Dissolution Behaviour of Metal Elements from Several Types of E-waste Using Leaching Test

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Abstract. Rapid development of the electrical and electronic was increasing annually due to the demand by the human being. Increasing production of electrical and electronic product led to the increasing of electric and electronic waste or can be called as the e-waste. The UN Environment Programme estimates that the world generates 20-50 million tons of the e-waste each year and the amount is raising three times faster than other forms of municipal waste. This study is focusing on the investigation of the dissolution behaviour of metal element from several types of e-waste by hydrometallurgical process. Leaching test was conducted on the e-waste by using acid as the reagent solution. Prior to the leaching test, manual dismantling, separation, and crushing process were carried out to the e-waste. The e-waste were characterized by Scanning Electron Microscopy (SEM) and the Energy Dispersive X-ray Spectroscopy (EDX) to define the elements inside the sample of e-waste. While the liquid residue from leaching test was analyzed by using Inductively Couple Plasma-Mass Spectrometer (ICP-MS) to define the dissolution behaviour of the metal element that contain in the e-waste. It was found that the longest time for dismantling process was the dismantling of laptop. The dissolution behaviour of Fe, Al, Zn and Pb elements in the e-waste has affected to the increase of pH. The increasing pH led to the reduction of the metals element during leaching process.

1. Introduction
Technology developments are very closely related to the growth in the use of electric and electronic equipment. Without electronic equipment, there is no advanced technology can be created like smartphones, tablets, notebooks, wireless router, digital camera, advanced machining and many more.
All these advance technology are very much needed for human daily life and help their activities. Therefore, the electronic equipment is increasing from year to year due to the high demand from customer and its reasonable and affordable prices [1]. In Malaysia, the electric and electronic equipment are increasingly used simultaneously with the development of the country. Thus, the production of e-waste in Malaysia is also increasing year by year and by year 2020, it is estimated that the total of E-waste that will be discarded in Malaysia is about 21.379 million metric tons [2, 3].

E-waste includes all type of electric and electronic waste which achieving their end of life are classified as e-waste [4]. Growing exponentially of e-waste attracted the considerable attention of people about the content of the e-waste which contain both precious and hazardous materials. Increasing quantity of e-waste can affect all nations in the world either directly or indirectly. Recovering the e-waste which contains precious metal such as gold, silver, platinum and some other metals can be an advantage to the developing country as it can be recycled and re-used [5, 6]. However, e-waste which contains hazardous materials can harm human being and can give huge impact to the environment such as mercury, lithium, lead, chromium, barium, beryllium, cadmium and etc are much more need to be concern. This highly toxic content in the e-waste give a risk on ecological exposure through air inhalation ingestion contaminated water, land and food sources [7, 8].

Nowadays, the use of landfill for the e-waste had been restricted in some countries because of environmental effect and depletion of natural resources [9, 10]. It is compulsory to recovery and recycling the precious materials to conserve the usage of natural resources and we can save the world which has nearing its end life. The hazardous metals also must be treating in a proper management so that we can nurture the environment and human life from all hazardous risk. The existing and potential of advance technologies might be used to treat and recycle the e-waste material in a correct way by using any advance techniques [11-13]. According to Department of Environment of Malaysia, the currently way of recovery precious metal from e-waste is using electrolysis and wet chemical process while there are still limited on the e-waste management and recovery process for hazardous metals [14]. In the previous studies, we have investigated the dissolution behavior for some type of e-waste and we have found that Pb and Mn showed high dissolution rate from the e-waste [15-18]. The current study also was limited on several types of e-waste such as CPUs, mobile phone, TVs and desktops [19]. Therefore, this research aimed to study the dissolution behavior of metal elements from various types of e-waste using leaching test. The leaching process is affected by several factors such as pH, temperature and type of sample but in this study we just observed the dissolution behavior for different types of e-waste.

2. Experimental Procedures

Fig. 1 shows the several types of e-waste used in the study. It is a common type of electric and electronic waste that can be easily found at the disposal area and second hand electronic shop. These products were manually dismantled and the time required to dismantle all parts was measured. The dismantled parts were then categorized into their type of material which consists of ferrous and non-ferrous material. *

The leaching test was conducted using the printed circuit boards (PCBs) from each product as the samples. The samples were characterized by Scanning Electron Microscopy (SEM) and the elements composition was measured by Energy Dispersive X-ray Spectroscopy (EDX) that equipped in the SEM before the leaching carried out. Other than to characterize the chemical composition of the e-waste, the purpose of EDX is also to determine what type of elements need to be analyzed using ICP-MS later. The size of PCBs from each type of e-waste being reduced in size into range less than 3mm x 3mm by using crushing machine as shown in Fig. 2. Then, the leaching test was carried out according to Fig. 3. The parameters of the leaching test are shown in Table 1. The ratio of the sample and the solution which is standard distilled water added with HCL is 1:100. 10g samples were inserted into glass beaker. The solution was placed under mechanical stirrer with 100rpm rotational speed and conducted in ambient air and temperature. 50 ml of liquid samples were collected every 1, 3, 6, 12, 24, 25
and 48 hours by syringe and filtered by filter paper. The liquid residue was then analyzed by Inductively Coupled Plasma - Mass Spectrometer (ICP-MS).

![Types of e-waste used](image1)

Fig. 1 Types of e-waste used; (a) Laptop, (b) External hard disk, (c) Tablet, (d) Digital camera, (e) Power bank, (f) Keyboard.

![Crushed PCBs](image2)

![Experimental apparatus for leaching test](image3)

Table 1 Parameters of Leaching Test

| Parameter                      | Value                        |
|--------------------------------|------------------------------|
| Rotation speed                 | 100 rpm                      |
| Amount of water                | 1000 ml                      |
| Amount of sample               | 10 g                         |
| Temperature                    | Ambient                      |
| Atmosphere                     | Air                           |
| Types of solution              | HCl + distilled water        |
| Leaching time [H]              | 1, 3, 6, 24 and 48           |
| pH                             | 4                            |

3. Result and Discussion

3.1. Dismantling Process of E-waste Products

Table 2 shows the time measured for each of dismantling process of the e-waste products. The dismantling process was conducted manually using hammer, screw driver, player and solder. The longest time of dismantling process is for the product of laptop with total time of 6295.7 seconds or
approximately 105 minutes and the least time taken for dismantling process is for power bank which only takes 104.4 seconds or approximately 2 minutes. This may due to the size and complex parts inside the each product of the e-waste.

| Process                      | Laptop (s) | Hard Disk (s) | Tablet (s) | Camera Digital (s) | Power Bank (s) | Keyboard (s) |
|------------------------------|------------|---------------|------------|--------------------|----------------|--------------|
| Dismantling the housing      | 2530.8     | 30.1          | 62.4       | 102.2              | 20.8           | 56.8         |
| Dismantling the main body parts | 1028.3     | 57.6          | 70.61      | 164.0              | 5.1            | -            |
| Dismantling body compartment | 786.1      | 211.8         | 31.8       | 267.3              | 14.7           | -            |
| Dismantling the PCB          | 867.3      | 59.9          | 118.3      | 192.9              | 20.5           | 5.03         |
| Dismantling the PCB’s components | 1093.2   | 143.7         | 112.0      | 174.9              | 31.4           | 5.2          |
| Dismantling battery          | 5.1        | -             | 2.1        | -                  | 3.0            | -            |
| Dismantling others part      | 99.7       | 189.5         | 32.3       | 12.2               | 8.9            | 62.0         |
| **Total**                    | **6295.7** | **692.6**     | **341.9**  | **913.2**          | **104.4**      | **129.0**    |

3.2. Characterization of the PCBs from the e-waste products

Table 3 shows the chemical composition or metal in the e-waste sample which calculated by using EDX that equipped in the SEM. 5 metal elements composition was computed which is Al, Pb, Zn, Fe, and Ni. The highest composition of metal is Zn in the sample of laptop followed by hard disk and the lowest composition of Zn is in the sample digital camera. Al has high composition in the sample of hard disk followed by laptop and the least composition of Al is in the sample of power bank. Pb is categories as hazardous metal element has high composition in the sample of digital camera followed by power bank and the least is in the sample of keyboard. Laptop has the higher composition of Fe rather than the others sample. For Ni element, hard disk, tablet, digital camera, power bank and keyboard almost have same average of metal composition but the higher composition goes for the sample of laptop.

| Type of Sample  | Al  | Pb  | Zn  | Fe  | Ni  |
|-----------------|-----|-----|-----|-----|-----|
| Laptop          | 1.30| 0.61| 4.23| 3.15| 2.83|
| Hard Disk       | 1.38| 0.39| 4.19| 0.16| 0.29|
| Tablet          | 1.0 | 1.72| 1.04| 0.73| 0.62|
| Digital Camera  | 0.37| 2.43| 0.93| 1.67| 0.73|
| Power Bank      | 0.34| 2.40| 1.95| 0.70| 0.24|
| Keyboard        | 1.28| 0.51| 1.72| 0.42| 0.58|
3.3. Leaching Behavior of the E-waste

Fig. 4 shows the change in pH during the leaching test. The pH for all samples has increased gradually due to increasing leaching time. The highest pH value is sample of laptop which has start increased to pH 5.6 right after one hours leaching process. It is continually increased as the increases of leaching time. Hard disk has the lowest pH changes which also increase gradually along the leaching process from pH 4.1 until the maximum pH 5.7. Sample of keyboard increase to pH 4.9 at the first hour of the leaching process and increase gradually until 6.7 for 48 hours leaching time. The pH value of digital camera at the first hour was stated at 4.2 of the leaching process and increase gradually until 6.5 for 48 hours leaching time. While the sample of power bank increase to the value of pH 6.7 during 48 hours of leaching time from pH4.8 at the first hour of leaching process. Tablet also has the consistency in the increasing of pH value which is pH 4.3 at the first hour of leaching and reached until pH 6.5 after 48 hours.

Fig. 5 (a) shows the concentration of Fe element against the leaching time with the highest concentration for Fe element is in the sample of laptop which is 0.036 mg/L at 48 hours of leaching time. The concentration of Fe stated about 0.0350 mg/L at first hour of leaching process. It has been decrease to 0.0297 mg/L at 3 hours of leaching process however its make up to increase gradually until the highest concentration of Fe at 48 hours of leaching process. Tablet has concentration of Fe 0.0695 mg/L and it has been decrease to 0.0136 mg/L until the end of leaching process. In the sample of hard disk, the highest is 0.0639 mg/L during 3 hours of leaching process but then the concentration was decreased until the lowest rate which is 0.00402 mg/L at the end of leaching process. The sample of camera digital has continually decreasing in the concentration of Fe which is from 0.0499 mg/L until 0.0198 mg/L throughout the leaching process. Keyboard has high at 6 hours and 48 hours of leaching test about 0.0327 mg/L and 0.0307 mg/L respectively. Power bank is one of the sample that contain highest concentration of Fe for each time interval of the leaching process which start as 0.0606 mg/L at the first hour and decrease 0.0489 mg/L at 48 hours.

Fig. 5 (b) shows the concentration of Al element against the leaching time with the highest concentration for Al element is in the sample of laptop which is 0.0550 mg/L at 48 hours of leaching time. The concentration of Al stated about 0.0129 mg/L at first hour of leaching process. It has been decrease to 0.0112 mg/L at 6 hours of leaching process however its make up to increase gradually until the highest concentration of Al at 48 hours of leaching process. Keyboard has the second highest concentration of Al at 0.0853 mg/L and has been decrease 0.0768 at 6 hours of leaching process but increase again until 0.0208 mg/L at the end of process. In the sample of hard disk, the highest is
0.0057 mg/L during 1 hour of leaching process but then the concentration was decreased until the lowest rate which is 0.0186 mg/L at the end of leaching process. The sample of camera digital has continually decreasing in the concentration of Al which is from 0.0136 mg/L until 0.00422 mg/L but the concentration was increase until 0.012 mg/L at the end of leaching process. Keyboard has increased the concentration at 3 hours of leaching test to 0.0169 mg/L but decreased to 0.00456 mg/L at the end of leaching process. The concentration of Al in sample of power bank is high at 48 hours which is 0.014 mg/L and the lowest is at the first hour of leaching process which is 0.00319 mg/L.

Fig. 5 (a) Concentration of Fe element against leaching time (b) Concentration of Al element against leaching time (c) Concentration of Zn element against leaching time (d) Concentration of Pb element against leaching time

Fig. 5 (c) shows the concentration of Zn element against the leaching time with the highest concentration for Zn element is in the sample of laptop which is 0.0928 mg/L at 1 hour of leaching time. The concentrations of Zn stated about 0.0848 mg/L at 3 hour of leaching process and start to decrease to 0.0365 mg/L at 48 hours of leaching process. Power bank has the second highest concentration of Zn at 0.0153 mg/L during 1 hour leaching and has been increased to 0.0476 mg/L at 12 hours before its decrease again to 0.0215 mg/L after 48 hours. The sample of hard disk has highest concentration which is 0.0388 mg/L during 12 hours of leaching process rising from 0.0275 mg/L.
concentration at first hour. The sample of camera digital has continually decreasing in the concentration of Zn from the concentration of 0.0214 mg/L. Keyboard has decreased the concentration at 6 hours of leaching test to 0.015 mg/L but increased again until the end of leaching process to 0.0256 mg/L. Tablet has high the concentration during 1 hour and 12 hours of leaching test about 0.0418 mg/L and 0.0408 mg/L respectively.

Fig. 5 (d) shows the concentration of Pb element against the leaching time with the highest concentration for Pb element is in the sample of hard disk which is 0.0947 mg/L at 6 hours of leaching time. The concentration of Pb stated about 0.0441 mg/L at first hour of leaching process and has been increase to 0.0947 mg/L at 6 hours of leaching process. It is decrease gradually until 0.0396 mg/L concentration of Pb at 48 hours of leaching process. Power bank has the second highest concentration of Pb at 0.0703 mg/L concentration and decrease to 0.0597 mg/L at 6 hours of leaching process then increase again until 0.0761 mg/L at 12 hours of the process. It is decrease again until concentration 0.0448 mg/L at the end of leaching process. In the sample of tablet, the highest is 0.0660 mg/L during 6 hour of leaching process but then the concentration was decreased until the lowest rate which is 0.0125 mg/L at the end of leaching process. The sample of camera digital has continually decreasing in the concentration of Pb which is from 0.0525 mg/L until 0.0248 mg/L but the concentration was increased slightly to 0.0277 mg/L at the end of leaching process. Keyboard has increased the concentration through the process of leaching from 0.0277 mg/L to 40.5 mg/L at at 6 hours and 48 hours respectively. However, the concentration has decrease from 0.0291 mg/L to 0.0277 mg/L at during time interval 3 to 6 hours. Then, the concentration of Pb in sample of power bank is low at 48 hours which is 0.000205 mg/L but the concentration of Pb in sample of laptop is high at 3 hours. It decreased continually until end of leaching process. From Figure 4 and Figure 5, it can be observed that initially, dissolution of metal elements inside the e-waste was contributed by the low initial value of pH used in this study. However, the dissolution of metal elements inside the e-waste into the solution has then led to the increase in the pH of the solution and hindered the further dissolution of Fe, Zn and Pb at the later stage of the leaching process.

4. Conclusion

The study of e-waste recycling was carried out to investigate the dismantling process and dissolution behavior of several types of e-waste. The longest time taken for dismantling process was laptop due to complex parts installed on it. It was observed that the dissolution behavior of Fe, Al, Zn and Pb elements in the e-waste has led to the increase of pH. The increasing pH has then led to the reduction of the metals element during leaching time and further decrease in the concentration of almost all dissolved elements was observed as the leaching continued for longer time.

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