UNIVERSITY OF THE
WITWATERSRAND,
JOHANNESBURG

Development of an integrated process flowsheet for the recovery of valuable metals from waste cathode ray tubes and printed circuit boards

By
Sello Tsebe

A dissertation submitted in partial fulfilment of the degree of
Master of Science in Engineering
in the School of Chemical and Metallurgical Engineering
University of the Witwatersrand
Johannesburg

February 2023

SUMMARY

Electrical and electronic waste (e-waste) is currently the fastest growing waste stream in the world. Generation of e-waste is driven mainly by rapid technological advancements and frequent innovations which in turn result in shorter lifespan of electronic devices and high rate of obsolescence of digital products. E-waste is considered a valuable stream of secondary metal resources because it contains valuable metals such as copper (Cu) and gold (Au). However, it is also classified as hazardous waste as it contains toxic heavy metals such as lead (Pb) and cadmium (Cd). If e-waste is not managed properly, the toxic metals may pose serious risks to the environment and human health.

In 2018, South Africa produced an estimated 360,000 t e-waste with reports of only about 10% recycled. The lack of processing technology was cited as an explanation for the low levels of recycling, especially for complex fractions such as printed circuit boards (PCBs) and cathode ray tubes (CRTs). Partially beneficiated PCBs are exported to Europe for processing, and stripped CRTs are either landfilled or stockpiled. Landfilling of CRTs has been banned effective August 2021. Exporting of partially beneficiated PCBs deprives the South African economy the opportunity to take full advantage of the value contained in PCBs. There is a need for a technology that will provide capacity for local processing of CRTs and PCBs for metal recovery.

The current study investigated a new process flowsheet for the thermal treatment of CRTs and PCBs in the same integrated flowsheet for metal recovery. The aim was to recover a crude Cu alloy from the PCBs and a crude Pb alloy from the CRTs. The two processes were integrated by flow of material from one process to the other. That is, slag from the CRTs furnace was recycled to the PCBs furnace to be utilised as a fluxing agent, and fume from the PCBs furnace was recycled to the CRTs furnace to be utilised as a source of lead oxide (PbO). The study aimed to answer this primary question:

Is it technically feasible to integrate the smelting of waste CRT funnel glass into the same flowsheet as the smelting of waste PCB concentrate?

In order to answer the above question, the study explored the following two questions:

1. Can oxidative smelting of PCB concentrate and CRT slag produce a crude Cu alloy with a grade of more than 95% Cu?
2. Can reductive smelting of CRT funnel glass and PCB fume produce a crude Pb alloy with a grade of more than 95% Pb?

The investigation was undertaken in a pilot-scale top blown rotary converter (TBRC). The furnace facility consisted of an oxy-propane burner supported by a gas supply train; a cylindrical refractory-lined reactor with a working volume of 20 L; and off-gas handling system featuring a two-stage filtration system, whereby primary filtration occurs through a bank of cartridge filters and secondary filtration occurs in a baghouse.

The PCBs smelting condition that achieved the required alloy grade was an average oxidation temperature of 1350°C, flame stoichiometry of 100 mol% O_2, and an oxidation time of 1 h. The amount of material recycled to integrate to the PCBs process was 45% CRT slag, per unit mass of PCB concentrate, to the PCBs smelting furnace. The grade of the Cu alloy obtained was 95.1% Cu.

The CRTs smelting condition that achieved the required alloy grade was an average reduction temperature of 1200°C, flame stoichiometry of 95 mol% O_2, and reduction time of 2 h. The amount of material recycled to integrate to the CRTs process was 10% PCB fume, per unit mass of CRT funnel glass, to the CRTs smelting furnace. The grade of the Pb alloy obtained was 96.1% Pb.

The test work provided experimental evidence that the integrated process can produce crude alloys of Cu and Pb at the required grade specification. Therefore, the study has shown that it is technically feasible to integrate the smelting of waste CRT funnel glass into the same flowsheet as the smelting of waste PCB concentrate. This process flowsheet can be optimised and developed into a technology that can provide technical capacity to locally process low-grade PCBs and CRTs for metal recovery.