E-Waste Recycling to Recover Base and Precious Metals

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Abstract

This research study reviews the treatment and recyclability of e-waste such as PCBs, e-plastics and CRTs. Land filling and incineration were found to be not good management methods as they do not deal with the toxic gases found in e-waste. Hydrometallurgy processing methods was developed and used in the extraction of base and precious metals. Since precious metal leaching is affected by copper content, to maximize precious metal leaching, a 2 step base metal leaching stage was employed. The first step mainly focused on the removal of Pb and Fe and the second step was to extract copper, zinc and nickel. First stage used nitric acid and the second stage used sulphuric acid and hydrogen peroxide. Lead recovery was almost 90% and copper recovery amounted to almost 95%. Precious metal leaching utilized ammonium thio-sulphate as the lixiviant and gold recovery was low, but silver recovery was significantly high.

Keywords: *PCBs, recycling, precious, base, metals, recycling, e-waste*

1. Introduction

The unprecedented growth of the electronic sector industry in the world, together with the rate of technological change has created an appetite among consumers for a replacement behavior leading to stockpiles of e-waste (Mutsau, et al., 2015)**.**Electronic waste products include used cell phones, television sets, laptops, fridges, microwaves and all devices that have an electronic circuit board in them. E-waste contain many constituents which include printed circuit boards(PCBs), plastics, steel, cathode ray tubes (CRTs) and other particles in smaller proportions. E-waste management and beneficiation is a subject that deals with proper planning and controlling of e-waste disposal in order to benefit from e-waste. E-waste management and beneficiation is not only done to make money but also as a way to preserve the environment in a bid to foster sustainable development of e-waste. This work therefore seeks to develop sustainable processes of managing and recycling e-waste so as to preserve the environment and also improve the livelihoods of people by recovering both precious and base metals from PCBs. The processing system should be able to detoxify the dangerous trace elements found in PCBs and e-plastics, as well as being affordable to people who may want to venture into the recycle industry.

2. Overview of e-waste leaching

According to (Kavitha, 2014), e-waste describes all the electronic and electrical gadgets that have reached the end of their use. Over the past decade the increase in electronic waste has reached unprecedented levels and this can be attributed to fierce competition among technology manufacturing companies, the need to produce superior gadgets and the appetite amongst consumers to change electronic gadgets. Advancement in technology has decreased the lifespan of electronic gadgets, leading to an upsurge in the generation of WEEE which in turn leads to the generation of vast quantities of Waste Electrical and Electronic Equipment (WEEE). A printed or wiring circuit board (PCB) is a piece of material hardware usually made of steel, wood and plastic and is used as a base to provide electrical connections to the components that have been mounted like resistors and capacitors(Gadekar, 2008).It is on these PCBs that a majority of metals are concentrated. Advancements in technology in EEE have reduced PCBs life span, and which in turn has caused a huge tonnage of waste PCBs to be produced, thus, presenting a new environmental challenge (Jadhav, et al., 2014). One of the reasons why electronic waste management has been of interest in the last years is that, environmental disaster looms if the electronic devices are not handled properly and also disposal and transportation these have to be done with due diligence because of the toxic heavy metals contained in them such as mercury, lead, cadnium, beryllium and cadmium which pollutes both underground water and the soil(Mlambo, 2013). Although these electronic devices contain toxic substances, if properly recycled and processed, precious materials like gold, copper and silver can be extracted from them and improve the livelihoods of many people. Three main types of materials can be recovered from PCBs which are; metals that are recyclable which include copper, aluminium, tin, lead and precious metals (gold, silver and platinum);recyclable polymeric materials, in which through incineration and combustion, energy can be recovered from and lastly materials made from ceramics, which can be reused or properly disposed if they do not contain metals or other substances which are hazardous (Bizzo, et al., 2014). The inconsistence in PCBs' composition makes it difficult to determine the exact amount of metal content in them(Albertyn, 2017), so in order to grade the PCBs some physical characteristics have to be used.

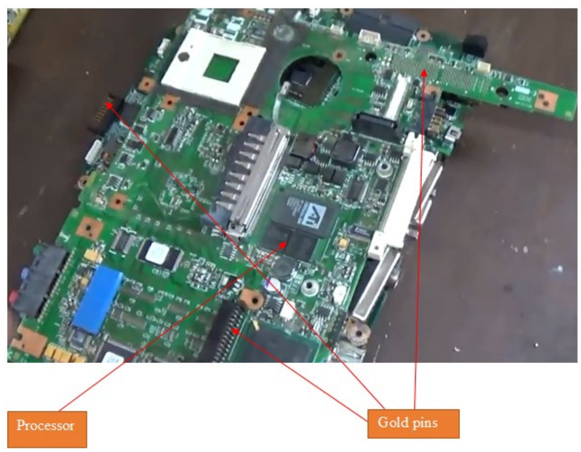

Figure 1 Typical PCB of a laptop

PCBs are graded as low grade, medium grade and high grade depending on the amount of gold it contains. The higher the amount of micro-processors and gold pins present on a PCB, the higher the grade. The PCB of a laptop, as shown in Figure 1 are typical high grade PCBs because many processors are concentrated on a small piece. Also, the presence of many processors on both the front part and the back part, makes it a high grade PCB as more precious materials can be recovered compared with medium grade and low grade PCBs. The three common processes that are commonly used in recycling of PCBs are: pyro-metallurgy, hydrometallurgy and bio-hydrometallurgy.

Base metal leaching is a leaching process done to obtain the material that is going to be fed in the stage that leaches precious metals. As precious metal extraction is affected by base metal impurities, this process helps to remove those base impurities from the PCBs. In the $Cu\text{-}NH_3\text{-}S_2O_3$scheme, for the leaching of precious metals, copper content should be as close to zero as possible as it inhibits leaching of gold. This happens with the dissolution of copper to $Cu(NH_3)_2^+$ through the consumption of the oxidizing agent for gold, $Cu(NH_3)_4^{2+}$(Albertyn, 2017).According to(Ha, et al., 2010),decreased concentration of $Cu(NH3)_4^{2+}$, means less gold will be leached. Base metal leaching, as previously mentioned by authors above is carried out on a two stage level. The first stage utilizes HNO_3 as the lixiviant and the second stage make use of H_2SO_4 and H_2O_2. Once the base metals have been removed from WPCBs, the next step is the recovery of precious resource metals like gold and silver from these WPCBs, using lixiviants different from the ones used in base metals extraction.

Precious metal leaching is leaching with thiosulphateis usually carried out with either sodium thiosulphate or ammonium thiosulphate. When compared with other non-cyanide leaching,thiosulphate leaching forms a more stable gold complex that is close to cyanide than any other alternatives however, have the advantage of a thermodynamically stable gold complex which is not the case with other lixiviantsand the thiosulphate gold complex is the closest in stability to the gold cyanide complex (Albertyn, 2017). Thiosulphate leaching has the advantages of high selectivity, nontoxic and non-corrosive(Zhang, et al., 2012). According to the system, the portion that is at anodic side of gold surface, oxidation occurs leading to the liberal of gold ions (Au+). The ions of gold then react with either ammonia or ammonia to form $Au(S_2O_3)_2^{3-}$ or $Au(NH_3)^{2+}$respectively.

4. Methodology and materials

Aqua regia was made in a laboratory, and HCL and HNO_3 were mixed to become a solution in 3:1 molar ratio respectively, to get the initial content of metal and also in order to have an estimate of the residence time needed for aqua regia digestion. Then followed by base metal leaching to calculate mass balances; and lastly, after the leaching of precious metal the final mass balance was established. After reducing the size, the ammonium thiosulphate was used as a lixiviant during precious metal leaching to yield best results.

5. Results and discussion

The evaluation of the exact composition of metals contained in crushed PCBs was done using aqua regia which was a mixture of HNO_3 and HCl. Four experimental tests were carried with the objective of determining the residence time needed for aqua regia to leach almost all the metals inside printed circuit boards. The graphs in Figure 2 below were drawn to illustrate this. The amount of metals leached from 25 g of the crushed PCBs samples.

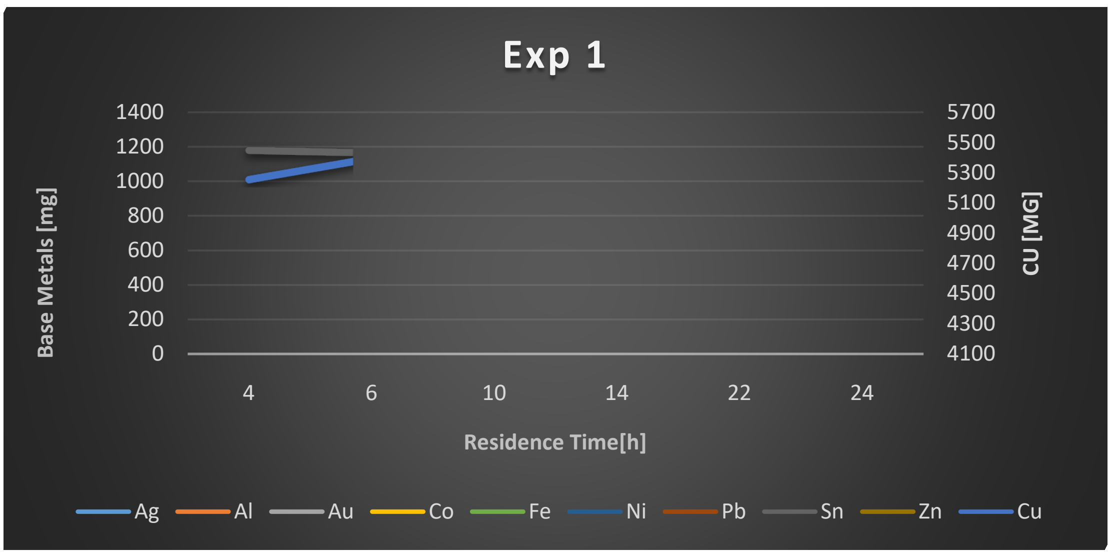

Figure 2 Experiment 1

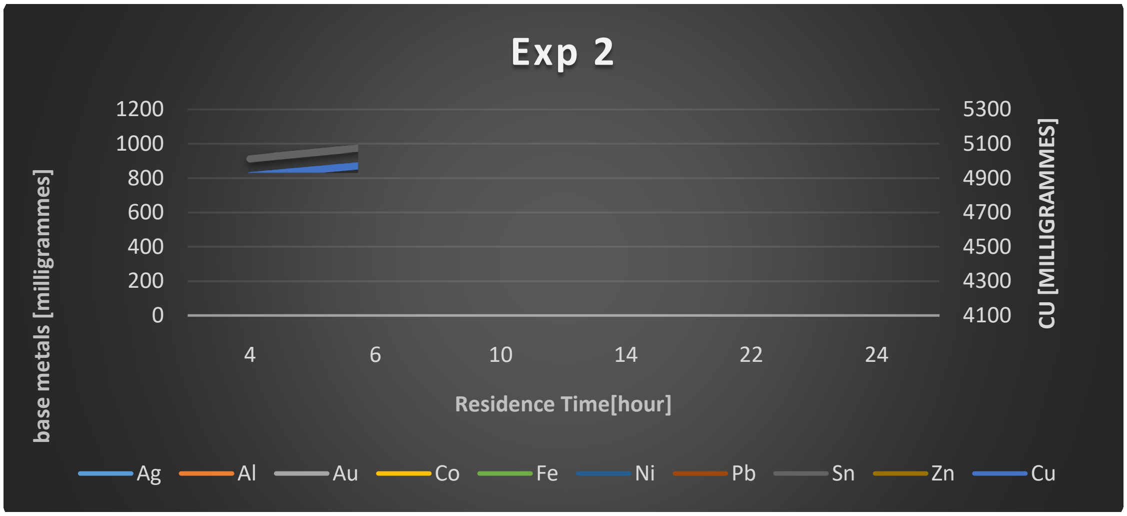

Figure 3 Experiment 2

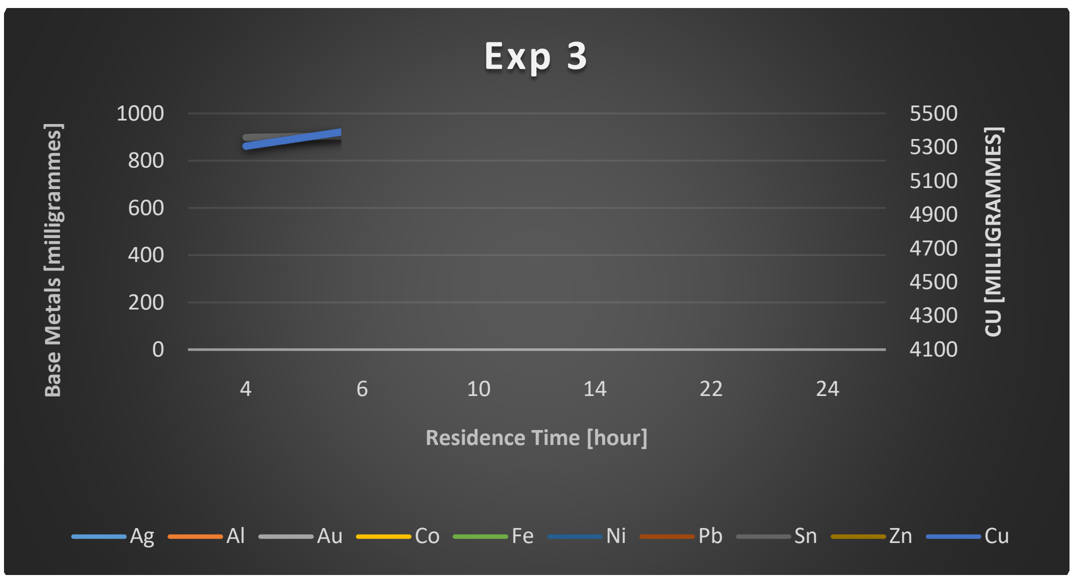

Figure 4 Experiment 3

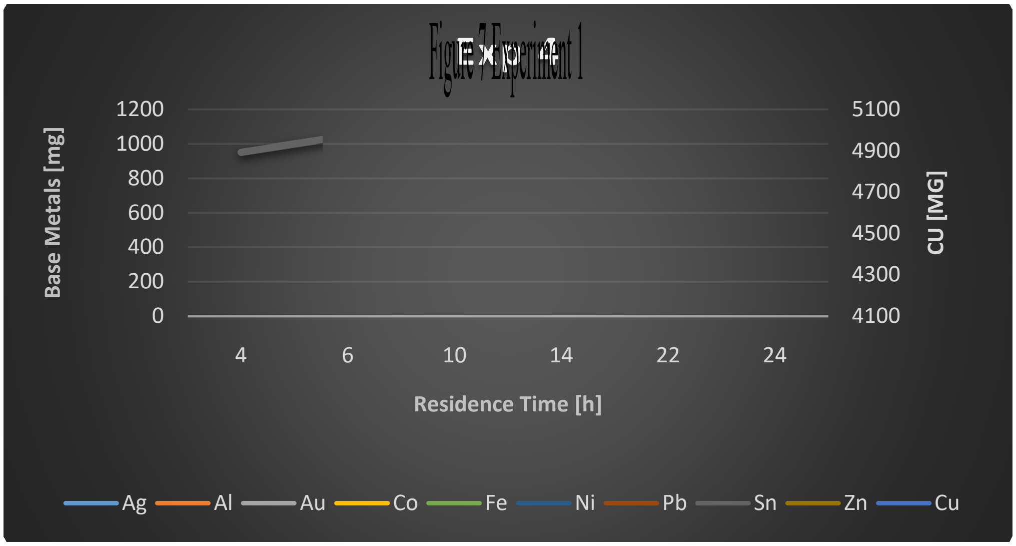

Figure 5 Experiment 4

From the graphs, it could be found out that, after 4 hours of digestion, a great amount of the base metals had been already leached with the exception of Cu and Sn and this is in accordance with literature findings. In Experiment 1 and 3, Sn leaching reached equilibrium but not in the other remaining 2 experiments. In Experiment 3, copper leaching increased from 4 hours to 24 hours and after 22 hours, equilibrium seemed to have been reached .The remaining tests supported the hypothesis that, the larger the residence time, the more Cu leached. The inconsistencies or irregularities in results are due to the diverse nature of PCBs. It was also noted that different amounts of metals were contained in the samples.

Base metal leaching: As the first step in the base metal leaching utilized nitric acid with the main aim of extracting Pb and Fe, Figure 6 is showing that, Pb was mostly extracted together with iron when compared with other base metals whilst copper, zinc, tin are not meaningfully extracted. This was supporting the literature that copper is not meaningfully extracted using nitric acid as a lixiviant. At a residence time of about 420 minutes, Pb and Fe had already reached equilibrium. Lead extraction is nearly 90%.Some base metals like cobalt and aluminium were partially extracted and would be wholly extracted during small base leaching.

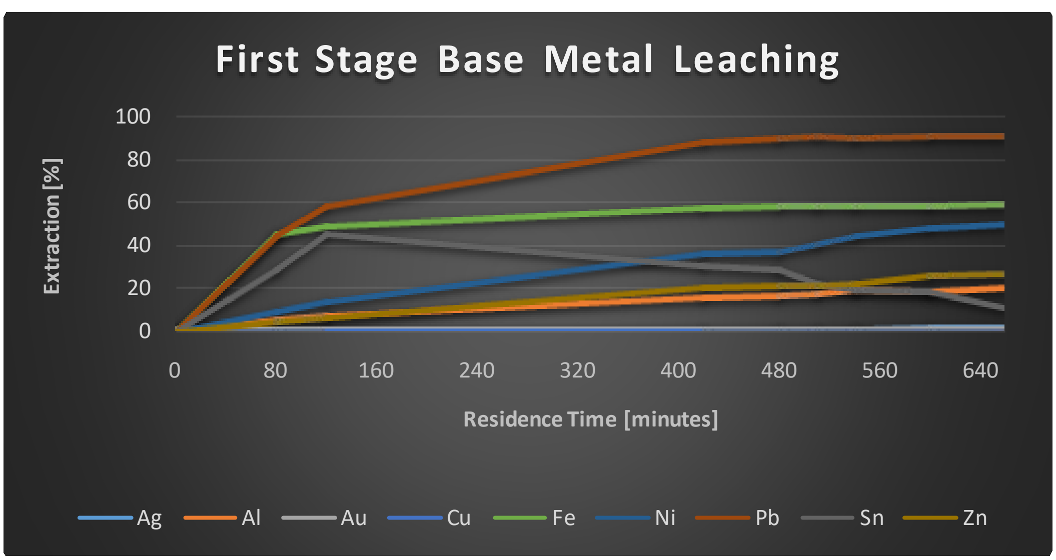

Figure 6 Leaching behavior of metals during large-scale HNO_3 leaching (step 1)

<u>Precious metal leaching</u>: Precious metal leaching involves a lot of parameters that have to be controlled if the metals are to be leached at a high percentage. The parameters that affects precious metal leaching were thiosulphate, ammonia, Cu(II) ions, Pulp density, pH and temperature, and in order to see how each parameter affects the precious metal leaching, these parameters had to be varied in separate experiments and see how the percentage extraction. Graphs of residence time against percentage extraction have to be drawn and necessary deductions could be made and compared with what literature says. Below are the graphs, of firstly gold under different conditions and silver under different conditions. From Figure 6, it could be seen that, thiosulphate concentration, Cu leftover, pulp density and temperature, played a part in the percentage extraction of gold. Experiment 4 had optimum conditions of higher thiosulphate concentration, lower pulp density, a high temperature and a lower percentage of Cu leftover and all these are known from literature to support high yield. Experiment 6 yielded less percentage extraction becauseithas lower thiosulphate concentration, low temperature and this

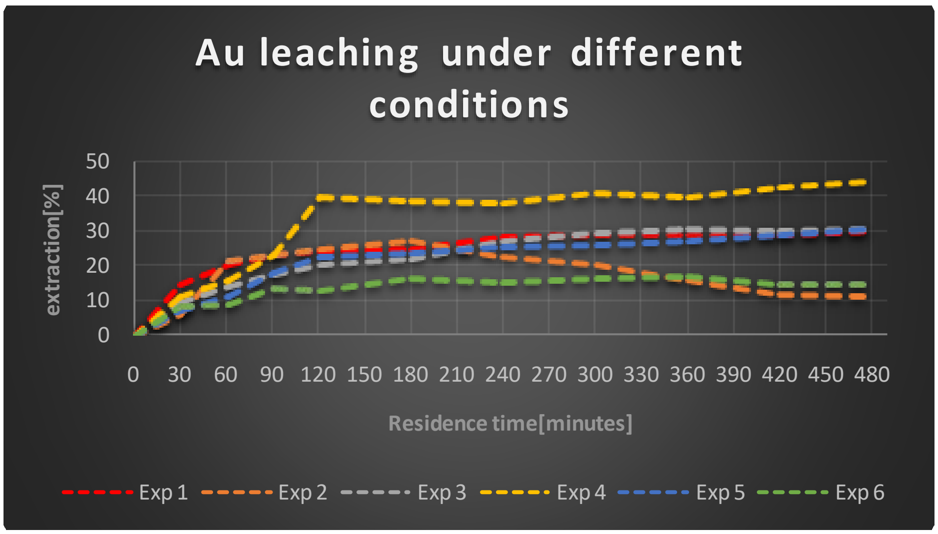

Figure 7 Au leaching under different conditions

have been known to be detrimental to the precious metal leaching. Exp 2 started on a higher leaching rate and after only 180 minutes it had reached equilibrium and precipitation started to occur. This could be attributed to little or no thiosulphate beyond 180 minutes. For Exp 1,3 and 5, the percentage is normal but did not yield higher results and this can be attributed to a higher pulp density which decreases the surface area of the lixiviant to act on the PCBs.

Figure 7 is showing the leaching silver and it could be concluded that, the parameters that affects gold leaching are nearly the same as those that affect silver leaching. From the graph below,it can be seen that, although parameters like thiosulphate concentration, pulp density and ammonia affect leaching of silver, it is temperature that has the most effect. Experiments which utilized a temperature of 25^{o}C all yielded percentage of silver extraction compared to tests which utilized a temperature of 40^{o}C.Experiment 1, 6 and 4 yielded better results compared to Exp 2, 3 and 5. It can beconcluded that, higher temperatures give rise to unstable systems as can be seen by the drop in percentage extraction for Experiment 2, 3 and 5 after about 90 minutes.

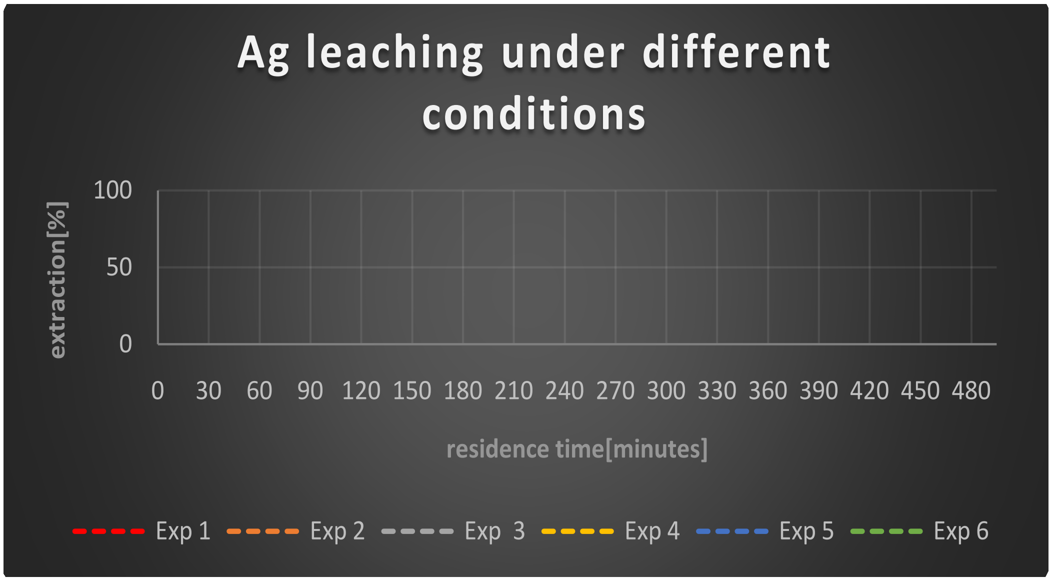

Figure 8 Ag leaching under different conditions

The factors that affects precious metal leaching are temperature, pulpy density, pH range, left over Cu content, thiosulphate concentration, as well as ammonia concentration.

6. Recommendations

For effective leaching, more emphasis has to be put on the pre-treatment of PCBs before precious metal leaching. Pre-treatment is an indispensable technique that cannot be done without as it affects precious metal leaching. The low yielding of gold could be attributed to the ineffective pretreatment stage as there would be a high percentage of leftover Cu, which inhibits both gold and silver leaching. PCBs contain an epoxy resin which contain solder that consists of lead and tin. By using a very strong organic solution, the pre-treatment stage can be able to leach all the lead and tin contained in those solders. Layers of epoxy resin also contain copper and by utilizing an organic solution that can be able to seep all the copper from the resin, precious metal leaching will be increased.

Conclusions

For effective precious metal extraction, PCB leaching was conducted in a 2 stage process in a bid to remove all the base metals especially Cu which could hinder precious metal leaching. Several parameters that affect precious metal leaching were identified and these were temperature, pulp density, thiosulphate concentration and ammonia concentration. For both Au and Ag leaching, the ratio of thiosulphate concentration to ammonia concentration should be between 0.5 and 1. That ratio has to be kept in that range if higher yields are to be realized. Lower pulp density of 25g/L yielded better results compared to a higher pulp density of 50g/L. This could be attributed to the fact the higher the amount of reagent per unit weight of PCBs the higher the yield. The effect of temperature is different on Au and Ag. For Au leaching, the optimum temperature was 40^0C and for Ag, the optimum temperature was 25^0C.

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