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Study on Recovery of the Energy from E-Waste (Pcbs) By Pyrolysis

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ABSTRACT

The pyrolysis of electronic waste (e-waste) for energy production and material recovery is the main topic of this master's thesis. In order to get insight into the qualities of electronic trash, a description of its composition and current waste management methods is first offered in the theoretical portion. The merits and disadvantages of the present treatment methods are examined in order to compare them with the ground-breaking technology of waste pyrolysis, since more and more sustainable waste handling solutions are needed. The printed circuit boards' fraction (PCBs) was the substrate employed for pyrolysis in the context of this master's thesis, hence a specific description of this fraction is provided. For an overview of the complete procedure, the pyrolysis as a thermal treatment approach is also fully detailed.

Since different materials are employed in the production of PCBs, sample preparation was also a component of the experimental process. Additionally, samples were given to an outside business for elemental, proximate, and final examination. Following sample preparation, the primary chemicals produced, the reactions' kinetics, and several other crucial parameters were all identified using analytical techniques such as the TGA. Additionally; the experimental data were further examined utilizing a variety of computation tools, Microsoft Office Excel, and Matlab. Since the pyrolysis of electronic waste is still being researched, a thorough analysis of the results is also included in the results section.

All the information acquired from the composition analysis, TGA curves, and a qualitative and quantitative analysis is summarized and shown in the results. Phenol and hydrocarbons with a high heating value are the primary byproducts of the pyrolysis of printed circuit boards, while the increased ash content shows promise for the recovery of metals.

I. INTRODUCTION

Printed Circuit Board (PCB) is an essential component of almost all electronic and electrical equipments such as computers, televisions, mobile phones, entertainment devices, household appliances and other such items. The rapid growth of the use of such equipments, combined with their early obsolescence has contributed enormously to the generation of large quantity of electronic waste (e-waste). The UNEP estimates that the world is generating collectively about 20-50 million tons of e-waste every year. It is also predicted that by the year 2020, e-waste in India from old computers will jump 5 times, while from discarded mobile phones will be 18 times higher compared to 2007 level.

The printed circuit board, which makes up around 30% of all electronic waste produced, is a significant component of outmoded and discarded electronic waste. Glass fibre, metals, and organic materials are all mixed together uniformly. About 70% of PCBs are composed of non-metals like epoxy, glass fiber, and other additives, while the remaining 30% are made up of metals including copper, tin, lead, iron, and nickel.

The approximate contents of the metal portion are as follows: copper 17%, solder 4%, iron 3%, and nickel 2%. There are also trace amounts of precious metals including palladium, silver, and gold. In addition, PCBs include several heavy metals and hazardous materials, such as lead, cadmium, mercury, PVC, and halogenated flame retardants, among others, that, if improperly disposed of, may gravely harm the environment. WPCB recycling is very challenging because of its multi-layered, multi-component architecture. Therefore, creating a processing technique for recycling WPCBs that is both inexpensive and pollution-free is necessary in order to both recycle valuable materials and prevent environmental contamination.

The thermo chemical degradation of organic material during pyrolysis occurs at high temperatures (generally without the participation of oxygen). It is irreversible and involves a

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simultaneous shift in chemical composition and physical phase. In the pyrolysis process, the organic portion of the PCB is broken down into low molecular products (liquids or gases), which can be used as fuel or chemical sources. Additionally, PCB becomes brittle and delaminates, making it easy to crush, while the inorganic portion, such as the glass fiber, remains fairly intense and can be recycled into other composites or other materials.

Material

Old and obsolete computers' Printed Circuit Boards (PCBs), a component of the computer mother board, were gathered through local sources. To obtain clean, component-free PCBs, the batteries, capacitors, and other electronic devices were manually removed. Several of these boards were broken into bits between 4 and 6 cm in size using a laboratory jaw crusher. Using a manual cutter, these huge pieces were further shrunk to a size of 2-3 mm.

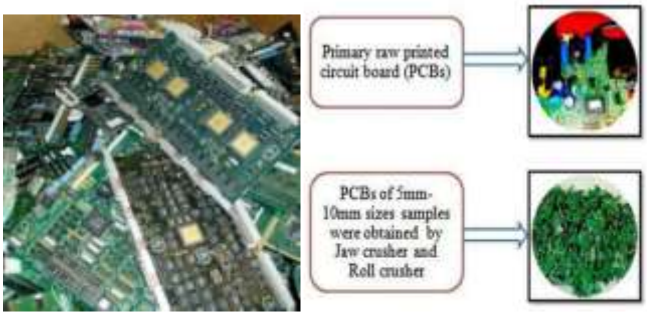

Figure 1. (a)PCB from computer mother board **(b)** PCB from jaw crusher

Methodology

In order to gather all the necessary background knowledge for pyrolysis, waste management, electronic waste, printed circuit boards, and materials recovery from waste, this master's thesis comprises an exhaustive literature review of numerous related papers, books, and publications.

The experimental research conducted at the lab housed in the LAB is the subject of the second section of this thesis. In order to learn how temperature fluctuations affect practical energy and material recovery, the experimental study concentrated on the pyrolysis of printed circuit boards. While the latter portion of the experiments was carried out using a thermo gravimetric analysis (TGA) apparatus to define the mathematical model of the reactions occurring.

Experimental

The experimental part includes all the necessary information regarding the experiments which were conducted at the laboratory located at the branch of Cytogene Research and Development for this master thesis.

Sample Preparation

Old and obsolete computers' Printed Circuit Boards (PCBs), a component of the computer mother board, were gathered through local sources. To obtain clean, component-free PCBs, the batteries, capacitors, and other electronic devices were manually removed. Several of these boards were broken into bits between 3 and 5 cm in size using a laboratory jaw crusher. Using a manual cutter, these huge pieces were further shrunk to 3-5 mm in size.

Since the sample should have a uniform composition, homogenization of the samples was also a crucial step in achieving repeatability of the results. The provided shredder was used to reduce the particle size, and the material was thoroughly mixed after pulverization to accomplish homogenization.

Conducting Thermogravimetric Analysis (TGA)

As was previously indicated, the powder chosen for these studies was less than 0.6mm to reduce heat transmission losses. Four alternative heating rates, which were chosen based on the literature review, were needed for the experimental approach.

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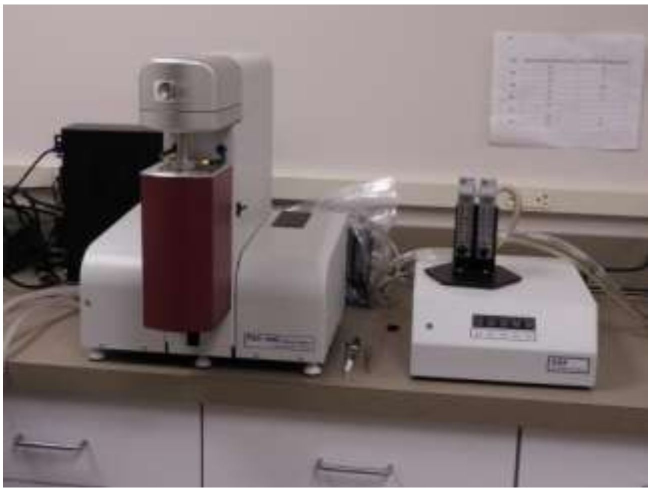

Figure 2: Thermogravimetric Analysis (TGA) used for this report

The studies were therefore conducted at 20oC/min and 40oC/min. Four crucibles were utilized for the experiments: one for the blank experiment, one for the sample experiment, and two for each variable heating rate.

A sample of 10 mg (+/- 2 mg) was present in each of the two crucibles. The blank was required to eliminate the analytical tool's inaccuracy for each distinct heating rate. This led to the collection of two distinct curves showing the sample's mass loss with increasing temperature and time (TGA curves) and two distinct curves showing the sample's heat flow with increasing temperature and time. The pyrolysis kinetics chapter will provide the methods utilized for the investigation, while the findings section will present and interpret the curves, and the appendix will contain the analytical data.

Figure 3: Samples inside the crucibles used for the experiments

Pyrolysis Kinetics

Printed circuit board pyrolysis is typically a multi-step, complicated procedure. The level of homogeneity is relatively low compared with other waste fractions. Such complicated systems make it extremely challenging to provide a thorough kinetic analysis while also calling for an average kinetic description.

The following equation can be used to describe the general kinetic processes of printed circuit boards:

Kissinger-Akahira-Sunose (KAS) method:

$$\ln\left(\frac{B}{T^2}\right) = \ln\left(\frac{AR}{E_a g(x)}\right) - \frac{E_a}{RT},$$

Where, β = heating rate in K/sec

T = temperature in K

A = pre-exponential factor

E = activation energy in J/mol

R = gas constant in J/mol K

The slope of the straight line that results from graphing ln(β/T2 vs. 1/T at constant conversion values is the activation energy for the given conversion value. The activation energy profile will be created by doing that across the entire range of conversion.

II. RESULTS AND DISCUSSIONS

The findings from the experiments carried out as part of this master's thesis project are presented in this section. To further clarify all the discovered correlations, a thorough analysis and discussion are also provided.

Composition of Printed Circuit Boards

Sample The composition of printed circuit boards has reportedly already been identified, per the literature. However, in order to compare the pyrolysis product with the original composition and to acquire more accurate results, proximate analysis and elemental analysis were performed. The laboratory analysis was done by a different lab.
The results of the analysis and the authorized procedures that were used are summarized in the following tables:

Moisture	120c	0.58wt%
Ash	580c	82.50wt%
Volatile	VM	22.30wt%
Fixed Carbon		0.30wt%

Table 1: Proximate Analysis of Sample Printed Circuit Board

The proximate analysis reveals that there is a significant quantity of ash on the printed circuit boards (82.50 wt %), which can be accounted for by the compound's high concentration in metals and ceramics. Due to its high concentration in organic compounds, polymers, and resins, the volatile compounds were also relatively high, at 22.30 wt%. Finally, as predicted from comparable investigations, the moisture content is relatively low.

6.1.2. Elemental Analysis

The elemental breakdown of the printed circuit board sample is presented in Table 2. Due to its extensive use on the motherboard's conductors, copper is the most prevalent metal in the printed circuit board portion, as predicted from the literature. Due to its application in ceramic materials and textiles, silica concentration is also high. Despite the low concentration of gold, silver, platinum, and palladium, the market's prices can act as a catalyst for their recovery. Additionally, large concentrations of hazardous compounds including lead, nickel, antimony, cadmium, arsenic, chromium, and mercury, which have been described in previous chapters and can have an adverse effect on the environment, exist in recycling facilities.

Table 2: Elemental Analysis of Sample Printed Circuit Board

Element	Mg/kg	%	Element	Mg/kg	%
Aluminum	29700	2.97%	Manganese	82	0.01%
Palladium	10.96	0.00%	Barium	1576	0.16%
Platinum	0.002	0.00%	Lead	47515	4.75%
Gold	5.46	0.00%	Boron	2590	0.26%
Potassium	430	0.04%	Cadmium	0.19	0.00%
Iron	11200	1.12%	Copper	412869	41.28%
Calcium	28000	2.80%	Silver	438	0.04%
Magnesium	427	0.04%	Zinc	8273	0.82%
Titanium	1478	0.15%	Chromium	372	0.03%
Sodium	953	0.09%			

Thermogravimetric Analysis (TGA)

As previously noted, four alternative heating rates (20°C/min and 40°C/min) were used for the thermo gravimetric study, with temperatures ranging from 70°C to 850°C. To obtain smaller heat transfer losses for more precise results, the sample was painstakingly and thoroughly shred to less than 0.08 mm. A blank experiment was also carried out at each different heating rate for the purpose of calibrating the TGA and optimizing the

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results in accordance with the manufacturer's instructions.

The thermo gravimetric curve demonstrates the relationship between temperature and the percentage of mass lost. As anticipated, the mass loss peaks at roughly 80%, which is consistent with the high ash content. Given the low moisture content and the fact that moisture escapes at temperatures above 100oC, the mass has hardly changed from the start of the experiment until 120oC. Figures 9 shows that the temperature range between 250oC and 370oC, where the derivative of mass loss was sufficiently reduced, was where the highest mass loss rates were seen.

The TGA curve was both pushed to higher temperatures as the heating rate was raised, which is another significant finding from both figures. The system's resistance to heat transport is influenced by this delayed breakdown. The system takes longer to reach the equilibrium temperature as more thermal energy is delivered to it at increasing rates. As a result, for the sample to reach the decomposition temperature, a longer residence time is required.

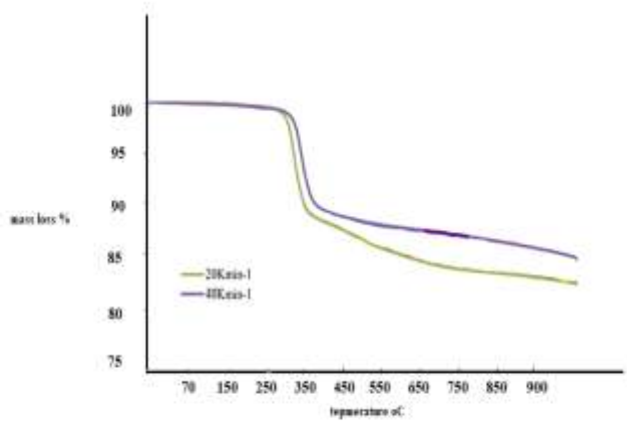

Figure 4: TGA curve Mass loss% vs. Temperature of the sample Printed Circuit Boards

Pyrolysis Kinetics

The data extracted from the Thermogravimetric analysis shows that the main reaction occurs between the temperature of 250oC and 370oC, where the mass loss rate becomes maximum. Therefore, the analysis of the activation energy as long as other kinetic parameters will be calculated by the KAS method between these temperatures.

The data extracted from these analyses can be used as a path providing the necessary information for the process of pyrolysis of printed circuit boards. On the other hand it has to be mentioned that the data calculated describes apparent and average reactions which can substitute the real reactions occurred on this process.

Activation Energy Estimation using the KAS method

Normalized conversion(a)	Activation Energy(kJ/mol)	Square of R
0.10	154.346	0.990273
0.15	151.476	0.99247
0.20	150.009	0.99478
0.25	149.490	0.995142
0.30	147.398	0.996658
0.35	149.637	0.995568
0.40	149.715	0.996222
0.45	150.829	0.993179
0.50	153.442	0.998278

By plotting the ln(β/T2) vs. the inverse temperature (1/T), one can determine the activation energy for conversions ranging from 0.10 to 0.50, which nearly cover all conversion processes in the temperature range of 250°C to 370°C, according to the analysis of the kinetic model KAS mentioned in earlier chapters.

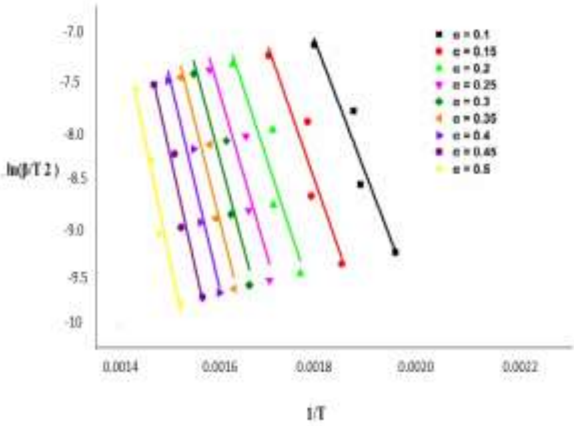

Table 3: Activation Energy estimated by KAS method in each different normalized conversion and the R2 factor

From 147.398 KJ/mol to 153.442S KJ/mol, the activation energy determined by the KAS technique ranges. These differences are frequent in the reactions of complex components, and the methods by which these reactions take place and decompose are equally complicated. With a standard deviation of 11,387, the average apparent activation energy that may be obtained using the KAS approach is 158,954 KJ/mol.

III. CONCLUSION

Concerning all the results and the discussions, it can be summarized that pyrolysis process of printed circuit boards can become a feasible method for energy production and material recovery.

Firstly, the metals which can be recovered after the pyrolysis process have relatively high quantity in precious metals such as gold, palladium, silver and platinum and high quantity in copper and other conventional metals. The high quantity of these metals, almost 40% of the total mass, can contribute to the additive value of the pyrolysis process. Furthermore, the quality of the recovered metal should be high due to the lack of oxygen in the process which usually contributes to formation of metal oxides.

The proximate analysis of the PCBs showed that the energy recovery cannot reach high levels since almost 80% of the total mass consists of ash. On the other hand, since the oxygen content of this fraction is relatively low, the produced gas and liquid fuel should expect to have high energy content. On the other hand, the quantity of phenol and phenolic compounds produced through the pyrolysis showed that feedstock recycling is a better option than producing fuels.

The pyrolysis process’s limitations were set by the ash properties analysis to 900oC, while in higher temperatures the ash starts to deform and becomes unstable. Furthermore, the quantification of the pyrolysis products showed that in higher temperature, the carbon dioxide increases as well as hydrocarbons, while the phenol decreases. Therefore, the process’ conditions should be set according to the desirable products. Moreover, the bromine containing compounds seems to have stable quantity on the entire temperature range, so a removal strategy through catalysis or other alternatives are necessary.

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