

Index

Title page.....	i
Certificates.....	ii
Acknowledgements.....	v
List of figures.....	xi
List of tables.....	xvi
List of abbreviations.....	xviii
Preface.....	xix

Table of Contents

CHAPTER 1	3
1. INTRODUCTION	3
1.1 Electronic waste (e-waste)	3
1.2 Printed circuit board assembly (PCBA)	4
1.2.1 Printed circuit boards (PCBs)	5
1.2.2 Electronic components (ECs)	5
1.3 Tantalum in electronics	6
1.3.1 Tantalum capacitor	7
1.4 Opportunities of metals recovery from waste tantalum capacitors (WTCs).....	9
1.5 Literature review	13
1.5.1 Bibliographic mapping	13
1.5.2 Metal recovery from ECs from e-waste	17
1.5.3 Tantalum recovery from WTCs.....	28
1.6 Research gap	36
1.7 Research objectives	38
1.8 Organization of the thesis.....	39
CHAPTER 2	45

2. EXPERIMENTAL DETAILS	45
2.1 Procurement of raw materials	46
2.2 Pre-processing and characterization of capacitors	46
2.3 Leaching of metal-rich fraction.....	49
2.4 Solvent extraction.....	52
2.4.1 Recovery of tantalum from alkaline leach liquor	52
2.4.2 Recovery of manganese and nickel from 1 st stage acidic leach liquor	53
2.5 Leaching of non-metallic-rich fraction	55
2.6 Precipitation of silver	56
CHAPTER 3	61
3. MATERIAL FLOW ANALYSIS OF TANTALUM	61
3.1 Material flow analysis (MFA) - Overview.....	61
3.2 Steps in material flow analysis.....	62
3.2.1 Identification of system boundaries.....	62
3.2.2 Data collection and assumptions	63
3.2.3 Flows and stock estimation.....	66
3.2.4 Economic assessment of the waste flows	67
3.3 The MFA model	68
3.3.1 Material flow analysis (MFA) of tantalum.....	68
3.3.1 Sensitivity analysis	71
3.4 Economic assessment of capacitor waste flow	73
3.5 Identification of key causes for low recycling rate (RR) of tantalum.....	74
3.6 Potential solution to improve recycling rate of tantalum	76
3.7 Conclusions	78
CHAPTER 4	81

4. RECOVERY OF TANTALUM AND SILVER FROM WASTE TANTALUM CAPACITORS	81
4.1 Characterization of capacitors	81
4.2 Recovery of tantalum from metal-rich concentrate (ERTC).....	83
4.2.1 Alkaline leaching	83
4.2.2 Single- stage acidic leaching	86
4.2.3 Two- stage leaching.....	90
4.3 Recovery of silver from non-metallic-rich concentrate	99
4.3.1 Leaching	99
4.3.2 Separation of silver using chemical precipitation.....	100
4.4 Conclusions	104
CHAPTER 5	109
5. RECOVERY OF MANGANESE AND NICKEL FROM STAGE-1 LEACH LIQUOR	109
5.1 Separation of manganese using D2EHPA as extractant.....	111
5.1.1 Effect of temperature	111
5.1.2 Effect of pH	112
5.1.3 Effect of carrier concentration.....	113
5.1.4 Effect of contact time	115
5.1.5 Effect of O/A ratio.....	116
5.2 Separation of manganese using CYANEX272 as extractant	118
5.2.1 Effect of carrier concentration.....	118
5.2.2 Effect of temperature	119
5.2.3 Effect of pH	120
5.2.4 Effect of O/A ratio.....	121
5.2.5 Multi-stage extraction- McCabe-Thiele plot	123
5.2.6 FT-IR analysis	125

5.2.7 Stripping of manganese from loaded organic phase.....	126
5.3 Conclusions.....	128
CHAPTER 6.....	133
6. COST-BENEFIT ANALYSIS OF PROPOSED RECYCLING ROUTE	133
6.1 Cost-Benefit Analysis (CBA)- General working framework.....	133
6.2 Cost estimation.....	134
6.3 Cost benefit analysis results	136
6.3.1 Process results	136
6.3.2 Economic analysis results.....	140
6.4 Sensitivity analysis results	143
6.5 Scenario analysis results.....	145
6.6 Discussion	147
6.7 Conclusions.....	148
CHAPTER 7.....	153
7. CONCLUSIONS AND SCOPE FOR THE FUTURE WORK	153
7.1 Conclusions.....	153
7.2 Scope for the future work.....	157
REFERENCES	159
LIST OF PUBLICATIONS	187