# Toxicity Characteristic Leaching Procedure (TCLP) for Waste Residue of Printed Circuit Boards (PCBs) and Soil from E-waste Dumping Site

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## Abstract

Health and environmental issues are major problems due to the generation of huge amounts of electronic and electrical wastes throughout the world. Printed Circuit Boards (PCB) are the most essential component of all electrical and electronic devices. PCBs contain plastics, metals (Copper, Gold, Palladium, etc.) and non-metals (epoxy resins, fibers and other Brominated Flame Retardants (BFRs). Traditional methods (open dumping and incineration) of disposal of these wastes result in environmental pollution including groundwater contamination. Studies have been done to measure the toxicity of PCBs collected from different electronic wastes. The objective of the present study was to determine the toxicity of the leachate from residual PCBs and compare it with soil collected from e-waste dumping site. For the study of Toxicity Characteristic Leaching Procedure, USEPA standard method (SW 864 Method 1311) was followed. The result showed after the metal leaching process, PCB residues contains less concentration of metals like 5 μg/g Copper, 1.89 μg/g Lead, 1.24 μg/g Zinc etc. In compare to the permissible limit provided by WHO, soil sample collected from e-waste dumping site contains much higher amount of metal concentration viz. 240 μg/g Copper, 307.42 μg/g Lead and 350 μg/g Zinc. Therefore, the residue of PCBs can be disposed in landfills or can be alternatively used in geopolymerization. Risk assessment of the site from which soil has been collected can be conducted for proper management of e-waste other than dumping into the environment.



***Keywords:*** Electronic waste, Printed Circuit Boards, Metal Recovery, Toxicity Characteristic Leaching Procedure, Heavy Metals

## 1. Introduction

In the last few decades, production and consumption of electronic and electrical equipment has increased rapidly [1]. Following the advancement of technology, the life span of e-products has decreased and the disposal rate has increased [2]. Open dumping of e-waste is the norm in India. Dumping and incineration of electronic wastes results in air, soil and water pollution including contamination of ground water [4, 5]. Bioaccumulation of toxic heavy metals present in e-waste can occur in plants, human beings and other animals and lead to serious health problems.

Printed Circuit Boards (PCB) are the most important part of any electrical and electronic equipment and contain metals like Cu, Ni, Pb, Au, Ag, Pd, Pt, Hg, Cr, and Zn, non-metals and organic compounds viz. chlorinated or brominated flame retardants [3]. Due to the presence of these toxic substances, disposal of these wastes becomes a huge problem. Therefore, restriction in application of hazardous substances which includes mercury, lead, cadmium, chromium and flame retardants in the e-products was implemented by the European Union (EU) Directive 2002/96/EC [6]. Several literatures reported the presence of heavy metals in the PCBs beyond its Toxicity Characteristic (TC) limit [7, 8].To evaluate the toxicity of various e-wastes, studies were carried out following protocols like Toxicity Characteristic Leaching Procedure (TCLP), Synthetic Precipitation Leaching Procedure (SPLP) tests of U.S. Environmental Protection Agency (USEPA), ASTMD-3987 and EN 12457 [9].

Metals recovery from e-waste is both technically and economically feasible. However, disposal of residual material after metals recovery remains a major environmental concern due to the presence of small amounts of toxic heavy metals in e-waste. The objective of the present study was to determine the residual metals remaining in PCBs after the bulk of the metals have been leached out and recovered [10]. TCLP was used to determine metals concentrations in the leachate from residual PCBs. Along with this, soil samples were collected from an e-waste dumping site and tested for metals present in it. This study helps in understanding the amount of hazardous substances present in residual PCBs and in the soil so that proper treatment can be applied before disposal of these wastes into the environment.

### Previous study

Study has been carried out for metal recovery from waste PCBs using hydrometallurgical methods. Leaching was done by 3M nitric acid, maintaining pulp density of 75 g/L at 75 °C and mixing time of 120 min. The overall process is shown in Figure 1.

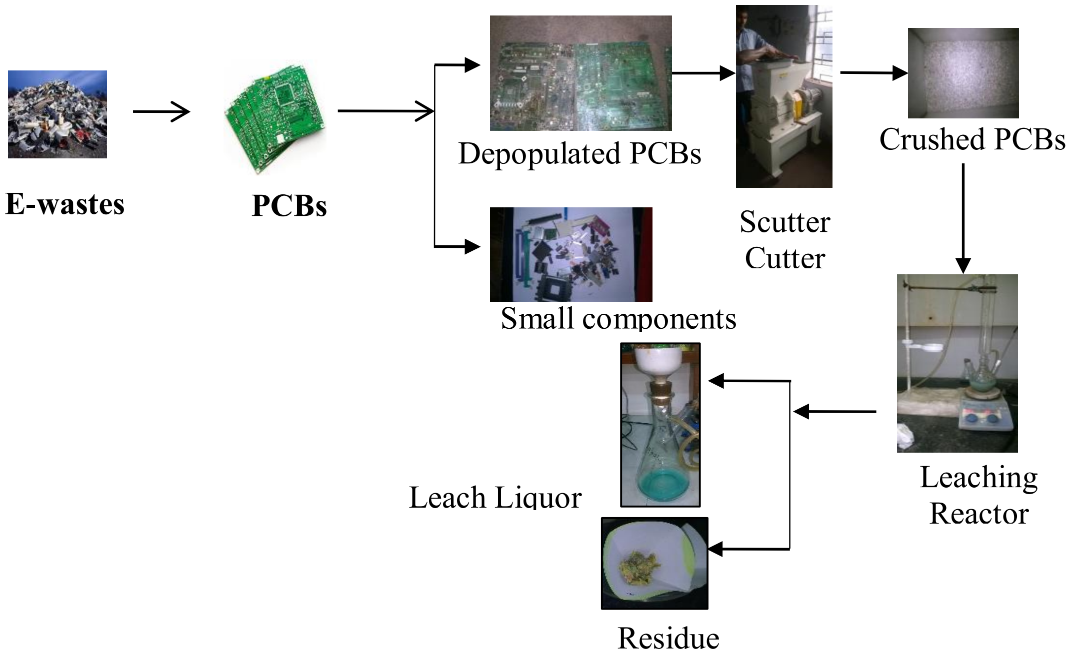


Figure 1. Leaching conditions for waste PCBs [10]

After the leaching process, the solution of solid and acid was filtered and the residue was separated from the leach liquor. This residue obtained from the leaching study was further tested for its toxicity before disposal.

## 2. Materials and methods

### 2.1. Study Area and sample collection

Soil samples were collected from depths of 5–10 cm by scraping top soil from five locations of a remote area near Kolkata, West Bengal, India. In this place, e-wastes are collected from different parts of West Bengal and are dumped. Approximately, 10 g of sediment samples were collected. The samples were homogenized and prepared for the TCLP test.

Residual PCBs remaining after metal recovery were taken for the TCLP test. These residues were generated after the leaching procedure for recovering different metals from waste PCBs [10].

### 2.2. Assessment Procedure

5 g of solid samples were taken and 100 ml of acid was added in a ratio of 1:20 (solid: liquid). The container was placed in rotary extraction vessel or simply in TCLP shaker (Figure 2). Standard method of USEPA (SW 864 Method 1311) was followed for the experimental study. Table 1 summarizes the extraction conditions for the study.

Table 1. Leaching conditions for TCLP of waste PCBs

| Solid-Liquid Ratio | Extraction medium (per liter) | Extraction Time (h) | pH | Agitation Speed (rpm) | Temperature (°C) |
|---|---|---|---|---|---|
| 1:20 | 5.7 mL glacial Acetic acid + 64.3 ml1 N NaOH | 18 ± 2 | 4.93 ± 0.05 | 30 ± 2 | 22 ± 2 |

Figure 2. TCLP Shaker

### 2.3. Elemental analysis

After conducting the experiment for 18 ± 2 h, the samples were filtered through a 0.22 μm glass fiber filter and were injected into i-CAP Q-Inductively Coupled Plasma Mass Spectrometry (ICPMS, Thermo Fisher Scientific®) considering dilution factor 20. Ultrapure (Type A) grade (Thermo Fisher Scientific®, Smart2Pure) was used for five-point calibration and laboratory blanks were also prepared with the same.

## 3. Results and Discussion

The percentage of metals present in residual PCBs is given in Table 2. After the leaching process following hydrometallurgical route, the metal content decreased in the residue left after separating the leach liquor. Disposal of these residues in the environment may get leached in the soil contaminating soil physical and chemical properties. TCLP test of the soil has been performed to measure the toxicity in this study. The maximum permissible limits of heavy metals in soil have been established by World Health Organization (WHO). Table 3 (column 2) shows the permissible limit of metals in soil, column 3 shows the concentration of metals obtained from the residual PCBs in laboratory tests and column 4 shows the concentrations of metals present in soil collected from the e-waste dumping site.

Table 2. Percentage of metals present in PCBs.

| Metals present in PCB | Cu | Sn | Pb | Fe | Ni | Cr | Au | Ag |
|---|---|---|---|---|---|---|---|---|
| % of total weight of PCB | 18.62 | 6.24 | 3.56 | 5.69 | 1.84 | 0.25 | 0.023 | 0.054 |

Table 3. Results of TCLP test with PCB waste and soil sample.

| Leachate Quality | Concentration (μg/g) in soil (WHO) | Concentration of metals in residual PCBs after recovery of metals (laboratory) (μg/g) | Concentration of metals in soil (Field Study) (μg/g) |
|---|---|---|---|
| Cadmium | 3 | 0.005 | 6.85 |
| Zinc | 300 | 1.24 | 350 |
| Copper | 100 | 5 | 240 |
| Chromium | 100 | 0.002 | 226.5 |
| Lead | 100 | 1.89 | 307.42 |
| Iron | 50000 | 1.33 | 54623 |
| Manganese | 2000 | - | 1927 |
| Cobalt | 50 | - | 62 |

From Table 3, it can be shown that after toxicity analysis, residual PCBs showed less quantity of metals present which is much below the permissible limit hence can be disposed of in the environment. Still due to its less metal concentration, it can result in bioaccumulation if disposed randomly in the environment and can enter into the food chain causing health hazards. An alternative method is to use the residual PCBs for geopolymerization; this method has been accepted throughout the world. In geopolymerization, the waste residues are used as binding agent for fiber composites, radioactive and toxic waste encapsulation and also in cements for concrete making.

Results of the TCLP test in this study show that soil collected from the e-waste dumping site has much higher amount of metals compared to residual PCBs. Heavy metals present in the e-wastes which due to the environmental conditions can leach into the soil and subsequently into groundwater. These are the prevailing conditions in developing countries like India and China where the informal sectors dominate in the recovery of metals and other useful commodities from e-waste. People including children are more vulnerable to various diseases when the wastes are handled improperly. Vegetation near to the sites contain metals in it and in this way, the metals enters the food chains present in the ecosystem.

## 4. Conclusion

Results from this study showed that after leaching metals from PCBs, less concentration of metals were present in the PCBs in comparison to WHO standards and higher concentration of metals were found in the soil from e-waste dumping site. Geopolymerization may be an alternative disposal technique for waste PCBs as it contains minimum amount of metals in it thus minimizing the waste disposal cost with long term benefits and valuable use for the society and its environment.


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