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FEASIBILITY STUDY OF WASTE PRINTED CIRCUIT BOARD RECYCLING THROUGH MANUAL DISMANTLING AND HYDROMETALLURGICAL PROCESS

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ABSTRACT

In the last years, there is an increasing acknowledgment of our impact on the environment due to our lifestyle, while the need to adopt a more sustainable approach as to our consumption habits emerges as of particular significance. This trend regards industrial sectors affecting the consumption habits and, especially, electronic industry where the short life cycles and the rapidly developing technology have led to increased e-waste volumes, such as discarded electronic equipment. The majority of such elements result in landfills. However, their partial recyclability, due to their material composition (combination of different metals, such as copper, aluminium and steel, attached to, covered with or mixed with several types of plastics and ceramics) along with the unavoidable restrictions in landfills, has led to the development of retrieval techniques for their recycling and re-use, highlighting the significance of e-waste recycling, not only from a waste management aspect but also from a valuable materials' retrieval aspect. In this paper the method of hydrometallurgy is adopted to recycle metals from waste printed circuit board (PCB). An experimental leaching test was built up to recover precious and hazardous metals from the PCB. Experimental results showed that HCi can be used as metals-formation material to separate metal from PCB during the leaching process. Those results helped to find a way to recover metals and precious metals from PCB. It was revealed that the metal elements in e-waste can be dissolved using this method and further investigation to increase the dissolution rate is required to ensure that the method proposed is applicable in industry. However, dissolved concentration of Pb must be controlled to ensure that it follows the permissible amount set under environmental standard.

Keywords: PCB waste, e-waste, dissolution, waste motor, recycling, hydrometallurgical, leaching.

INTRODUCTION

Our world is undergoing a rapid growth in the production of electrical and electronic equipments (EEE). It is undeniable that without the EEE, there is no high technology can be created or designed. However, along with the fast growth of EEE production, tremendous amount of E-waste has also been produced every year. It is estimated that by 2020, the cumulative total of E-waste from seven categories of E-waste (television sets, personal computers, mobile phones, refrigerators, air conditioners, washing machines and rechargeable batteries) that will be discarded in Malaysia is about 1,165 billion units (21.379 million metric tons) (DOE Malaysia, 2006).

In Malaysia, E-waste is generally defined as 'used' electrical and electronic assemblies categorized as scheduled wastes in the First Schedule of the Environmental Quality (Scheduled Wastes) Regulations 2005, administered by the Department of Environment (DOE) (Chong T.L., 2008). E-waste management is taken seriously nowadays not only because of the tremendous amount of production volume but also because it has grown in increasing complexity. It is chemically and physically distinct from other forms of municipal or industrial waste; it contains both valuable and hazardous materials that require special handling and recycling methods to avoid environmental contamination and detrimental effects on human health (Terazono A. *et al.* 2006). There are many health and environmental problems occurred from e-waste such as the toxic pollution from materials such as cadmium, chromium, lead, mercury, beryllium and many more. For instances, sampling of heavy metals and toxic organics sediments in e-waste recycling sites such as Guiyu (China) and Bangalore (India) showed that heavy contamination from backyard recycling brings severe damage to the local environment and leads to human health risks (Huo X *et al.* 2007) (Ha, N.N. Agusa *et al.* 2009). Air pollution around the e-waste processing area was also found in China (Li H. Yu *et al.* 2007). Thus, technology on the E-waste handling, managing as well as recovering and recycling is very much essential in order to reduce the environmental impact brought by the E-waste.

There are several methods for the metal recovery from waste materials or by-product. Oishi et al. conducted research on recovery of copper from printed circuit board (PCB) by hydrometallurgical techniques (Oishi T. *et al.* 2007). Frey and Park performed research for recovery of high purity precious metals from PCBs using aqua regia as leachant (Y. J. Park, D. Fray., 2009). According to DOE Malaysia, the main technology employed to recover e-wastes in terms of precious metals in Malaysia is still limited to wet chemical processes and electrolysis. There are still very limited literatures on the e-waste management, handling and recovery process of hazardous materials in Malaysian e-waste industry. In our previous study, the re-utilization of industrial waste had been investigated (Hisyamudin, M.N.N. *et al.* 2009) (Yokoyama S. *et al.* 2010a) (Yokoyama S. *et al.* 2010b). Thus, the current study is to investigate the recycling process of E-waste through the manual dismantling process and hydrometallurgical process. The E-waste that been used is waste dc motor due to the massive amount of it in the E-waste industry in Malaysia.

EXPERIMENTAL PROCEDURES

Figure-1 shows the waste PCB from a desktop computer used in the study. It is a common PCB that can be easily found at the e-waste disposal area or second hand electronic shops. The computer was manually dismantled and the time required to dismantle all parts was measured. The dismantled parts were then categorized into ferrous, non-ferrous, PCB and plastic parts, and composition of each types of part was measured. Then, in order to investigate the leaching behavior of PCB parts, the PCB parts were collected from one single desktop computer and the leaching test of the PCB parts was conducted. The leaching test of the PCB parts was carried out according to Figure-2. The parameters of the leaching test are shown in Table-1.

Figure-1. Waste PCB sample.

The ratio between samples and leachant is 1:10. 100g samples were inserted into glass beaker and then the leachant which is purified water with the pH adjusted to be 6.0 by HCl was softly poured into the beaker. After that, the water in the vessel was mixed at rotational speed of 100 rpm. The test was conducted in ambient air and temperature. 50 ml liquid samples were collected every 1, 3, 6, 12, 24 and 48 hours by syringe and filtered by filter paper. The liquid residue was then analyzed by Atomic Absorption Spectroscopy (AAS). Before the leaching test, the sample chemical composition was measured by Energy Dispersive X-Ray Spectroscopy (XRD).

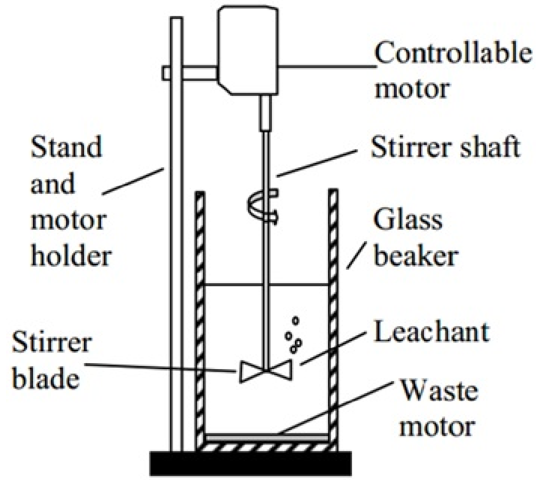

Figure-2. Schematic of leaching test.

Table-1. Parameter of leaching test.

Leaching Time (H)	1, 3. 6. 12. 2 and 48
pH	4 and 6

RESULTS AND DISCUSSION

The dismantling process was conducted manually using player and screw driver. The sequences of dismantling processes and time required for each processes is shown in Table-2. The total time required to dismantle all components is about 1925 seconds or about 32 minutes. The process that required longest time is the process to separate the electronic components from the PCB. If this process can be simplified, the overall dismantling time can be reduced and it can ease the recycling process of PCB. There are seven types of parts consisted in the desktop computer; ferrous and non-ferrous, aluminum, LCD, PCB and contact, wire and cable and mixture of cooper, steel and plastic parts, as shown in Figure-3. The weight contributions of each type of parts are 29.4%, 1.8%, 5.9%, 27.8%, 11.3%, 4.9% and 18.7% respectively.

Table 2. Time require in the dismantling process.

Process	Time (s)
Dismantling housing	180
Dismantling the wire and connection	65
Dismantling drivers adapter	120
Dismantling drivers	180
Dismantling PCB	180
Dismantling components from PCB	1200
Total	1925

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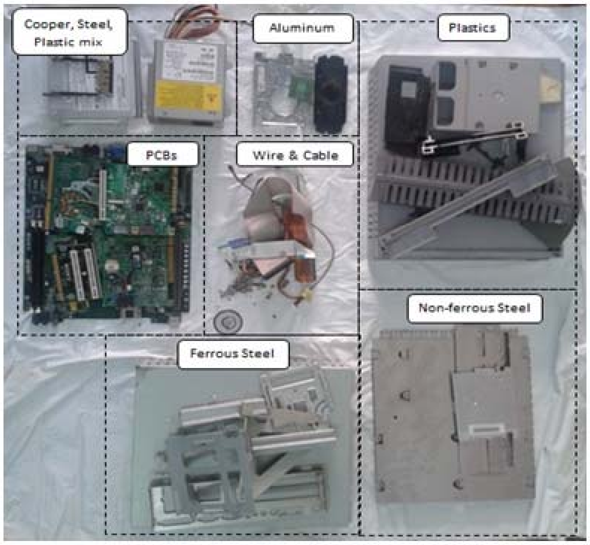

Figure-3. Categories parts by type

Characterization of the PCB

Table-3 shows the material composition contained in the PCB. A typical PCB composition is 30% plastics, 30% refractory oxides and 40% metals. The most abundant metal is copper with a concentration between 10% and 30%. Metal compositions in PCBs are different according to the manufacturer and the year of its manufacturing and technology (Montero R. *et al.* 2012).

Table-3. Material composition (Montero R. *et al.* 2012).

Element	Composition
Cu	10-26.8 (%)
Pb	0.99-4.19 (%)
Zn	0.16-2.17 (%)
Au	80-1,000
Au	110-3,301
Pt	.6-30 (g/t)
Pd	10-29 (g/t)

Leaching Behavior of Waste Desktop PCB

Figure-4(a) shows the change in pH during the leaching test. The initial pH was 6 and it increased as the leaching started and continuously increased up to 8 at the end of the leaching test. The standard of river pH value based on Interim National Water Quality Standards (INWQS). The final pH was within the permissible range of pH set in INWQS Class 1. Class 1 is considered as the "best" with no requirement of treatment and suitable for the conservation of natural environment. However, in the case of initial pH were 4, the final pH were not in range of class I, but in class III which is requires extensive treatment. Since this work is more on the fundamental study of the dissolution behavior of each main element in the waste PCB, more study is required to validate this expectation in the coming works.

Figure-4(b) shows the dissolved concentration of main elements inside waste PCB during the leaching test. Pb shows the highest dissolved concentration during the initial stage of leaching. However, it gradually decreased afterward after 12 hours leaching. As expected, Cu was observed by XRD on the main parts as stated above, but the dissolution of Cu was observed slightly low than Pb during the leaching test. The concentration of Zn was low from the early stage of leaching and almost unchanged afterward. The dissolved concentration of Pb was higher than permissible level class IV of INWQS and all pollutions of EQS as shown in Table-4.

Figure-4(c) shows the behavior of dissolved concentration of each element with changes in pH of the leachant. Pb concentration increased as the pH increased and the dissolved decreased after pH exceeded 6.8. Cu also decreased after pH more than 6.8. On the other hand, concentration of Zn almost unchanged with the increasing pH. It can be concluded that there is a high potential of recycling of waste PCB by utilizing the leaching test and hydrometallurgical method. However, more effort has to be putted on reducing the dismantling time of the waste PCB and on managing the dissolved Pb during the recycling process.

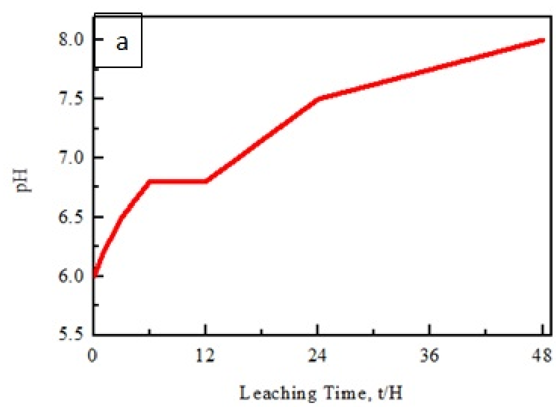

Figure-4(a). pH changes during the leaching test.

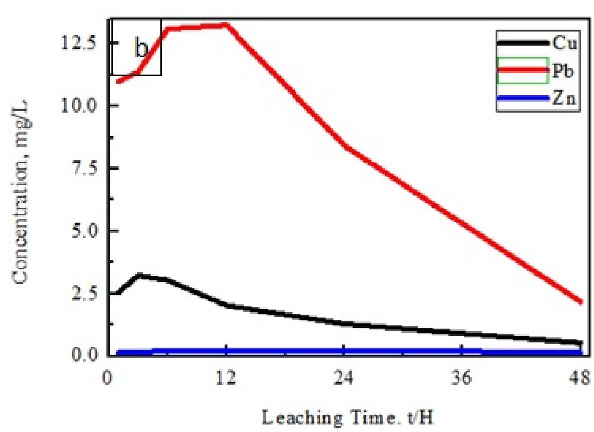

Figure-4(b). Dissolution behavior of main elements.

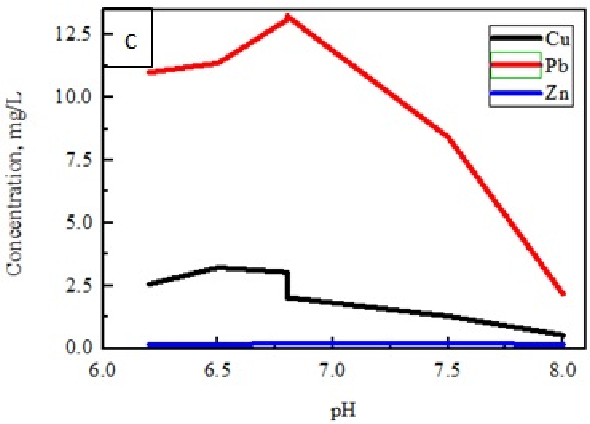

Figure-4(c). Dissolution behavior of main elements during the leaching test.

Table-4. Malaysian interim national water quality standard (INWQS) (Ahmad, A.K. *et al.* 2009).

Parameters	Malaysian INWQS Classes					
	I	IIA	IIB	III	IV	V
Pb [mg/l]	NL	0.05	-	-	5	AIV
Cu [mg/l]	NL	0.02	0.02	-	-	AIV
Zn [mg/l]	NL	5	5	0.4	2	AIV

CONCLUSIONS

Fundamental study of waste printed circuit board was carried out to investigate the dismantling processes and dissolution behavior of the waste. It was found that the longest dismantling time was contributed by the dismantling of electronic component from the PCB. More efficient recycling technique can be achieve by reducing the dismantling time especially when it involve huge amount of waste desktop computer. Dissolution of each main element in the waste desktop PCB was observed and it has affected the increasing of pH value. The increase of pH has then led to the reduction of Pb and Cu concentration. Pb dissolved concentration must be controlled to ensure that it does not excel the permissible amount set under INWQS,

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REFERENCES

[1] Ahmad, A.K. Mushrifah, I. and Othman, M.S. (2009). Water Quality and Heavy Metal Concentrations in Sediment of Sungai Kelantan, Kelantan, Malaysia: A Baseline Study. Sains Malaysiana, 38(4), p. 435-442.

[2] Chong, T.L. (2008). E-waste Management, Impak 1, p. 12-13.

[3] Ha, N.N. Agusa, T. Ramu, K. Tu, N.P.C Murata, S. et al. (2009). Contamination by trace elements at e-waste recycling sites in Bangalore, India. Chemosphere, 76 (2009) p. 9-15.

[4] Hisyamudin, M.N.N. Yokoyama, S. Kawakami, M. and Umemoto, M. (2009). Reaction between CO2 and CaO under Wet Grinding. Powder Technology 196(2), p. 156-162.

[5] Hisyamudin, M.N.N., Seiji, Y., Minoru, U. (2010). Storage of CO2 in Low Al2O3 EAF oxidizing slag by grinding with vibration mill. Materials Science Forum 654-656, pp. 2927-2930.

[6] Huo, X. Peng, L. Xu, X.J. Zheng, L.K. Qiu, B. Qi, Z.L. *et al*. (2007). Elevated blood lead levels of children in Guiyu, an electronic waste recycling town in China. Environ Health Perspect, 115, p. 1113-1117.

[7] Information on Department of Environment Malaysia, E-waste inventory project in Malaysia, http://www.env.go.jp/en/recycle/asian_net/Project_N_Research/E-wasteProject/06. pdf

[8] Li, H. Yu, L. Sheng, G. Fu, J. and Peng, P. (2007). Severe PCDD/F and PBDD/F pollution in air around an electronic waste dismantling area in China. Environ. Sci. Technol., 41, p. 5641-5646.

[9] Montero, R. Guevara, A. and Torre, E.D.L. (2012). Recovery of Gold, Silver, Copper and Niobium from Printed Circuit Boards Using Leaching Column Technique. Journal of Earth Science and Engineering 2, 590-595.

[10] Oishi, T. Koyama, K. Alam, S. Tanaka, M. and Lee, J.C. (2007). Recovery of high purity copper cathode from printed circuit boards using ammoniacal sulphate or chloride solutions. Hydrometallurgy, 89(1-2), p. 82-88.

[11] Terazono, A. et. Al. (2006). Current status and research on E-waste issues in Asia, J Mater Cycles. Waste Management, 8, p. 1-12.

[12] Y. J. Park and D. Fray. (2009). Recovery of high purity precious metals from printed circuit boards. Journal of Hazardous Materials, 164(2-3), p. 1152-1158.

[13] Yokoyama, S. Suzuki, A. Hisyamudin, M.N.N. Kanematsu, H. Ogawa, A. Takahashi, T. Izaki, M. and Umemoto, M. (2010). Serial Batch Elution of Electric Arc Furnace Oxidizing Slag Discharged from Normal Steelmaking Process into Fresh Water. Tetsu-To-Hagane 96 (12), pp. 698-705.