Inertization of arsenic in the resin by microwave plasma

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Abstract

The aim of this study was to analyze the inertization of arsenic in the resin and its mixture with quartz sand using microwave plasma. Plasma ignition was maintained 900 W for 5 minutes, using nitrogen with a 8.5 l/min flow under 40 psi. The crucible was positioned approximately 14 cm under the copper wire. This study showed that the concentration of arsenic in the sample before treatment was 1.1 mg/L. Furthermore, after treatment using microwave plasma, the concentration of the arsenic in the resin was 0.084 mg/L (92.36% efficiency). It was higher than the mixture of resin and quartz sand with the ratio 1:1 and 1:2 that were 0.088 mg/L (92%) and 0.102 mg/L (90.72%), respectively.

Keywords: plasma ignition, nitrogen, quartz sand, crucible.

1. Introduction

The increasing and development of economic, science and technology cause the rise of amount of electronic waste (e-waste) [1]. E-waste has the complex structure that requires the proper treatment due to its toxicity and harmfulness towards environment [2]. Some parts of the e-waste such as printed circuit boards (PCB), cathode ray tube (CTR), plastic housing of desktop monitors and moist paste of batteries consist of heavy metals [3, 4, 5, 6, 7, 8, 9]. In this context, e-waste requires proper treatment to prevent and handle the contamination to a polluted environment.

Resin, the part of the waste from PCB, requires the special treatment due to its hazardous elements. According to Vasile et al., [10] Carbon (C), Hydrogen (H), Bromide (Br) and Antimony (Sb) are the major elements that can be found widely in the resin. However, the other elements also have the possibility that be found widely in the sample due to the using as a layer in PCB. Precisely, investigation of heavy metals from the resin is necessary to be conducted to assess the distribution and concentration of heavy metals.

Arsenic (As), the metalloid properties, is harmful to the environment. In the context of toxicology, arsenic is a heavy metal [11]. In the electronic waste, arsenic is found widely in several parts such as the plastic housing of desktop monitors and PCB [3, 5]. Arsenic may contaminate the ecosystem, transferred into the human body by the food chain. It also toxic and carcinogenic [11, 12]. Furthermore, the biotransformation of arsenic in humans and excretion in urine is recognized as the carcinogens dimethylarsinate (DMA) and methylarsonate (MA) [12]. Indeed, it is necessary to treat e-waste with the proper technology. Some technologies have been performed widely to treat heavy metal, particularly the conventional technologies such as sanitary landfills, composting and incinerator have been implemented regularly to solve the heavy metal issues [13, 14] However, the drawbacks like toxic substances, land availability, potential dumping without a proper treatment have been known predominantly as the disadvantages of these technologies [13. 14]. This means that it has a harmful risk to the environment and human health.

Plasma technology has a potential role to treat hazardous waste [14]. The treatment using plasma related to the high temperature and atmospheric pressure. The conversion of electricity to thermal energy related from the establishment of the electric arc in the two electrodes. Furthermore, the transformation occurs based on the ionization of gases that is heated in a high temperature and atmospheric pressure [15]. In other words, this mechanism has an enormous potential to degrade the heavy metals, particularly electronic waste.

Some studies of plasma technology have been addressed in order to degrade the heavy metals from the part of the electronic waste [7, 16]. An investigation by Cubas et al., [7] find the high efficiency removal of zinc and magnesium in the batteries moist paste with the proportion between the sample and quartz sand (1:2) reached 97% and 99.74%, respectively. As well as a moist paste of batteries, the addition of quartz sand into the galvanic sludge from the industrial metal degrades 100% for iron, 100% for chromium and 99% for Zinc, respectively [16].

Despite microwave plasma having a good efficiency removal for some elements such as magnesium, zinc [7], iron and chromium [14], further investigation related to the degradation of arsenic is necessary to be conducted due to its enormous potential to degrade heavy metal. Owing to this reason, the pyrolysis of arsenic in the resin using microwave plasma is necessary to be examined, especially its efficiency removal. In other words, the microwave plasma may be carried out to degrade the arsenic in the resin from PCB's waste and it may be considered as the environmentally methods to treat heavy metal [7].

In this study, inertization of arsenic, in particular, using the microwave plasma to the samples before and after treatment.

2. Methods

2.1. Collection and preparation of the sample

The 500 g resin samples were collected from the recycling company in Taoyuan District, Taiwan. The resin is processed from the solvent distillation of the PCB waste recycling process. Then, approximately 10 g of samples were crushed using the pulverizing machine in 30.000 rpm until the particle size was about less than 0.1 mm. After that, the sample was sieved to obtain 0.074 mm (200 mesh) particles. The samples were labelled in 15 mL containers and stored in the 25°C at the room temperature

2.2. Characterization of samples

The samples with the size 0.074 mm (200 mesh) were used in the analysis. Chemical composition, particularly the distribution and percentage of arsenic in the samples was analysed using scanning electron microscopy-energy dispersive X-ray analysis (SEM-EDX) (Hitachi S-3000N). Also, the visualization of the surface in the sample was determined in this technique.

2.3. Preparation of samples for pyrolysis

The preparation of the samples was conducted by weighing a resin sample (Shimadzu AUY 220). The particle size of the quartz sand <0.100 mm [7]. Percentages of the sand in the sample were 100% and 200%, respectively. The weight of the sample was 1 g resin while the weight of the quartz sands was 1 g and also 2 g. The comparison of the resin and quartz sand were 1:1 and 1:2, respectively.

2.4. Pyrolysis of the samples

The pyrolysis of the samples was performed in a microwave plasma. The samples were put into the crucible and it was locked using the screw tightly to hold the crucible on its position. Nitrogen was used as the plasmogenic gas that provides the ionization gas. The microwaves are from magnetron propagate and the plasma ignition was performed at 900 W for five minutes. In addition, the flow of the gas was controlled at 8.5 l/min and the pressure was 40 psi. The distance or position of the crucible approximately 14 cm under the copper wire that produce a plasma ignition. The samples were placed into the crucible. The resin samples were used with the combination of quartz sand. The analysis of chemical composition was performed using a scanning electron microscope-energy dispersive X-ray analysis (SEM-EDX) and the analysis of arsenic concentration on the inertization was carried out by inductively coupled plasma (ICP).

2.5. Inductively coupled plasma analysis

The digestion method refers to Taiwan Standard NIEA S321.63B [17] was performed to analyse the residue. 21 mL of hydrochloric acid 37% and 7 mL of nitric acid 70% were added into the 500 mL flask that containing the sample in the batch condition during 16 hours. After that, the sample was heated in a soxhlet extractor for 2 hours. Furthermore, the sample was transferred into the 50 mL reaction tube and it was centrifuged using a centrifuge machine (Kubota 2000) on 2500 rpm. Then, the sample was filtered using a 0.45 μm membrane filter. The filtrate was analysed using inductively coupled plasma technology (ICP) consider the dillution factor. The arsenic concentration in the samples before and after treatment were analyzed using inductively coupled plasma (Shimadzu ICPE 9820). The flow rate of the argon gas was 10 l/min. The auxiliary gas and carrier gas were performed 0.60 l/min and 0.70 l/min, respectively. The exposure time was 30 seconds and the power was controlled at 1.20 kW. The standard solution of arsenic contained 5, 2.5, 1.25, 0.625 and 0.314 mg/L.

3. Results

3.1. Analysis of the resin sample prior pyrolysis

Figure 1 outlines the arsenic concentration and the surface of the resin before treatment was determined using SEM-EDX. Based on the analysis, the composition of arsenic in the samples was 0.94%. It means that in the samples, the concentration of arsenic based on the PCB. Furthermore, the results of the ICP analysis shows that the concentration of arsenic was 1.1 mg/L. In the several legislation of countries, the concentration of 1.1 mg/L exceeds the quality standard of some legislations. Table 1 shows the legislation of arsenic. According to Li et al., [18], an arsenic concentration that exceeding the certain levels has a potential harmful element (PHEs).

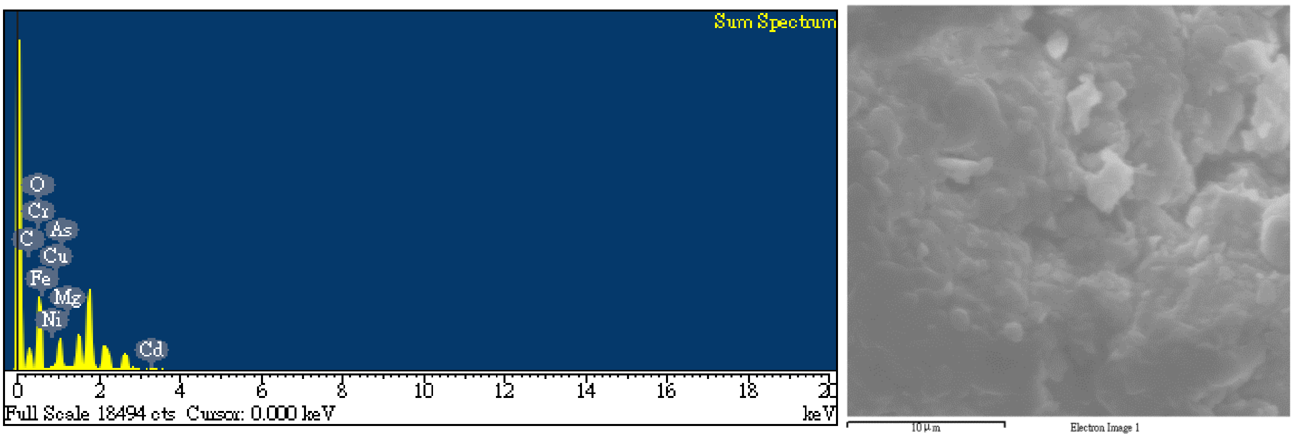

Figure 1. The result of scanning electron microscope energy dispersive x-ray analysis (SEM-EDX)

Table 1. Legislation Parameter of arsenic concentration of some countries

Country	Legislation	As Concentration (mg/L)
Indonesia	Government Regulation of the Republic of Indonesia Number 101 the Year 2014	0.5
Taiwan	Water and Semiconductor Manufacturing Industry Effluent Standards	0.5
Japan	Ministry of the Environment Government of Japan, National Effluent Standards	0.1

3.2. Analysis of the resin sample after pyrolysis

Table 2 shows the concentration of heavy metals after pyrolysis that is analysed by Inductively Coupled Plasma (ICP). During the pyrolysis, there are two types of variation of samples namely the resin and the combination of resin with quartz sand.

The results confirm that there was no significant difference amount of arsenic after the inertization by pyrolysis, particularly the addition of the quartz sand into the samples. Although the quartz sands were fused directly with resin into the crucible, the results were lower than the inertization of resin. Table 2 compares the results between the resin and the mixture of resin and quartz sand. It indicates that the pyrolysis of resin has the greatest result for arsenic (92.36%). Then, it was followed by the ratio of resin and quartz sand ratio 1:1 and 1:2 which were 92% and 90.72%, respectively. Interestingly, the range difference of the addition of quartz sand in the sample was only 0.36% - 1.64%. This means that the inertization efficiency of the addition of quartz sand into a resin to degrade the arsenic has no significant effect.

Cubas et al., [7] and Cubas et al., [16] point out that the fuse of quartz sand in the sample has the efficiency range from 94% - 100% for inertization of zinc, manganese, cobalt and iron. Cubas et al., [7] state that physical-chemical reaction occurs in the pyrolysis in the microwave plasma. In this context, the transformation of heavy metal to liquid phase probably occurs. In addition, it was followed by solidification and vitrification [7]. In this experiment, the inertization efficiency result was lesser than 94%. It was probably caused by the position between the crucible to the plasma ignition that was set up around 14 cm from the copper wire. Furthermore, the setting of power was 900 W. It is lower than the plasma furnace that reported by Cubas et al, [7] using 2.4 kW or 2400 W of power to obtain the 99%-100% efficiency results. In other words, the lower power may cause the low electricity that affects the gas ionization. In this experiment, the microwave plasma has a limitation of power, which is suggested no more than 2000 kW during its operation.

Leins et al., [19] reports that the higher microwave power and lower flow of the gas have an influence to the plasma ignition or the plasma dimension. The setting of the microwave power with a value of 2 kW and 10 slm flow rate indicated more stable ignition than 70 slm of flow rate. Interestingly, it indicates a smaller dimension in the radial and axial of plasma ignition when the power of plasma was controlled to 1 kW with the same treatment of the gas flow. In this context, the setting of microwave power and gas flow play an important role in the plasma ignition.

In this experiment, the setting of gas flow was 8.5 l/m and the microwave power was controlled to 900 W. However, the future experiment related to the modification of the microwave power and gas flow rate is necessary to be conducted. In other words, the proper plasma ignition has a crucial impact during the inertization of solid waste in microwave plasma treatment, particularly to treat heavy metals.

Inductively coupled plasma results (Table 2) show that the treatment of resin and the addition of quartz sand may decrease the concentration of arsenic. As shown in Table 2, the concentration of arsenic in the sample decreased from 1.1 mg/L to 0.084 mg/L, 0.088 mg/L and 0.102 mg/L, respectively after it was conducted by microwave plasma. Interestingly, the resin has fulfilled the requirement of the quality standard of legislation due to less than 0.5 mg/L such as Indonesia and Taiwan. Furthermore, it almost reached 0.1 mg/L that suitable with the quality standard of arsenic in Japan (Table 1). These results indicate that plasma technology may solve fundamental issues on heavy metal.

Table 2. Results of the plasma pyrolysis and the proportion of the quartz sand for the arsenic treatment by microwave plasma. The analysis obtained from Inductively Coupled Plasma (ICP).

Proportion of Resin and Quartz Sand	Concentration (mg/L)	Inertization Efficiency (%)
1:0 (Resin Only)	0.084	92.36
1:1 (Resin : Quartz Sand)	0.088	92
1:2 (Resin : Quartz Sand)	0.102	90.72

4. Conclusion

Resin, the solid waste from the PCB waste, has the arsenic. Arsenic is harmful to human health and the environment. Owing to this reason, proper technology is necessary to be conducted for solving the arsenic issue in hazardous waste. Microwave plasma, the pyrolysis using ionization of the gas and high electricity power, may be considered and applied to degrade the arsenic in the resin.

In the samples, the concentration of arsenic before treatment was 1.1 mg/L. Based on the composition analysis, the percentage of resin was 0.94%. The inductively couple plasma analysis results show that there are no significant difference in the addition of quartz sand in the resin during the pyrolysis by microwave plasmas. The treatment of resin without the fuse of quartz sand demonstrate 92.36% efficiency removal of arsenic. The concentration of arsenic reduces from 1.1 mg/L to 0.084 mg/L. In addition, the mixture of 1 g quartz sand into the resin show slightly lower efficiency removal (92%) than the treatment only resin, which the concentration was decreased from 1.1 mg/L to 0.088 mg/L. Lastly, the increasing of quartz sand into resin not improve the removal efficiency of arsenic. Based on the test, the efficiency removal of arsenic was 90.72% (from 1.1 mg/L to 0.102 mg/L). In other words, the fuse of quartz sand into the resin does not improve the efficiency removal of arsenic during pyrolysis.

In the future, some modifications of microwave plasma treatment related to power, gas and position of the crucible are necessary to be conducted in order to find the optimum removal efficiency or inertization of arsenic and other heavy metals using the microwave plasma. Furthermore, the modification of the samples proportion of samples should be considered in the microwave plasma treatment.

5. References

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