

Molecular Recognition TechnologyTM (MRTTM) for Selective Metal Separation in Green E-Waste Processing [†]

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Abstract

The rapid growth of electronic waste (e-waste) demands sustainable recovery solutions based on green chemistry. Conventional recycling relies on energy-intensive pyrometallurgical routes that cause emissions and material losses. This study applies Molecular Recognition TechnologyTM (MRTTM) for selective energy-efficient recovery of base (Cu, Ni, Fe, Sn) and precious/platinum group metals (Ag, Pd, Pt) from a collector metal alloy. A hydrometallurgical process combining electrowinning, sequential acid leaching, and MRTTM separations achieved >99% metal purity with minimal waste generation. The results demonstrate MRTTM as a scalable green alternative for high-efficiency metal recovery from e-waste, supporting circular economy objectives.

Keywords: Molecular Recognition TechnologyTM (MRTTM); e-waste recycling; selective metal recovery; hydrometallurgical processing; sustainability; green chemistry; platinum group metals

1. Introduction

The growing accumulation of electronic waste (e-waste) presents both environmental and economic challenges [1]. Exposure to e-waste is associated with adverse health outcome, including thyroid dysfunction, DNA damage, respiratory issues, and adverse neonatal effects, particularly in children and individuals living or working in e-waste recycling areas [2]. The rapid growth of e-waste, driven by expanding electronic industries and product obsolescence, necessitates sustainable management through design for environment, extended producer responsibility, recycling, and remanufacturing.

E-waste contains a complex mixture of base metals (BMs) and precious/platinum group metals (PMs/PGMs), including copper (Cu), nickel (Ni), iron (Fe), tin (Sn), platinum (Pt), palladium (Pd), silver (Ag), and gold (Au). Traditional processing methods for e-waste include pyrometallurgical, conventional hydrometallurgical, and biohydrometallurgical techniques, each with distinct advantages and drawbacks [3].

In contrast, Molecular Recognition TechnologyTM (MRTTM) provides a highly selective and efficient approach for metal extraction, enabling sustainable e-waste recycling with minimal environmental impact [4–7]. Unlike conventional hydrometallurgical techniques, MRTTM operates under milder conditions, reducing reagent consumption, minimising waste production, lowering energy use and improving the purity of recovered metals [8].



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This study explores the application of MRT™ for the selective separation of valuable metals from anodic slime residues (ASR) generated during electrowinning processes. By employing a hydrometallurgical approach, this work aims to optimise metal extraction using sulfuric acid leaching for BMs and aqua regia leaching for PMs/PGMs. The research demonstrates the feasibility of high-purity metal recovery through MRT™, offering an innovative solution for circular economy initiatives in e-waste management.

2. Materials and Methods

A hydrometallurgical process incorporating MRT™ was designed to recover valuable metals from an e-waste collector metal alloy (CMA). The process begins with electrowinning to recover copper in a single pass, leaving PMs/PGMs and some BMs undissolved as ASR. This by-product is then processed through a four-stage workflow (Figures 1 and 2): Stage 1 involves sulfuric acid leaching; Stage 2 consists of the individual recovery of the BMs via MRT™ separations. The filter cake resulting from the initial sulfuric acid leaching (Stage 1) undergoes a subsequent aqua regia leaching in Stage 3, followed by Stage 4, which involves the extraction, separation, and recovery of PMs/PGMs using MRT™.

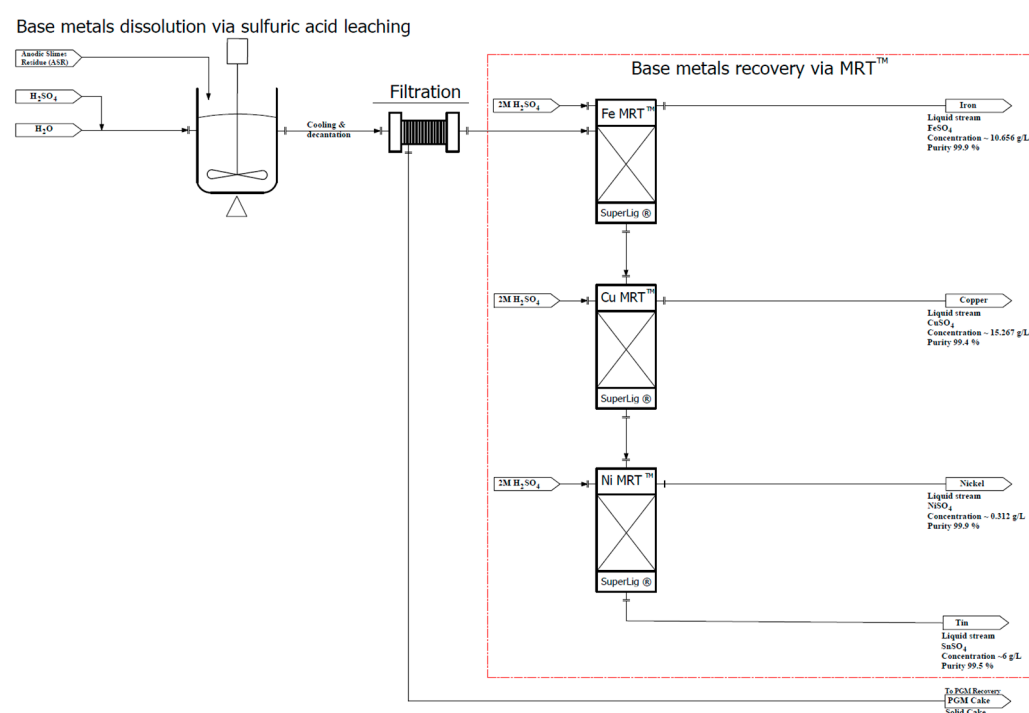


Figure 1. Schematic flow diagram of Stage 1 (sulfuric acid leaching) and Stage 2 (BM recovery via MRT™) of the hydrometallurgical process. The red dashed box delineates the MRT™-only recovery section.

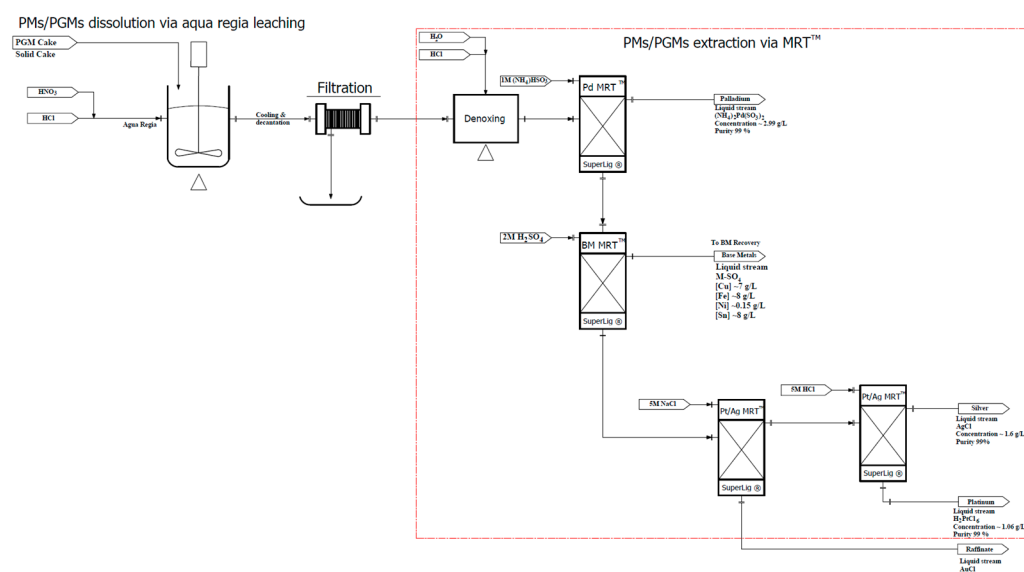


Figure 2. Schematic flow diagram of Stage 3 (PMs/PGMs aqua regia acid leaching) and Stage 4 (PMs/PGMs recovery via MRT™) of the hydrometallurgical process. The red dashed box delineates the MRT™-only recovery section.

3. Results

Figures 3–7 illustrate the MRT™ performance for each metal: the loading, washing, and elution profiles highlight the efficient binding and recovery with minimal impurity crossover. The capacity values ranged from 0.048 to 0.432 mM/g depending on the SuperLig® resin used and the metal target.

3.1. Base Metals Recovery (Stages 1 and 2)

Sulfuric acid leaching was performed under various oxygenation conditions to extract base metals (Cu, Ni, Fe, Sn). The results indicated enhanced extraction with oxygen flow, reaching over 80% recovery for Cu, Ni, Fe, and Sn. The base metals leach liquor (BMLL) was processed through MRT™ columns: Fe was first recovered using SuperLig® 92 (Figure 3), followed by Cu using SuperLig® 146 (Figure 4), and Ni using SuperLig® 132 (Figure 5). Each separation showed high selectivity and >99% product purity (Table 1), while Sn remained in solution.

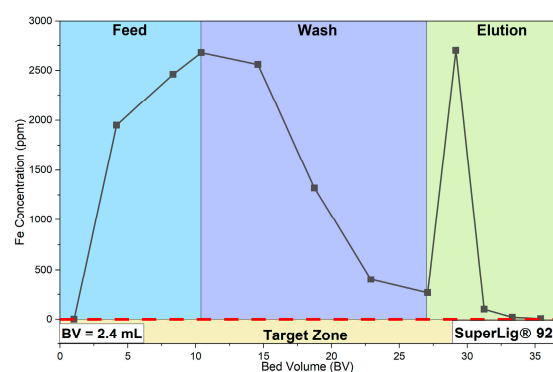


Figure 3. Optimal cycle data for Fe initial separation from BMLL feed loading, followed by 0.01 M H₂SO₄ wash, followed by 2 M H₂SO₄ elution at a 0.3 mL/min flow rate, with a 1 g column of SuperLig® 92.

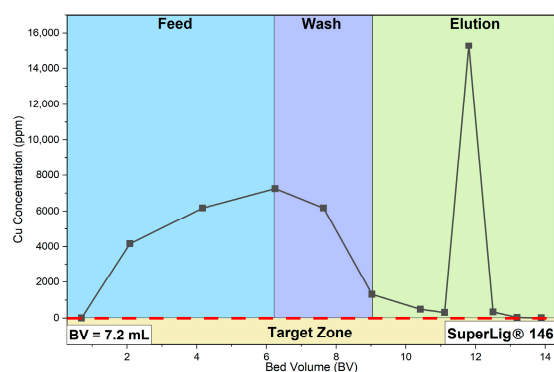


Figure 4. Optimal cycle data for Cu separation from BMLL Fe-free feed loading, followed by water wash, followed by 2 M H₂SO₄ elution at a 0.6 mL/min flow rate, with a 3 g column of SuperLig® 146.

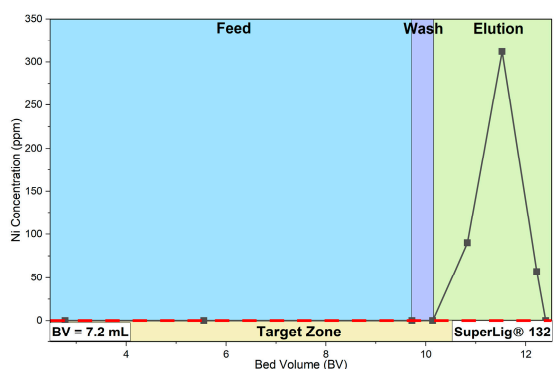


Figure 5. Optimal cycle data for Ni initial separation from BMLL Fe/Cu-free feed loading, followed by 0.1 M H₂SO₄ wash, followed by 2 M H₂SO₄ elution at a 0.6 mL/min flow rate, with a 3 g column of SuperLig® 132.

Table 1. Stage 2 MRT™ individual separations results.

Element	SuperLig®	Capacity of SuperLig® (mM/g of SuperLig®)	Product	Element Concentration (g/L)	Product Purity (%)
Fe	92	0.254	FeSO ₄	10.656	99.9 +
Cu	146	0.432	CuSO ₄	15.267	99.4 +
Ni	132	0.155	NiSO ₄	0.312	99.9 +

3.2. Precious and Platinum Group Metals Recovery (Stages 3 and 4)

The PM/PGM-rich residue was leached with aqua regia, producing an aqua regia leach liquor (ARLL), followed by denoxing and oxidation–reduction potential (ORP) adjustment. Palladium was selectively captured using SuperLig® 2 (Figure 6). The remaining base metals were removed with SuperLig® 132 before the final recovery of Ag and Pt using SuperLig® 186 (Figure 7), which enabled effective separation at 700 mV ORP. The product purities exceeded 99% for Pd, Pt, and Ag (Table 2).

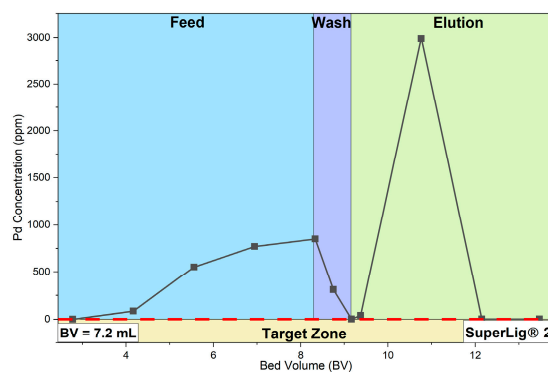


Figure 6. Optimal cycle data for Pd separation from ARLL feed loading, followed by 0.01 M H₂SO₄ wash, followed by 2 M H₂SO₄ elution at a 0.6 mL/min flow rate, with a 3 g column of SuperLig® 2.

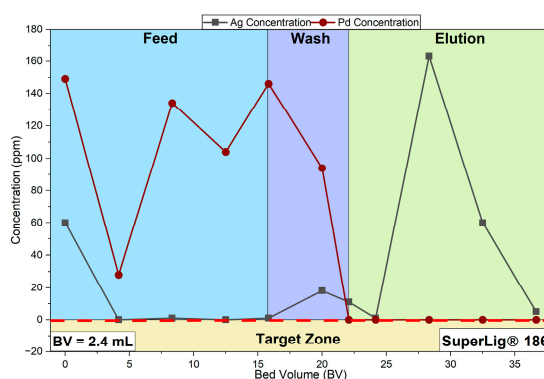


Figure 7. Optimal cycle data for Ag/Pt separation from Pd-Free ARLL feed loading, followed by 2 M H₂SO₄ wash, followed by 8 M HCl elution at 0.33 mL/min for a 1 g column of SuperLig® 186, at an ORP of separation of Pt and Ag of 700 mV.

Table 2. Stage 4 MRT™ individual separation results.

Element	SuperLig®	Capacity of SuperLig® (mM/g of SuperLig®)	Product	Element Concentration (g/L)	Product Purity (%)
Pd	2	0.282	(NH ₄) ₂ Pd(SO ₃) ₂	2.99	99 +
Pt	186	0.101	H ₂ PtCl ₆	1.06	99 +
Ag	186	0.048	AgCl	1.60	99 +

This experimental demonstration confirms the feasibility of MRT™ for the selective and scalable recovery of valuable metals from ASR. The process aligns with green chemistry principles, minimises chemical waste, and achieves high-purity outputs using targeted SuperLig® resin–metal interactions.

4. Conclusions

This study confirms that Molecular Recognition Technology (MRT™) is a sustainable efficient solution for recovering valuable metals from e-waste collector metal alloy products. Using selective sulfuric acid and aqua regia leaching, followed by MRT™ separation, >99% metal purity was achieved with minimal waste. The process aligns with green chemistry principles and offers a scalable environmentally friendly alternative to traditional methods. IBC's test work validated, through confirmatory testing, that MRT™ is suitable for the extraction of valuable metals from anode slime residues derived from collector metal alloy. Future work will target large-scale implementation and reagent recovery to enhance sustainability.

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