:1 (HCI:HNO_3); concentrated HCI is about 35% and concentrated HNO_3 is about 65%. So that volume ratio will be 4 parts concentrated HCI and 1 part concentrated HNO_3. The solution is kept away from organic contaminants because it leads to vigorous or violent reactions and a low temperature should be maintained.

2.4 Treatment of PCBs with aqua regia

All the experiments are carried out in a conical flask incorporated with a temperature-controlled shaker. Primary analysis was conducted by applying specific conditions to obtain a standard recovery rate. 5gm of PCB samples are allowed to react with 20 ml of leaching media inside the conical flask at 60°C and shaken in a mechanical shaker at a shaking speed of 120 rpm for 2 hrs. At the end of this effective contact time, the shaker is stopped and the solution in the conical flask is filtered using filter paper. After complete filtration, the filtrate is sent for SEM with EDX analysis to determine the composition of metals retained. The rate of leaching is affected by a number of factors, including sample size, concentration, temperature, shaking speed, and contact time. By varying these parameters, different values for the recovery rate and composition of heavy metals are obtained.

3. Results and discussion

3.1 Sample analysis of PCBs

It is important to conduct sample analysis before subjecting the crushed samples to the leaching process. The primary sample had followed three size reduction operations, namely crushing, pulverizing, and milling, and the weight fractions obtained at each operation are explained with their corresponding mesh size shown in **Figure 3**. The ultimate purpose of size reduction has been studied previously and data analyzed.

The graphical representation of size analysis shows that the fraction of sample obtained in the sieves with larger mesh sizes has been decreasing when subjected to a sequence of size reduction operations. However, the total weight obtained in the sieves is approximately conserved with a trace of negligible loss. From the sieve analysis data of each operation, the sample obtained from the ball mill has a fraction of weight in the pan that is less than 0.05 mm. Various studies used shredded samples with a size of less than 0.5 mm, which resulted in a high recovery rate of heavy metals [4, 5]. Present research comprises leaching particle sizes of 0.05 mm and 0.1 mm, which is the sample retained just above the pan (**Figures 4** and **5**).

3.2 Optimization of various parameters for recovery of heavy metals

3.2.1 Effectof concentration

By varying the concentration, the leaching process shows a significant change in the recovery rate. The recovery rate increases with an increase in the concentration of the sample with respect to time. After attaining an equilibrium state, the rate of leaching becomes constant. 20 ml of aqua regia is used to leach heavy metals from 2, 4,

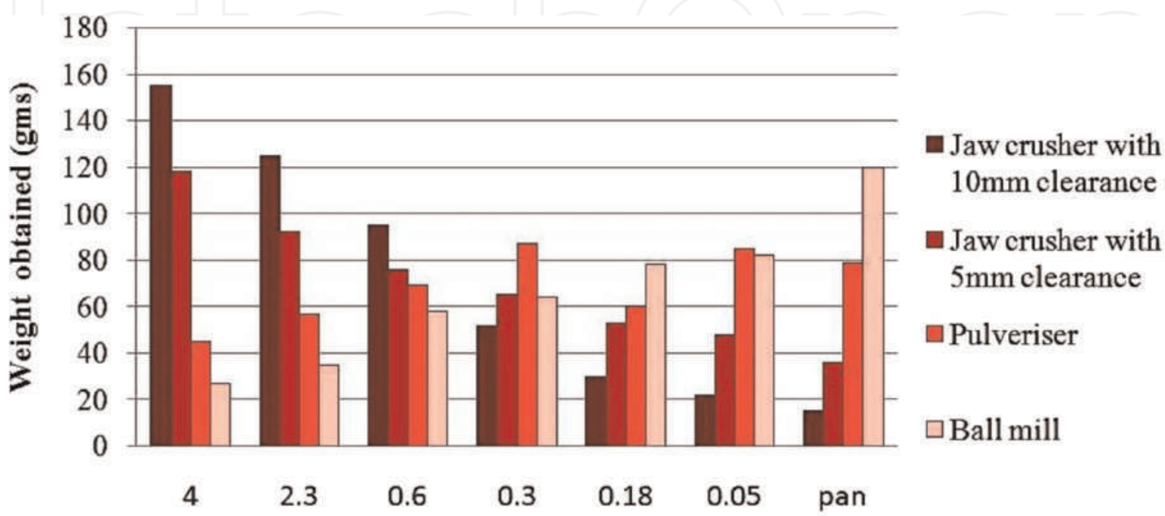

Figure 3.
Graphical representation of size reduction in different operation.

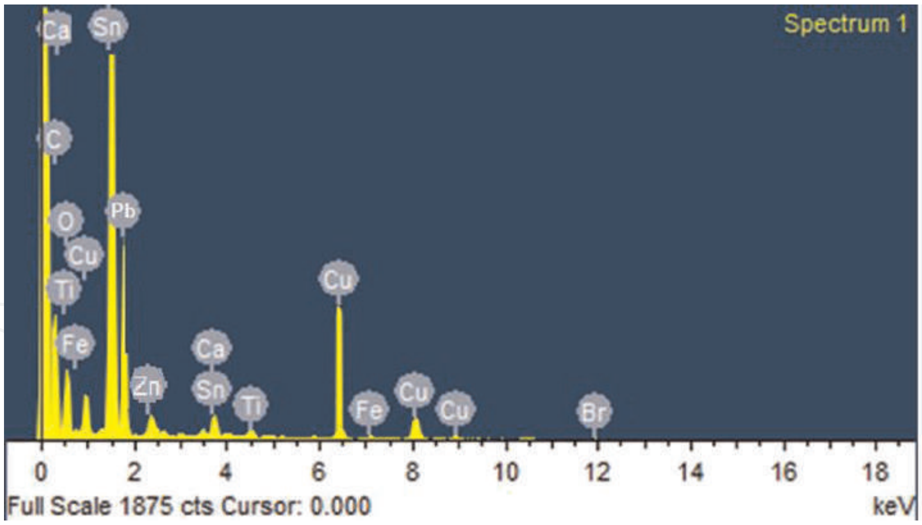

Figure 4.
Presents of metal components from PCBs by the EDXs.

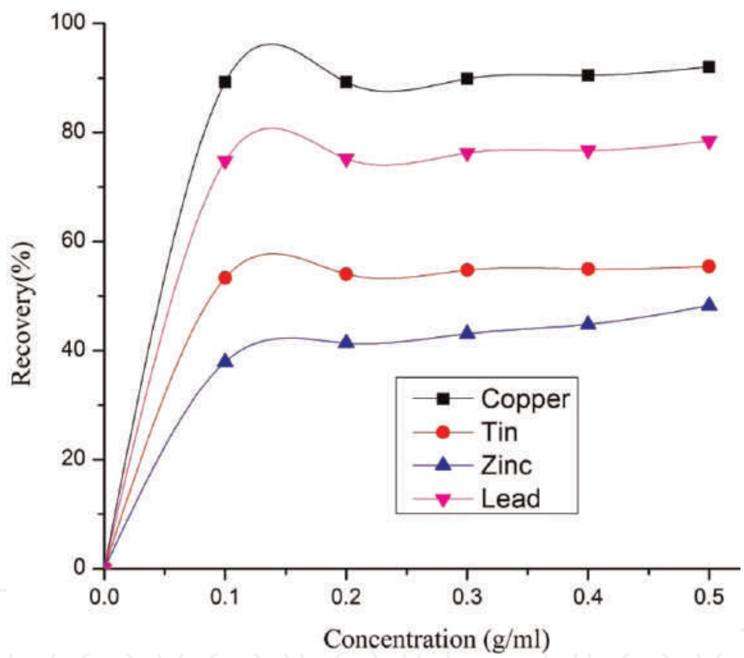

Figure 5.
Graphical representation of % recovery of metals with concentration.

6, 8, and 10 g of 0.3 mm sized PCB samples at standard conditions of 80°C of temperature and 200 rpm of speed for 2 hrs. The graph shows an increase in the recovery rate of metals with an increase in the concentration of PCB. The metals recovered in the decreasing order of Cu, Pb, Sn, and Zn were recovered. Copper is the most recovered metal, whereas zinc is the least recovered. When the concentrations were increased by 0.1 g ml^{-1}, all metals showed a slight increase in recovery rate.

As there is no decrease in the percentage of metals recovered, it is confirmed that the metallic distribution of powdered PCBs is uniform. When the concentration is 0.5 g/ml, the graph shows the maximum recovery with metallic composition as 92.06% of Cu, 55.42% of Sn, 48.27% of Zn, and 78.42% of Pb. Based on the previous studies of metal recoveries [28, 29].

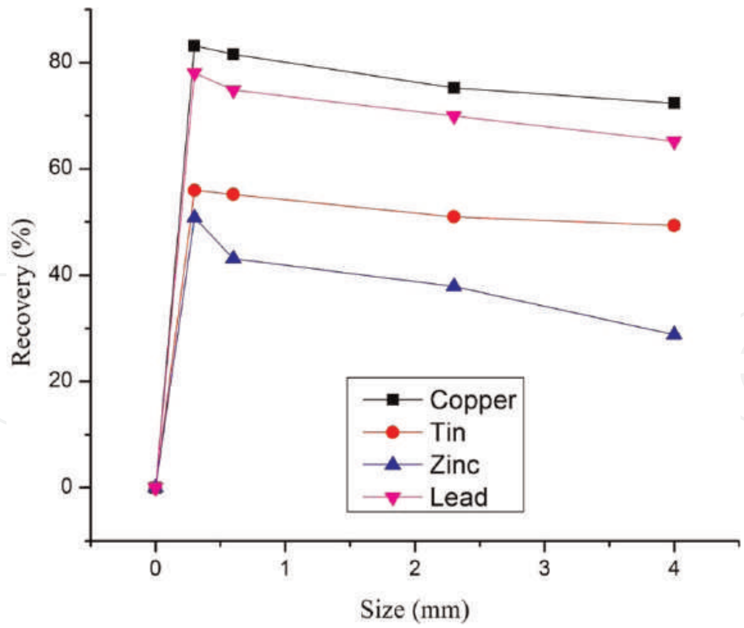

Figure 6.
Graphical representation of % recovery of metals with size.

3.2.2 Effect of size

The different sieve size particles are leached using aqua regia and the weight fraction of metallic components is analyzed. 5 gm of particles with sizes of 4, 2.3, 0.6, 0.3, and 0.05 mm are leached for hours at 80°C with a shaking speed of 200 rpm. **Figure 6** explains the relationship between size and recovery. It shows recovery increases with an increase in contacting surface.

The graph shows an appreciable increase in the percentage of metals recovered with a decrease in the size of the sample. The higher recovery rate is shown for the PCB sample at the lowest size, which is 0.05 mm. The uniformity of metallic distribution is also conserved here. Copper is the major component present in the leached sample and zinc is the minimum. It results in a percentage recovery of copper, tin, zinc, and lead of 83.49, 58.72, 57.75, and 78.42%, respectively.

3.2.3 Effect of temperatire

5 gm of PCB samples of size 0.3 mm are treated with aqua regia in a conical flask and shaken at a speed of 200 rpm for 2 hrs. Five samples of the same condition are maintained at varying temperatures of 40, 60, 80, 100, and 120°C. After completion of effective time, the leached PCB sample is analyzed. The data obtained is represented graphically and the relations between recovery and temperature are studied. The graph shows an appreciable increase in recovery rate with an increase in temperature for a particular point of temperature [30, 31]. When the sample is leached at a temperature above 80°C, there is no appreciable change in recovery, which is negligible. It indicates that the leaching depends on temperature only for a particular limit, and that after a certain point of temperature, leaching is independent of temperature. At 80°C, the result shows a metallic composition of 89.84% of Cu, 69.05% of Sn, 65.51% of Zn, and 82.45% of Pb (**Figure 7**).

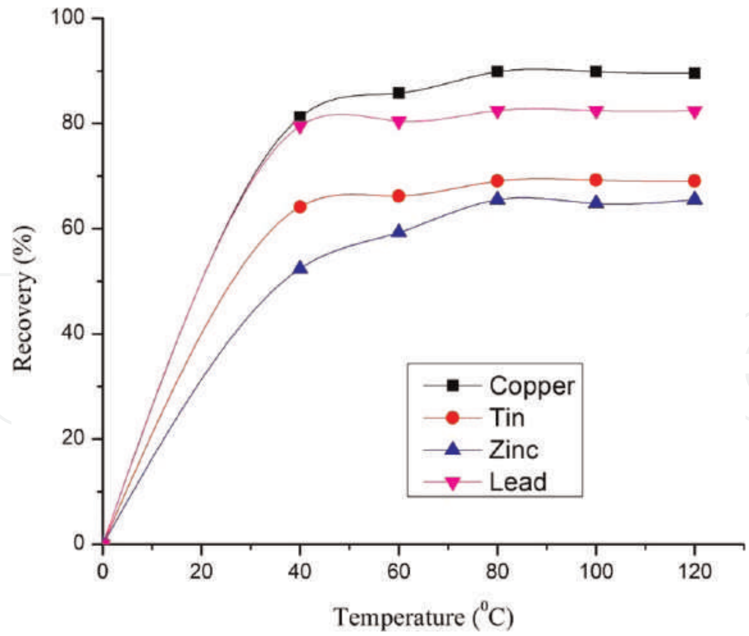

Figure 7.
Graphical representation of % recovery of metals with temperature.

3.2.4 Effect of time

To determine the effective leaching time, the sample is allowed to be leached for different intervals of time. The persistent condition is maintained as a 5gm sample of size 0.3 mm shaken with 20 ml of aqua regia in a conical flask and shaken at a speed of 200 rpm while the temperature is maintained at 80°C. Then it is allowed to be leached for 1, 2, 3, 4 and 5 hrs, respectively. The data collected is graphically represented in **Figure 8** below. It shows that the recovery percentage is almost constant when a sample is leached for more time after a certain period of time. The graph shows that the recovery of metals increases with an increase in time for a certain period, and after a particular point of time, the recovery becomes almost constant. That means all the

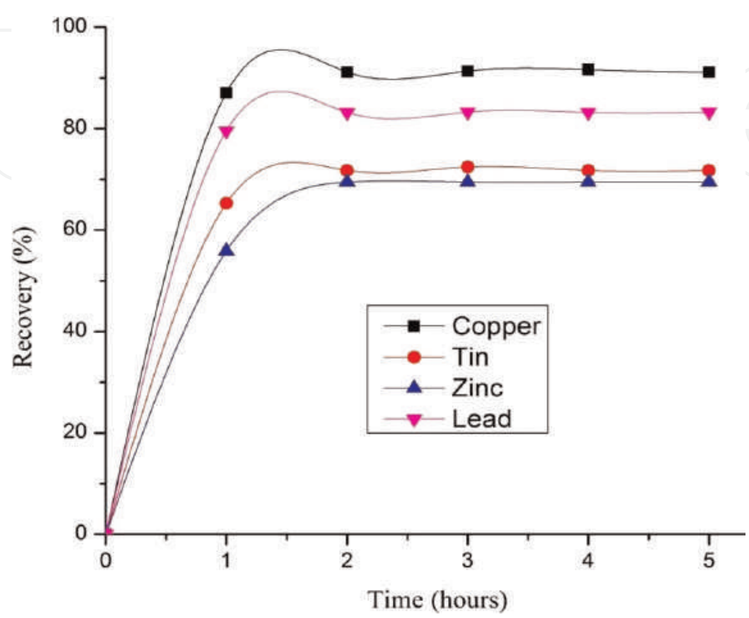

Figure 8.
Graphical representation of % recovery of metals with time.

metals in contact are leached from the sample within a particular time period, and there is no use in leaving the system under leaching condition after a certain period of time. The results show the maximum recovery when the sample is leached for 3 hrs. When the sample is leached for 3 hrs, the result shows the recovery of metals as 91.36, 69.43, 72.41, and 83.22% of Cu, Sn, Zn, and Pb, respectively.

3.3 Optimum conditional parameter studies

Once all the results for recovery with respect to various parameters are evaluated and studied as explained above, we get the optimum condition to obtain maximum recovery of metals. The optimum condition is the value of concentration, size, temperature, shaking speed, and time at which the maximum recovery is obtained. The results obtained at optimum conditions show that the recovery of heavy metals is as high as 99.9% of copper, 98.3% of lead, 96.8% of tin and 93.1% of zinc, respectively. In this study, specific conditions of 800°C, 0.05 mm of thickness, 3 hours of contacting time, 80 rpm shaking speed, and pulp density of PCB sample of 20gm L^{-1} were met in both stages, with a 3:1 ratio of first stage HCI and HNO3 and second stage HCI and H_2SO_4) prepared as a leaching agent. The experimental results were obtained under the above mentioned conditions and have been shown in (**Figure 9**) and (**Table 2**). Results found that the optimum recovery rate for stage I Cu was 89.5%,

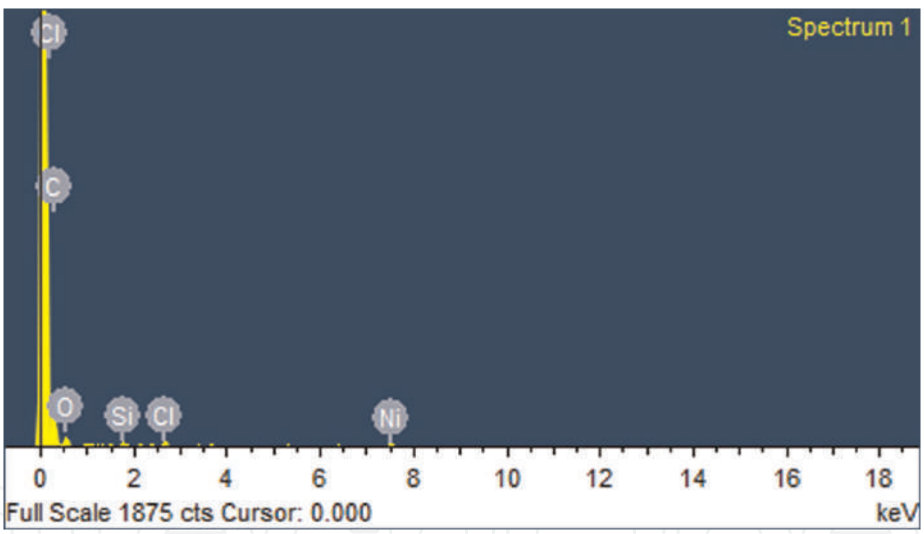

Figure 9.
EDXs spectrum analysis for metal ions obtained after leaching.

Metals	Initial C_O	Stage-I & II weight fraction				% Recovery	
		C_e-I (PCBs sample)	C_e-I Leached solution	C_e-II (PCBs sample)	C_e-II Leached solution	Stage-I	Stage-II
Cu	3.15	0.325	2.825	0.031	3.119	89.5%	99.0%
Sn	42.40	15.09	27.31	1.36	41.04	64.4%	96.8%
Pb	27.81	5.31	22.5	0.47	27.34	80.9%	98.3%
Zn	1.16	0.403	0.757	0.076	1.084	63.4%	93.1%
Others	27.81	12.4	15.41	1.168	26.642	52.6%	95.4%

Table 2.
Metallic composition of leached PCBs at optimum conditions by stage-I & II.

Sn 64.4%, Zn 63.4%, Pb 80.9%, and stage II Cu was 99.0%, Sn 96.8%, Zn 93.1%, and Pb 98.3%, respectively.

4. Conclusions and outlook

The study shows the dependency of the rate of recovery on the condition in an arbitrary manner. The recovery rate has a different approach with each parameter. The results show that the maximum percentage of metals recovered at 80°C, 0.05 mm thickness, 3 hours of contacting time, 80 rpm shaking speed, and PCB sample concentration of 0.5 g/ml^{-1}.Under this condition, the resultwas obtained with 97.59% of copper, 96.29% of lead, 94.66% of tin, and 96.64% of zinc, respectively. It is the most effective recovery condition for this experiment. However, targeted extraction of a particular metal can be made possible by varying a particular parameter only. In such a way, the percentage recovery of that particular metal can be increased with negligible loss. In such extractions, the other heavy metals are retained in the sample or less amounts of other metals are separated. Disposal of such residuals also causes environmental issues. Since this type of extraction is promoted in order to reduce the environmental problems caused by these kinds of heavy metals, the targeted extraction of a particular metal is not advisable, even if it is economically profitable. It was concluded that the combination of aqua regia (HCI and HNO_3 and HCI and H_2SO_4) leaching is an effective and economic way for the recovery of copper from leached solution. According to studies, modifying the dissolving of metal ions in the reagents increases the rate of leaching, but this raises the total cost and results in the introduction of additional chemicals into the atmosphere. As a result, attempts will be made in the future to resolve these issues. Only a few field trials have been performed, and more systematic studies are needed to decide the best conditions for using aqueregia as a leaching medium.

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Highlights

- The heavy metals in PCBs were leached with two-step aqua regia (HCI and HNO_3 and HCI and H_2SO_4).
- Optimization of various parameters has been tested to enhance the recovery of heavy metals.
- The maximum recovery rates obtained were Cu 97.59%, Pb 96.89%, Sn 94.66%, and Zn 96.64%.
- The combination of aqua regia leaching and PCBs is an efficient and cost-effective method for recovering heavy metals from PCBs.

Nomenclature

Cu	Copper (–)
EEE	Electrical and electronic equipment (–)
E–Waste	Electronic waste (–)
EDX	Energy-dispersive X-ray spectroscopy (–)
HCI	Hydrochloric acid (–)
PVC	Polyvinyil chloride (–)
Pb	Lead (–)
HNO_3	Nitric acid (–)
PCBs	Printed circuit boards (–)
SEM	Scanning electron microscopy (–)
H_2SO_4	Sulfuric acid (–)
Sn	Tin (–)
WEEE	Waste of electrical and electronic equipment (–)
Zn	Zinc (–)

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3.4.4 Details of books and chapters in edited volumes / books per teacher during the year

Sl. No.	Name of the Teacher	Title of the Book published	Title of the Chapter published	Title of the proceedings of the conference	Name of the conference	National / International	Year and month of publication	ISBN of the Book/Conference Proceeding	Affiliating Institute of the teacher at the time of publication	Name of the Publisher
1	Dr. S. Mohankumar	Some Recent topic in theory of graphs andd Its Applications	A Mathematical Model for the secretion of vasopressin using Fuzzy Truncated Normal Distribution	-	-	National	Feb-22	ISBN:978-93-5625-425-1	Excel Engineering College	Scientific International Publishing

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