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## 8.0 CONCLUSIONS

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Recovery of material resource from end-of-life electronics, and the PCB in particular, continues to be a major challenge for material sustainability of technological development in the face of dwindling natural reserves. This investigation was aimed at exploiting the versatility of froth flotation for beneficiation of the PCB comminution fines. The investigation approach was extensive, involving characterisation of the sample, investigation of various flotation schemes and many follow-up investigations.

Characterisation work shows the PCB comminution fines has loose bulk density lighter than water and a true material density of about  $3 \text{ g/cm}^3$ . This, coupled with surface hydrophobicity observed in the sample, necessitates that pulping must be done under water – a procedure that entails breaking a paste of the sample under water. Wet assaying of the sample was found to be highly dependent on the digestion condition. Absolute assays of a constituent element as for hazardous constituent analysis will require comparison of data from more than one digestion condition. Comparative assaying of samples from beneficiation treatments can however use aqua regia digestion. It gives a less hazardous procedure compared to hydrogen fluoride plus microwave and nitric acid treatment. It also provides analysis liquor from which all constituent elements can be analysed, compared to that from total digestion via sodium peroxide fusion. It implies that, for this sample, total digestion will not always give better results compared to partial digestion. It was also found that certain analytical techniques, such as thermogravimetric analysis, may not be recommended in PCB characterisation. It gave no distinct inflexion point to characterise any constituent. This is due to the diverse material constituents of the sample.

Particle liberation in the sample was found to be very high, but still not complete. An instance of the unliberated fraction at  $-75 \mu\text{m}$  gave about 5000 particles per million. The morphology of the metallic particles was highly diverse, with an average circularity shape factor of 0.63. This, coupled with the material diversity, posed a major constraint in sub-sieve particle size distribution analysis. The liberated particles themselves contain more than one chemical element, being alloys. Beneficiation operation therefore cannot attempt to separate such particles into

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constituent elements; realistic schemes can aim only at achieving some bulk collection of metallic values into a concentrate.

Reverse flotation of metallic values based on natural hydrophobic response (NHR) was proposed and found to be successful in application to this sample. Microflotation indicated the favourable kinetic regime in implementing PCB comminution fines flotation would be low compared to conventional minerals. A study of the favorable kinetics under the scheme described as natural hydrophobic response gave about 500 rpm and 500 ml/min aeration rate, at 300 g sample in a 3.5 l Leeds cell. Without the use of a collector, natural hydrophobic response was observed. This also gave stable froth without the aid of a frother. The NHR froth was critically discussed purely as a fine particle stabilised froth and not surfactant stabilised. Au and Pd, which are the major economic drivers of PCB processing, were among the elements best enriched into the sink at an adjudged optimal 64% recovery for Au, at an enrichment ratio above three. Ti achieved an even better performance. Recovery loss of metal to the float was observed to increase with mass pull and not water recovery when results of flotation over varying PSDs were compared. Such loss will, therefore, be due more to carry-over under bulk upward mass transfer and entrapment in the froth. The flotation over narrower (coarser) PSD (+106 – 75  $\mu\text{m}$ ) also supports the fine particle stabilisation mechanism advanced for the NHR froth, as the dynamic froth stability height was very low compared to that of the finer fraction. It also indicated that the NHR scheme can be successfully applied at the coarser fraction.

The chemical conditioning of the PCB CF flotation system is quite challenging. Responses to the reagents were minimal. Potassium amyl xanthate did not condition the metallic particles for flotation remarkably as it does with native metals. Sulfidation showed a little improvement in response to PAX. SMBT – a selective collector for tarnished copper and lead minerals – did not show such selectivity in the PCB comminution fines pulp. Some cationic pull with TBAC toward further selective pull of non-metallic values after NHR pull had subsided was observed (although also very little). Macromolecular depression with CMC achieved virtually no depression of the natural hydrophobic response within practical dosages. Depression by lowering surface tension with Betamin 127A was effective, but still not very helpful for selective pull after chemical conditioning. Frothing and entrainment sets in within dosages required to suppress the NHR.

Surface oxidation of the metallic particles and generally low reactivity of end use alloy compared to natural mineral surfaces are probable causes for this poor response to reagent. The complex flotation system the pulp itself represents cannot be ruled out, pointing to calcium depression as another possible explanation for the overall depression observed in the system. The sample itself contains about 7 % calcium by mass. ICP-MS trace element analysis of the process water confirmed a calcium presence up to 7 ppm equilibrium concentration in the pulp water. Surface investigations, with field emission scanning electron microscope and auger electron spectroscopy composition depth-profiling, revealed the presence of organic layers on the surface of the metallic particles. The surfaces were also found to be oxidised down to about 340 nm depth profiled. None of the surface is pure alloy, occurring in forms that are relatively inert to reagents.

Summing up from all the analyses and results from these investigations, the complexity observed in the chemical conditioning of PCB CF, coupled with the difficulty of suppressing naturally floating particles, it can be submitted that the natural hydrophobic response remains the ideal scheme that can be recommended for PCB CF flotation. Recovery compromise is a major challenge to the NHR scheme when pulling too high. In a continuous system, provision for scavenging and cleaning will improve this. The very low impeller energy and aeration rate found to be favourable for PCB CF flotation will make the cleaning and scavenging inexpensive. Lastly, it must be noted that the NHR scheme operates at zero reagent cost (no collector, no frother). Optimisation of the performance of the scheme responds remarkably well to kinetic parameter variation. These are major scorecards which will keep campaigning for the natural hydrophobic response scheme in consideration of froth flotation for beneficiation of this peculiar material fraction.

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