RECOVERY OF PALLADIUM FROM AQUEOUS SOLUTION USING SURFACTANT MEDIATED PRECIPITATION PROCESS

JUNAIDAH BINTI BUHARI

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Chemical)

Faculty of Chemical Engineering
Universiti Teknologi Malaysia

OCTOBER 2015

Dedicated to VVIP of my life

my beloved mother, Siti Arba'yah Bt Miskam,

my beloved late father, Allahyarham Hj. Buhari B. Hj. Padlan

and siblings, Junainah, Nor Azmi, Nor Azuan, Nor Azam

ACKNOWLEDGEMENTS

In the name of Allah the Most Gracious, the Most Merciful and the Most Loving. Peace be upon Prophet Muhammad S.A.W, the messenger of Allah. Alhamdulillah to the Almighty Allah for His guidance and helps throughout my journey in this world. In addition, I would like to express my gratitude to my supervisor, Assoc. Prof. Dr. Hanapi Mat for his supervision, encouragement and knowledge throughout the project period. Certainly, without his continued provision and motivation, this thesis would not have been the same as presented here.

Besides, I would like to thank my beloved mother for her continuous pray, love, support and understanding during my studies. Also, thanks to my siblings for their endless support and motivation. I also would like to thank my friends Siti Shilatul Najwa, Aishah, Aqilah, Khairunissa, Syed Nassrun Wafa and AMPENmate for being there during my ups and down of research life and for their encouragement and help. Furthermore, special thank is dedicated to Mr. Yassin for helping me in sample analysis. I am also indebted to Universiti Teknologi Malaysia (UTM) for funding my Master study.

Finally, sincere appreciation to those who not been mentioned which direct or indirectly involved in accomplished this thesis. My wish is that this thesis could be beneficial to other researchers. With that, thank you.

ABSTRACT

In recent years, the demand for precious metals has increased in most emerging countries. The precious metals are mainly used not only in jewellery but also in electrical devices, medical instruments and as catalysts. They can be primarily recovered not only from the ores but also secondary sources like electronic wastes and spent catalysts. This research aimed to develop a method for the recovery of palladium (Pd) from synthetic and real Pd solutions using surfactant mediated precipitation process. The surfactant used was cetyltrimethylammonium bromide (CTAB), while the leaching agents used were hydrochloric acid (HCl), nitric acid (HNO_3): sulphuric acid (H_2SO_4), hydrochloric acid (HCl): hydrogen peroxide (H_2O_2) and aqua regia. The real Pd solution was prepared using selected leaching agents and spent catalyst. The effect of process parameters such as leaching agent types, CTAB concentrations, Pd concentrations, temperature, and contact time on Pd recovery efficiency were studied. Comparative study between CTAB and other reducing agent (i.e. formic acid) was also carried out. The concentration of Pd was determined using atomic absorption spectroscopy (AAS), while the CTAB concentration was determined by the two-phase titration method. The experimental results show that the Pd recovery efficiency strongly depends on the CTAB and Pd concentrations. The increase of temperature resulted in lowering the Pd recovery efficiency. The precipitation process was relatively fast (less than 3 minutes). The Fourier transform infrared (FTIR) spectroscopy and X-ray photoelectron spectroscopy (XPS) analyses showed changes in CTAB functional groups after the precipitation process. The stoichiometry reaction between Pd and CTAB as given by the molar ratio of Pd to CTAB was 2. The results from the leaching process of spent catalyst using several leaching agents (i.e. HCl, HNO_3:H_2SO_4, aqua regia) show that HCl as the leaching agent gave high selectivity towards Pd compared to other metals present in the spent catalyst. It was found that 85% Pd could be recovered from the real Pd solution (i.e. spent catalyst leaching solution) using 1 mM CTAB.

ABSTRAK

Sejak kebelakangan ini, permintaan logam berharga telah meningkat di negara-negara yang membangun. Logam berharga kebanyakannya digunakan bukan sahaja sebagai perhiasan tetapi juga dalam peranti elektrik, alatan perubatan malahan sebagai pemangkin. Selain itu, ia bukan sahaja boleh diperoleh daripada bijih tetapi juga sumber sekunder seperti buangan elektronik dan pemangkin terpakai. Oleh itu, kajian ini dijalankan untuk membangunkan satu kaedah bagi perolehan paladium (Pd) daripada larutan menggunakan proses pemendakan melalui pengantara surfaktan. Surfaktan yang digunakan dalam kajian ini ialah setiltrimetil ammonium bromida (CTAB) manakala ejen pengurasan yang digunakan ialah asid hidroklorik (HCl), asid nitrik (HNO_3): asid sulfurik (H_2SO_4), asid hidroklorik (HCl): hidrogen peroksida (H_2O_2) dan akua regia. Larutan Pd sebenar telah disediakan menggunakan ejen pengurasan yang terpilih dan pemangkin terpakai. Kesan daripada parameter proses seperti jenis ejen pengurasan, kepekatan CTAB, kepekatan paladium (Pd), suhu dan masa sentuhan ke atas prestasi perolehan telah dikaji. Kajian perbandingan antara CTAB dan ejen pengurangan yang lain (asid formik) juga telah dilaksanakan. Kepekatan Pd telah ditentukan dengan menggunakan spektroskopi penyerapan atom (AAS) manakala kepekatan CTAB ditentukan menggunakan kaedah pentitratan dua fasa. Keputusan eksperimen menunjukkan kecekapan perolehan Pd sangat bergantung kepada kepekatan CTAB dan Pd. Peningkatan suhu menyebabkan penurunan kecekapan perolehan Pd. Proses pemendakan telah berlaku dengan pantas (kurang dari 3 minit). Analisa daripada spektroskopi inframerah transformasi Fourier (FTIR) dan spektroskopi fotoelektron sinar X (XPS) menunjukkan perubahan pada kumpulan berfungsi CTAB selepas proses pemendakan. Tindak balas stoikiometri antara Pd dan CTAB yang diberikan oleh nisbah molar Pd kepada CTAB adalah 2. Keputusan proses pengurasan pemangkin terpakai menggunakan beberapa ejen pengurasan (cth. HCl, HNO_3:H_2SO_4, akua regia) menunjukkan dengan menggunakan HCl sebagai ejen pengurasan, pemilihan ke atas Pd lebih tinggi berbanding dengan logam lain yang terdapat di dalam pemangkin terpakai. Dalam kajian proses perolehan logam melalui larutan pengurasan pemangkin terpakai, 85% Pd boleh diperoleh menggunakan 1 mM CTAB.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENTS	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	x
	LIST OF FIGURES	xii
	LIST OF ABBREVIATIONS	xv
	LIST OF APPENDICES	xvii
1	**INTRODUCTION**	1
	1.1 Research Background	1
	1.2 Problem Statement	3
	1.3 Objectives and Scopes of Research	5
	1.4 Thesis Outline	6
	1.5 Summary	7
2	**LITERATURE REVIEW**	8
	2.1 Precious Metals	8
	2.1.1 Introduction to Precious Metals	8
	2.1.2 Source of Precious Metals	9
	2.1.3 Application of Precious Metals in Industries	14
	2.2 Precious Metals Recovery Technologies	15

	2.2.1	Pyrometallurgical Process	15
	2.2.2	Biometallurgical Process	18
		2.2.2.1 Bioleaching	19
		2.2.2.2 Biosorption	21
	2.2.3	Hydrometallurgical Process	23
		2.2.3.1 Leaching Process	23
		2.2.3.2 Hydrometallurgy Recovery Methods	30
	2.3	Palladium	39
	2.3.1	Source of Palladium	40
	2.3.2	Recovery Technology for Palladium	42
	2.4	Surfactant Based Separation Process	44
	2.4.1	Introduction to Surfactant	44
	2.4.2	Surfactant Separation Process Technologies	49
	2.5	Summary	55
3		**MATERIALS AND METHODS**	57
	3.1	Introduction	57
	3.2	Materials	59
	3.2.1	Chemicals	59
	3.2.2	Spent Catalysts	59
	3.3	Experimental Procedure	59
	3.3.1	Preparation of Synthetic Pd Solution	59
	3.3.2	Preparation of CTAB Solution	60
	3.3.3	Preparation of Pd Leaching Solution	60
	3.3.4	Pd Recovery Procedure	60
	3.4	Characterization Procedures	61
	3.4.1	Composition Determination	61
	3.4.2	Functional Groups Determination	61
	3.4.3	X-ray Photoelectron Spectroscopy (XPS) Analysis	62
	3.5	Analytical Procedures	62
	3.5.1	Analysis of Palladium Concentration	62
	3.5.2	CTAB Concentration Determination	63
	3.5.3	pH Determination	64

	3.6 Summary	64
4	**RESULTS AND DISCUSSIONS**	66
	4.1 Introduction	66
	4.2 Palladium (Pd) recovery from synthetic solution	67
	4.2.1 Precipitation Equilibrium	67
	4.2.2 Stoichiometry of reaction	79
	4.2.3 Kinetics of Precipitation Process	80
	4.2.4 Mechanism of Pd Recovery Process	83
	4.2.5 Comparative study	88
	4.3 Palladium Recovery from Leaching Solution	90
	4.3.1 Characterization of Spent Catalysts	90
	4.3.2 Leaching and Recovery Process	92
	4.4 Summary	95
5	**CONCLUSIONS AND RECOMMENDATIONS**	97
	5.1 Introduction	97
	5.2 Summary of Research Findings	97
	5.2.1 Recovery Parameters Study	95
	5.2.2 Mechanism of Recovery Process	99
	5.3 Future Researchers	100
	5.4 Summary	101
REFERENCES		102
Appendices		117

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Sources of precious metals from various origin (Won *et al.*, 2014)	12
2.2	Composition of spent catalysts from previous studies.	13
2.3	The summarization of several pyrometallurgical methods for metals recovery from electronic waste (Cui and Zhang, 2008)	17
2.4	Several studies on bioleaching process of some metals	21
2.5	Precious metal biosorption by several sorbents (Mack *et al.*, 2007)	22
2.6	The summary of leaching in acidic solution studies	24
2.7	Advantages and disadvantages of leaching reagents for precious metals	25
2.8	Advantages and disadvantages of treatment technologies for the removal of heavy metals from wastewater.	31
2.9	Hydrometallurgical techniques for recovery of metals from electronic waste (Cui and Zhang, 2008)	32
2.10	Summary of cementation studies in hydrometallurgical techniques	33
2.11	The summarized of amine based extractants in solvent extraction process for precious metals recovery (Jha *et al.*, 2014)	36

2.12	Several sources of Palladium	41
2.13	Palladium Recovery Technologies	43
2.14	Surfactants classifications	47
2.15	A summary of some surfactant separation processes	50
3.1	Standard AAS condition for palladium concentration determination	63
4.1	The initial rates of different concentrations of Pd and CTAB	82
4.2	Metals composition of 5 different spent catalysts by XRF	91
4.3	Metal composition after leaching process	93
4.4	Recovery efficiency of various metals	95

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	The flow sheet of recovery of gold or silver by Merrill-Crowe process (Chi *et al*., 1997)	34
2.2	Schematic illustration of surfactant (Pytlakowska *et al*., 2013).	45
2.3	(a) The schematics of micelles formation from its monomers above its critical micellar concentration (cmc) and (b) Variety forms of surfactant aggregates (Paleologos *et al*., 2005).	46
2.4	Adsorbing colloid flotation (ACF) of heavy metal ions schematic diagram (Huang *et al*., 2000)	53
2.5	Micellar-enhanced ultrafiltration schematic diagram	54
3.1	The flowchart of overall experimental work	58
3.2	The Calibration Curve for CTAB	64
4.1	Effect of leaching agents on Pd recovery efficiency. Experimental conditions: [Pd] = 0.5 mM; [CTAB] = 1mM and temperature = 30^{o}C.	69
4.2	Pd graph as a function of free chloride concentration (Barakat *et al*., 2006)	70
4.3	Effect of HCl concentration on removal efficiency of Pd and CTAB. Experimental conditions: Leaching agent = HCl; [Pd] = 0.5 mM; [CTAB] = 1mM; and temperature = 30^{o}C.	71

4.4	The Pd recovery efficiency (A) and CTAB removal efficiency (B) as a function of CTAB and Pd concentrations. Experimental conditions: Leaching agent = HCl; [HCl] = 0.1 mM and temperature = 30^{o}C.	73
4.5	The Pd recovery efficiency and CTAB removal efficiency as a function of CTAB and Pd concentrations. Experimental conditions: Leaching agent = HCl; [HCl] = 0.1 mM and temperature = 30^{o}C.	75
4.6	The Pd recovery efficiency as a function of temperature and Pd concentrations. Experimental conditions: Leaching agent = HCl; [HCl] = 0.1 mM and [CTAB] = 5 mM.	78
4.7	The plot of mole Pd versus CTAB involved in the precipitation reaction process.	80
4.8	The recovery efficiency of (A) Pd and the removal efficiency of (B) CTAB as a function of time at various Pd and CTAB concentrations. Experimental conditions: Leaching agent = HCl; [HCl] = 0.1 M and temperature = 30^{o}C.	81
4.9	FTIR of (a) pure CTAB and (b) Pd-CTAB-Pd.	84
4.10	The wide scan XPS spectra of (a) pure CTAB and (b) CTAB-Pd	86
4.11	O_{1s} XPS core level spectra of the (a) pure CTAB and (b) CTAB-Pd	86
4.12	N_{1s} XPS core level spectra of the (a) pure CTAB and (b) CTAB-Pd	87
4.13	C_{1s} XPS core level spectra of the (a) pure CTAB and (b) CTAB-Pd	87
4.14	The Pd recovery efficiency as a function of Pd concentrations for precipitating agents. Experimental conditions: Leaching agent = HCl; [HCl] = 0.1 M and temperature = 30^{o}C.	87

4.15	Recovery efficiency of palladium (Pd) from three different leaching agents. Experimental conditions: [CTAB] = 1mM and temperature = 30^{o}C.	94

LIST OF ABBREVIATIONS

AAS	-	Atomic Absorption Spectrophotometer
ACF	-	Adsorbing Colloid Floatation
Ag	-	Silver
Au	-	Gold
BWN	-	Bleached waste newspaper
CMC	-	Critical micellar concentration
CPC	-	Cetyl pyridinium chloride
CPE	-	Cloud point extraction
CPT	-	Cloud point temperature
CTAB	-	Cetyltrimethylammonium bromide
ELM	-	Emulsion Liquid Membrane (ELM)
FTIR	-	Fourier Transform Infra-Red
HLLW	-	High Level Liquid Waste
MAC	-	Maximum allowed concentration
MEUF	-	Micellar-enhanced ultrafiltration
OTAB	-	Octadecyl trimethyl ammonium bromide
PCB	-	Printed circuit board
Pd	-	Palladium
PEG	-	Polyethylene glycol
PGMs	-	Platinum group metals
PM	-	Precious metal
Pt	-	Platinum
PWB	-	Printed wiring board
REEs	-	Rare earth elements
SDS	-	Sodium dodecylsulphate
TTAB	-	Tetradecyl trimethyl ammonium bromide

WEEE	-	Waste electric and electronic equipment
WN	-	Waste newspaper
WPCB	-	Waste printed circuit board
XPS	-	X-ray photoelectron spectrophotometer
XRF	-	X-ray fluorescence spectrophotometer

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Data Collection for Precipitation Process	117

CHAPTER 1

INTRODUCTION

1.1 Research Background

The peculiar physical and chemical properties of precious metals have attracted numerous industries. Fujiwara *et al.* (2007) stated that platinum group metals (PGMs) are greatly used in various fields. One example is as the catalyst in many chemical process, electrical and electronic devices, medicine and jewellery. Despite the continuous demand of these materials, the consumption of precious metals by the industry is growing and is expected to increase further in years to come. The scarcity of precious metals and their increasing demands have encouraged many studies to recover these precious metals for a sustainable development.

Due to the fact that these metals occurred in small amounts on earth, they must be effectively recovered from various wastes for recycle and reuse purposes (Bernardis *et al.*, 2005). From the economic point of view, the recovery process should be highly selective towards the precious metals as to separate the metal from base metals such as copper, iron, and zinc that often coexist with the precious metals in disproportionate amounts. The conventional and traditional processes used for separating and refining precious metals consist of a series of steps involving dissolution of aquaregia, conditioning, and then precipitation, of which are inefficient in terms of the degree of purification, yield, operational complexity, energy consumption, and labor costs.

Two sources for valuable metal recovery are from the primary sources (ore) and from secondary sources like electronic scraps and industrial wastes. Besides, precious metals can also be recovered from spent catalysts. In recent years, the amount of spent hydroprocessing catalysts produced throughout the world was in the range of 150,000–170,000 tons year^{-1} (Dufresne, 2007). A stable growth in the processing of heavier feedstock is estimated to increase the generation of spent catalysts in the coming years because of the instant growth in diesel hydrotreating capacity, such that is to meet the increasing demand for cleaner fuels with ultralow sulphur levels. For instance, it is projected that in Kuwait alone, the generation of spent catalysts will be more than double in the near future in which approximately, 75% of the all industrial chemical processes are based on catalysis (Dufresne, 2007). Supported metal catalysts are also widely used in many chemical processing industries. Thus, spent catalysts are a potential source of the contained critical metals.

Unfortunately, spent catalysts fall under the category of hazardous industrial waste and their disposal is a problem (Kumar *et al.*, 2013). The treatment of spent catalysts has gained importance recently owing to two reasons which are, the metal values present and the need for safe disposal to avoid environmental pollution. In addition, precious metals can easily transfer via root plants into biological material. It also gives harmful effects towards human health, of which may cause eye irritation, primary skin burning and restrain enzyme activity. Hence, precious metal recovery has become economically and environmentally very important (Awual *et al.*, 2014).

Being significantly crucial, this issue has triggered numerous scientific inquiries on the development of methods for pre-concentration of precious metals and their selective recovery. Lopes *et al.* (2012) stated that the main technologies that have been developed for precious metal recovery from its solutions include adsorption (Xiong *et al.*, 2009), ion exchange (Liang *et al.*, 2013), cementation, solvent extraction (Young *et al.*, 2010), electrodeposition(Giridhar *et al.*, 2006), membrane processes, precipitation (Pakarinen and Paatero, 2011), electrolytic recovery and reductive exchange. Of those, adsorption, precipitation and ion-exchange were claimed the most favourable technologies available for metal recovery.

Fujiwara *et al.* (2007) stated adsorption method is effective for pre-concentration and separation of gold from aqueous solutions. Instead, Matsubara *et al.* (2000) claimed, as the solution also comprise large quantities of other metals the adsorption of precious metals from acidic chloride solution is a challenging task in term of its selectivity. Along with that, adsorption or solvent extraction is constrained by elution or stripping for the recovery of precious metals from hydrochloric acid. Xiong *et al.* (2009) found that chemically modified persimmon waste as the adsorbent could improve the selectivity of precious metal recovery. Nonetheless, in order to extract tannin from feed materials, a high cost is needed. In addition, the persimmon waste gel has a slow kinetic of reduction and adsorption.

Precipitation by biphasic system approach that include micellar extraction with ultrafiltration, polyethylene glycol (PEG) biphasic aqueous system or surfactant liquid membrane system were found to be in advantage due to the non-flammable, inexpensive components and nontoxic process involved. Studies on the use of surfactants for precious metal recovery are rarely found. So far, researchers have studied the recovery of Cr (VI) using cationic surfactant (Jing *et al.*, 2011), and recovery of platinum group metal anions by cationic surfactant using micellar-enhanced ultrafiltration (MEUF) (Ghezzi *et al.*, 2008 and Gwicana *et al.*, 2006). In fact, the micellar-enhanced ultrafiltration (MEUF) method is quite simple, saves time and cost-effective.

1.2 Problem Statement

Precious metal is a widely consumed material not only in jewellery, health care and equipment, but also in many chemical process industries such as petroleum reforming, pharmaceutical and petrochemical. The great demand of the precious metals has brought problems with regards to the supply of raw materials, due to the highly valuable and limited source. Meanwhile, the growing amount of spent catalysts, along with the electrical and electronic industrial wastes that contained precious metals such as palladium is creating negative impacts upon human and the environment. Hence, recovery of precious metals from secondary sources is one of the ways that can be applied in order to manage the two main concerns regarding precious metals.

The awareness of researches about this problem has brought to the development of numerous methods in recovering precious metals from secondary sources. Previous studies have mentioned many hydrometallurgical methods to recover platinum and palladium in spent petroleum catalysts (Kumar *et al*., 2013). Other methods being studied for precious metal recovery are as claimed by previous researchers that adsorption, precipitation and ion-exchange are among the preferable methods (Lopes *et al*., 2012).

Generally, conventional ion exchangers are not sufficiently selective to remove certain metals from large accompanying metals. Meanwhile, solvent extraction is less effective in the recovery of very dilute solutions, and electrolytic process is not preferable for low metal concentration due to the low performances of the process. Recent developments in the studies of metal recovery have led to renewed interest in the use of surfactants. Micellar-enhanced ultrafiltration that was proposed by Ghezzi *et al*.(2008) have managed to remove 90% of palladium (II) ions from water with a cationic surfactant. The function of the surfactants was to attract metal ions prior to separation of the metal-surfactant association through ultrafiltration. Besides, an impregnation of surfactants on the surface of adsorbents enhanced the capacity to adsorb heavy metals (Taylor *et al*., 2011). In addition, Akita *et al.* (1997) has been using polyoxyethylene nonyl phenyl ether (PONPEs) as a non-ionic surfactant in the MEUF of gold(III) from a diluted hydrochloric acid solution. However, the ultrafiltration membrane could be damaged if a highly acidic solution is used. Another method involving precious metal separation using surfactant is the liquid surfactant membrane (LSM) technique (Kakoi *et al*., 1996). Thiourea was practically used as the stripping agent for palladium recovery. Though, the use of thiourea has been doubt by some because of its carcinogenic property.

Another method involving precipitation using surfactant was introduced by Talens-alesson and Porras-rodriguez (1999) which was known as adsorptive micellar flocculation. In this method, cations were bound onto micelle surface and forming flocs to be filtered. This method has been implemented for 2, 4-Dichlorophenoxyacetic acid removal and so far has not yet been applied for palladium recovery. Thus, this research has focused on recovering palladium from aqueous solution with surfactant mediated precipitation process. The surfactant, namely cetyltrimethylammonium bromide (CTAB) was used to precipitate palladium chloro-complex from the solution. The palladium (Pd) chloro-complex is an anionic form, whereas the CTAB is a positively charged surfactant. Generally, at the concentration above CMC value, the CTAB aggregated forming micelles that entrapped the Pd chloro-complexes (i.e. $PdCl_4^{2-}$). The aggregation eventually increased in size which later precipitated as a result of its decreasing solubility. Compared to the complexity of other surfactant separation techniques, this method was considered simple to implement. The recovery of Pd using CTAB is so far understudied and would potentially become a reliable source in the recovery of other precious metals from leaching solutions in the near future.

1.3 Objectives and Scopes of Research

The objectives and scopes of this research are as follows:

1) To study the palladium recovery performance from synthetic solution

In this study, the precious metal used was palladium. The recovery of palladium was carried out using synthetic solution at various experimental conditions. The effect of parameters such as CTAB concentrations, pH, leaching agents and palladium concentrations on recovery performance were investigated. The concentration of palladium was determined using Atomic Absorption Spectroscopy (AAS).

The experimental data were analysed in terms of equilibrium and kinetics of the precipitation process. The stoichiometry of the precipitation reaction was determined. In order to understand the mechanism of Pd recovery process, the analytical techniques such as the Fourier Transform Infrared (FTIR) Spectroscopy and X-ray Photoelectron Spectroscopy (XPS) were used.

2) To investigate palladium recovery performance from leaching solutions

In order to evaluate the palladium recovery performance from a few leaching solutions, the spent catalyst from a local industry was used. The spent catalyst was first characterized with XRF to determine its chemical composition. Various leaching solutions were studied and the metal concentration in the leaching solution was determined by Atomic Absorption Spectroscopy (AAS). The palladium recovery performance from leaching solutions was investigated at various experimental conditions.

1.4 Thesis Outline

This thesis was organized into 5 Chapters. Chapter 1 presents the general information regarding the research which includes introduction, problem background, objectives and scopes of the study, thesis outline and chapter summary. Chapter 2 discusses precious metals and their recovery. A special attention was focused on surfactants and its application for the separation process was reviewed. The research methodology was discussed in Chapter 3 that outlined the materials, experimental procedures for palladium recovery process, and the analytical techniques Chapter 4 exhibits the results and discussions, while Chapter 5 summarizes the conclusion and listed some future research recommendations.

1.5 Summary

The fundamental issue of this study was the recovery of palladium from synthetic solution at various experimental conditions followed by the investigation on palladium recovery from the leaching solution prepared from a spent catalyst. The scientific understanding provided from this research could lead towards the application of the same method for the recovery of various precious metals such as Pd, Ag, Pt and Au from other secondary sources like electrical appliances, photographic waste and automobile catalysts.

REFERENCES

Abbruzzese, C., Massidda, R., Vegli, F., and Ubaldini, S. (1995). Thiosulphate Leaching for Gold Hydrometallurgy. *Hydrometallurgy*, 39, 265–276.

Aberasturi, D. J. De, Pinedo, R., Larramendi, I. R. De, Larramendi, J. I. R. De, and Rojo, T. (2011). Recovery by Hydrometallurgical Extraction of The Platinum-Group Metals from Car Catalytic Converters. *Minerals Engineering*, 24(6), 505–513.

Aderhold, D., Williams, C. J., and Edyvean, R. G. (1996). The Removal of Heavy-Metal Ions by Seaweeds and Their Derivatives. *Bioresource Technology*, 58, 1–6.

Ahmad, A. L., and Puasa, S. W. (2007). Reactive Dyes Decolourization from An Aqueous Solution by Combined Coagulation/Micellar-Enhanced Ultrafiltration Process. *Chemical Engineering Journal*, 132(1-3), 257–265.

Ahmed, I. M., Nayl, A. A., and Daoud, J. A. (2011). Extraction of Palladium from Nitrate Solution by CYANEX 471X. *International Journal of Mineral Processing*, 101(1-4), 89–93.

Akita, S., Yang, L., and Takeuchi, H. (1997). Micellar-Enhanced Ultrafiltration of Gold (III) with Nonionic Surfactant. *Journal of Membrane Science*, 133, 189–194.

Akl, M., Am, Y., and Al-Awadhi, M. (2013). Adsorption of Acid Dyes onto Bentonite and Surfactant-Modified Bentonite. *Journal of Analytical & Bioanalytical Techniques*, 4, 174.

Awual, M. R., Khaleque, M. A., Ratna, Y., and Znad, H. (2015). Simultaneous Ultra-Trace Palladium(II) Detection and Recovery from Wastewater using New Class Meso-Adsorbent. *Journal of Industrial and Engineering Chemistry*, 21, 405–413.

Awual, M. R., Yaita, T., El-Safty, S. A., Shiwaku, H., Okamoto, Y., and Suzuki, S. (2013). Investigation of Palladium(II) Detection and Recovery using Ligand Modified Conjugate Adsorbent. *Chemical Engineering Journal*, 222, 172–179.

Baek, K., Kim, B. K., Cho, H. J., and Yang, J. W. (2003). Removal Characteristics of Anionic Metals by Micellar-Enhanced Ultrafiltration. *Journal of Hazardous Materials*, B99, 303–311.

Barakat, M. ., and Mahmoud, M. H. . (2004). Recovery of Platinum from Spent Catalyst. *Hydrometallurgy*, 72(3-4), 179–184.

Barakat, M. A., Mahmoud, M. H. H., and Mahrous, Y. S. (2006). Recovery and Separation of Palladium from Spent Catalyst. *Applied Catalysis A: General*, 301, 182–186.

Behnamfard, A., Salarirad, M. M., and Veglio, F. (2013). Process Development for Recovery of Copper and Precious Metals from Waste Printed Circuit Boards with Emphasize on Palladium and Gold Leaching and Precipitation. *Waste Management*, 33(11), 2354–2363.

Bernardis, F. L., Grant, R. A., and Sherrington, D. C. (2005). A Review of Methods of Separation of The Platinum-Group Metals through Their Chloro-Complexes. *Reactive and Functional Polymers*, 65, 205–217.

Can, M., Bulut, E., Örnek, A., and Özacar, M. (2013). Synthesis and Characterization of Valonea Tannin Resin and Its Interaction with Palladium (II), Rhodium (III) Chloro Complexes. Chemical Engineering Journal, 221, 146–158.

Chang, Q., and Chen, J. (1995). Separation and Purification of Two Enzymes from Bacillus Subtilis using Aliquat 336 Reversed Micelles : Study of The Effect of Cosolvent Concentration. *The Chemical Engineering Journal*, 59, 303–308.

Chassary, P., Vincent, T., Sanchez Marcano, J., Macaskie, L. E., and Guibal, E. (2005). Palladium and Platinum Recovery from Bicomponent Mixtures using Chitosan Derivatives. *Hydrometallurgy*, 76(1-2), 131–147.

Chi, G., Fuerstenau, M. C., and Marsden, J. O. (1997). Study of Merrill-Crowe Processing . Part I : Solubility of Zinc in Alkaline Cyanide Solution. *International Journal of Mineral Processing*, 49, 171–183.

Cibati, A., Cheng, K. Y., Morris, C., Ginige, M. P., Sahinkaya, E., Pagnanelli, F., and Kaksonen, A. H. (2013). Selective Precipitation of Metals from Synthetic

Spent Refinery Catalyst Leach Liquor with Biogenic H_2S Produced in A Lactate-Fed Anaerobic Baffled Reactor. *Hydrometallurgy*, 139, 154–161.

Cieszynska, A., and Wisniewski, M. (2011). Selective Extraction of Palladium (II) from Hydrochloric Acid Solutions with Phosphonium Extractants. *Separation and Purification Technology*, 80(2), 385–389.

Coman, V., Robotin, B., and Ilea, P. (2013). Nickel Recovery / Removal from Industrial Wastes : A Review. *Resources, Conservation & Recycling*, *73*, 229–238.

Cowley, A., and Steel, M. (2007). *Platinum Today*. London: Johnson Matthey.

Crini, G. (2005). Recent Developments in Polysaccharide-Based Materials used As Adsorbents in Wastewater Treatment. *Progress in Polymer Science*, 30(1), 38–70.

Cserháti, T., Forgács, E., and Oros, G. (2002). Biological Activity and Environmental Impact of Anionic Surfactants. *Environment International*, 28, 337–348.

Cui, J., and Zhang, L. (2008). Metallurgical Recovery of Metals from Electronic Waste : A Review. *Journal of Hazardous Materials*, 158, 228–256.

Dakshinamoorthy, a., Dhami, P. S., Naik, P. W., Dudwadkar, N. L., Munshi, S. K., Dey, P. K., and Venugopal, V. (2008). Separation of Palladium from High Level Liquid Waste of PUREX Origin by Solvent Extraction and Precipitation Methods using Oximes. *Desalination*, 232(1-3), 26–36.

Danis, U., and Aydiner, C. (2009). Investigation of Process Performance and Fouling Mechanisms in Micellar-Enhanced Ultrafiltration of Nickel-Contaminated Waters. *Journal of Hazardous Materials*, 162(2-3), 577–587.

Das, a., Ruhela, R., Singh, a. K., and Hubli, R. C. (2014). Evaluation of Novel Ligand Dithiodiglycolamide (DTDGA) for Separation and Recovery of Palladium from Simulated Spent Catalyst Dissolver Solution. *Separation and Purification Technology*, 125, 151–155.

De Sá Pinheiro, A. A., de Lima, T. S., Campos, P. C., and Afonso, J. C. (2004). Recovery of Platinum from Spent Catalysts in A Fluoride-Containing Medium. *Hydrometallurgy*, 74(1-2), 77–84.

Doke, S. M., and Yadav, G. D. (2014). Process Efficacy and Novelty of Titania Membrane Prepared by Polymeric Sol – Gel Method in Removal of Chromium

(VI) by Surfactant Enhanced Microfiltration. *Chemical Engineering Journal*, 255, 483–491.

Dorin, R., and Woods, R. (1991). Determination of Leaching Rates of Precious Metals by Electrochemical Techniques. *Journal of Applied Electrochemistry*, 21, 419–424.

Dufresne, P. (2007). Hydroprocessing Catalysts Regeneration And Recycling. *Applied Catalysis A: General*, 322, 67–75.

El-hefny, N. E., and Daoud, J. A. (2013). Solvent Extraction of Palladium (II) from Aqueous Chloride Medium by Triphenylphosphine , Triphenylphosphine Oxide or Triphenylphosphine Sulphide in Benzene. *Journal of Physical Science*, 24(2), 35–47.

Fang Li , Gan-Zuo Li , Han-Qing Wang, Q.-J. X. (1997). Studies on Cetyltrimethylammonium Bromide (CTAB) Micellar Solution and CTAB Reversed Microemulsion by ESR and HNMR. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 127, 89–96.

Feng, D., and Van Deventer, J. S. J. (2006). Ammoniacal Thiosulphate Leaching of Gold in The Presence of Pyrite. *Hydrometallurgy*, 82(3-4), 126–132.

Ferella, F., Prisciandaro, M., Michelis, I. De, and Veglio, F. (2007). Removal of Heavy Metals by Surfactant-Enhanced Ultrafiltration from Wastewaters. *Desalination*, 207, 125–133.

Flandinet, L., Tedjar, F., Ghetta, V., and Fouletier, J. (2012). Metals Recovering from Waste Printed Circuit Boards (WPCBs) using Molten Salts. *Journal of Hazardous Materials*, 213-214, 485–490.

García, M. T., Campos, E., & Ribosa, I. (2007). Biodegradability and Ecotoxicity of Amine Oxide based Surfactants. *Chemosphere*, 69, 1574–1578.

Ghezzi, L., Robinson, B. H., Secco, F., Tiné, M. R., and Venturini, M. (2008). Removal and Recovery of Palladium(II) Ions from Water using Micellar-Enhanced Ultrafiltration with A Cationic Surfactant. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 329(1-2), 12–17.

Giridhar, P., Venkatesan, K. a., Srinivasan, T. G., and Vasudeva Rao, P. R. (2006). Extraction of Fission Palladium by Aliquat 336 and Electrochemical Studies on Direct Recovery from Ionic Liquid Phase. *Hydrometallurgy*, 81(1), 30–39.

Gönen, N., Körpe, E., Yıldırım, M. E., & Selengil, U. (2007). Leaching and CIL Processes in Gold Recovery from Refractory Ore with Thiourea Solutions. *Minerals Engineering*, 20(6), 559–565.

Grosse, A. C., Dicinoski, G. W., Shaw, M. J., and Haddad, P. R. (2003). Leaching and Recovery of Gold using Ammoniacal Thiosulfate Leach Liquors (A Review). *Hydrometallurgy*, 69(1-3), 1–21.

Gupta, B., and Singh, I. (2013). Extraction and Separation of Platinum, Palladium and Rhodium using Cyanex 923 and Their Recovery from Real Samples. *Hydrometallurgy*, 134-135, 11–18.

Gupta, V. K. (2009). Application of Low-Cost Adsorbents for Dye Removal – A Review. *Journal of Environmental Management*, 90(8), 2313–2342.

Gurung, M., Babu, B., Kawakita, H., Ohto, K., and Inoue, K. (2013). Recovery of Gold and Silver from Spent Mobile Phones by means of Acidothiourea Leaching followed by Adsorption using Biosorbent Prepared from Persimmon Tannin. *Hydrometallurgy*, 133, 84–93.

Gwicana, S., Vorster, N., and Jacobs, E. (2006). The Use of A Cationic Surfactant for Micellar-Enhanced Ultrafiltration of Platinum Group Metal Anions. *Desalination*, 199(1-3), 504–506.

Holt, M. S., Waters, J., Comber, M. H. I., Armitage, R., Morris, G., and Newbery, C. (1995). AIS/CESIO Environmental Surfactant Monitoring Programme. SDIA Sewage Treatment Pilot Study on Linear Alkylbenzene Sulphonate (LAS). *Water Research*, 29(9), 2063–2070.

Huang, J., Huang, D., Liu, Y., Chen, H., Jing, X., Sun, D., and Li, Q. (2015). Rapid Au Recovery from Aqueous Solution by A Microorganism-Mediated , Surfactant-Directed Approach : Effect of Surfactants and SERS of bio-Au. *Chemical Engineering Journal*, *267*, 43–50.

Huang, S., Su, P., Ho, Y., and Tsai, T. (2000). Adsorbing Colloid Flotation with Polyaluminum Chloride : A Powerful Technique for Removing Heavy Metals from Wastewater Adsorbing Colloid Flotation with Polyaluminum Chloride : A Powerful Technique for Removing Heavy Metal. *Separation Science and Technology*, 35(8), 1223–1232.

Hua-sheng, Z., Zhu-qiang, C., and Gang, L. (2007). A Novel Recovery Technology of Trace Precious Metals from Waste Water by Combining Agglomeration and Adsorption. *Transactions of Nonferrous Metals Society of China*, 17, 858–863.

Hubert, F., Testard, F., and Spalla, O. (2008). Cetyltrimethylammonium Bromide Silver Bromide Complex As The Capping Agent of Gold Nanorods. *Langmuir : The ACS Journal of Surfaces and Colloids*, 24(17), 9219–9222.

Hubicki, Z., and Hubicka, H. (1996). Studies on The Separation of Silver(I) Microquantities from Macroquantities of Salts of Other Elements on selective Ion-Exchangers. *Hydrometallurgy*, 41(2-3), 287–302.

Hubicki, Z., Wolowicz, A., and Leszczynska, M. (2008). Studies of Removal of Palladium (II) Ions from Chloride Solutions on Weakly and Strongly Basic Anion Exchangers. *Journal of Hazardous Materials*, 159, 280–286.

Jainae, K., Sanuwong, K., Nuangjamnong, J., Sukpirom, N., and Unob, F. (2010). Extraction and Recovery of Precious Metal Ions in Wastewater by Polystyrene-Coated Magnetic Particles Functionalized with 2-(3-(2-aminoethylthio) propylthio)ethanamine. *Chemical Engineering Journal*, 160(2), 586–593.

Janos, P., and Smídová, V. (2005). Effects of Surfactants on The Adsorptive Removal of Basic Dyes from Water using an Organomineral Sorbent-Iron Humate. *Journal of Colloid and Interface Science*, 291(1), 19–27.

Jaree, A., and Khunphakdee, N. (2011). Separation of Concentrated Platinum (IV) and Rhodium (III) in Acidic Chloride Solution via Liquid – Liquid Extraction using Tri-Octylamine. *Journal of Industrial and Engineering Chemistry*, 17(2), 243–247.

Jayakumar, M., Venkatesan, K. A., Sudha, R., Srinivasan, T. G., and Vasudeva Rao, P. R. (2011). Electrodeposition of Ruthenium, Rhodium and Palladium from Nitric Acid and Ionic Liquid Media: Recovery and Surface Morphology of The Deposits. *Materials Chemistry and Physics*, 128(1-2), 141–150.

Jha, M. K., Gupta, D., Lee, J., Kumar, V., and Jeong, J. (2014). Solvent Extraction of Platinum using Amine Based Extractants in Different Solutions: A Review. *Hydrometallurgy*, 142, 60–69.

Jing-ying, L., Xiu-li, X., and Wen-quan, L. (2012). Thiourea Leaching Gold and Silver from The Printed Circuit Boards of Waste Mobile Phones. *Waste Management*, 32(6), 1209–1212.

Jing, X., Cao, Y., Zhang, X., Wang, D., Wu, X., and Xu, H. (2011). Biosorption of Cr(IV) from Simulated Wastewater using a Cationic Surfactant Modified Spent Mushroom. *Desalination*, 269, 120-127.

Kakoi, T., Goto, M., and Nakashio, F. (1996). Separation of Platinum and Palladium by Liquid Surfactant Membranes Utilizing A Novel Bi-Functional Surfactant. *Journal of Membrane Science*, 120, 77–88.

Kakoi, T., Horinouchi, N., Goto, M., and Nakashio, F. (1996). Selective Recovery of Palladium from A Simulated Industrial Waste Water by Liquid Surfactant Membrane Process. *Journal of Membrane Science*, 118(1), 63–71.

Kang, K. H., Kim, H. U., and Lim, K. H. (2001). Effect of Temperature on Critical Micelle Concentration and Thermodynamic Potentials of Micellization of Anionic Ammonium Dodecyl Sulfate and Cationic Octadecyl Trimethyl Ammonium Chloride. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 189, 113–121.

Kawakita, H. (2012). Metal Recovery Using Polyphenols Prepared by Enzymatic Reactions of Horseradish Peroxidase. *Science and Technology*, 2(1), 25–29.

Kim, D. J., Mishra, D., Park, K. H., Ahn, J. G., and Ralph, D. E. (2008). Metal Leaching from Spent Petroleum Catalyst by Acidophilic Bacteria in Presence of Pyrite. *Materials Transactions*, 49(10), 2383–2388.

Kim, M., Kim, E., Jeong, J., Lee, J., and Kim, W. (2010). Recovery of Platinum and Palladium from the Spent Petroleum Catalysts by Substrate Dissolution in Sulfuric Acid. *Materials Transactions*, 51(10), 1927–1933.

Kinoshita, T., Akita, S., Ozawa, S., Nii, S., Kawaizumi, F., and Takahashi, K. (2003). A Study on Gold (III) Recovery Via Foam Separation with Nonionic Surfactant in Batch Mode. *Journal of Minerals & Materials Characterization & Engineering*, 2(2), 71–82.

Kumar, M., Lee, J., Kim, M., Jeong, J., Kim, B., and Kumar, V. (2013). Hydrometallurgical Recovery / Recycling of Platinum by The Leaching of Spent Catalysts : A Review. *Hydrometallurgy*, 133, 23–32.

Lawley, A. (2010). Precious Metals. *International Journal of Powder Metallurgy*, 45(5), 122–124.

Lee, J., Yang, J.-S., Kim, H.-J., Baek, K., and Yang, J.-W. (2005). Simultaneous Removal of Organic and Inorganic Contaminants by Micellar Enhanced Ultrafiltration with Mixed Surfactant. *Desalination*, 184(1-3), 395–407.

Li, X., Zeng, G., Huang, J., Zhang, C., Fang, Y., and Qu, Y. (2009). Recovery and Reuse of Surfactant SDS from a MEUF Retentate containing Cd^{2+} or Zn^{2+} by Ultrafiltration. *Journal of Membrane Science*, 337, 92–97.

Liang, F., Song, Y., Huang, C., Li, Y., and Chen, B. (2013). Synthesis of Novel Lignin-Based Ion-Exchange Resin and Its Utilization in Heavy Metals Removal. *Industrial & Engineering Chemistry Research*, 52, 1267–1274.

Liu, C.-K., Li, C.-W., & Lin, C.-Y. (2004). Micellar-Enhanced Ultrafiltration Process (MEUF) for Removing Copper from Synthetic Wastewater Containing Ligands. *Chemosphere*, 57(7), 629–634.

Liu, X. H., Luo, X. H., Lu, S. X., Zhang, J. C., and Cao, W. L. (2007). A Novel Cetyltrimethyl Ammonium Silver Bromide Complex and Silver Bromide Nanoparticles Obtained by The Surfactant Counterion. *Journal of Colloid and Interface Science*, 307, 94–100.

Liu, Y., Huang, Z., Chen, M., and Chen, L. (2014). Solvent Extraction of Palladium (II) with 2-Hexyl-5-Methyl Benziminazole Sulfide. *Journal of Chemical and Pharmaceutical Research*, 6(6), 2634–2640.

Liu, Y., Tourbin, M., Lachaize, S., and Guiraud, P. (2013). Silica Nanoparticles Separation from Water: Aggregation by Cetyltrimethylammonium Bromide (CTAB). *Chemosphere*, 92(6), 681–687.

Lopes, C. B., Lito, P. F., Cardoso, S. P., Pereira, E., Duarte, A. C., and Silva, C. M. (2012). *Metal Recovery , Separation and / or Pre-concentration*. *Ion Exchange Technology II:Applications* (pp. 237–322).

Luo, F., Zeng, G.-M., Huang, J.-H., Zhang, C., Fang, Y.-Y., Qu, Y.-H., and Zhou, C.-F. (2010). Effect of Groups Difference in Surfactant on Solubilization of Aqueous Phenol using MEUF. *Journal of Hazardous Materials*, 173(1-3), 455–61.

Ma, X., Lee, N.-H., Oh, H.-J., Kim, J.-W., Rhee, C.-K., Park, K.-S., and Kim, S.-J. (2010). Surface Modification and Characterization of Highly Dispersed Silica Nanoparticles by A Cationic Surfactant. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 358(1-3), 172–176.

Mack, C., Wilhelmi, B., Duncan, J. R., and Burgess, J. E. (2007). Biosorption of precious metals. *Biotechnology Advances*, 25(3), 264–71.

Mahmoud, M. H. H. (2003). Leaching Platinum-Group Metals in a Sulfuric Acid / Chloride Solution. *Journal of The Minerals,Metals and Materials Society*, 55(4), 37–40.

Marafi, M., and Stanislaus, A. (2003). Options and Processes for Spent Catalyst Handling and Utilization. *Journal of Hazardous Materials*, 101(2), 123–132.

Marafi, M., and Stanislaus, A. (2008). Spent Hydroprocessing Catalyst Management: A Review. *Resources, Conservation and Recycling*, 53(1-2), 1–26.

Marinho, R. S., Afonso, J. C., and da Cunha, J. W. S. D. (2010). Recovery of Platinum from Spent Catalysts by Liquid-Liquid Extraction in Chloride Medium. *Journal of Hazardous Materials*, 179(1-3), 488–494.

Matjie, R. H., Scurrell, M. S., and Bunt, J. (2005). The Selective Dissolution of Alumina, Cobalt and Platinum from A Calcined Spent Catalyst using Different Lixiviants. *Minerals Engineering*, 18(8), 801–810.

Meeravali, N. N., and Jiang, S.-J. (2009). A Novel Cloud Point Extraction Approach using Cationic Surfactant for The Separation and Pre-Concentration of Chromium Species in Natural Water Prior to ICP-DRC-MS Determination. *Talanta*, 80, 173–178.

Mehta, S. K., Bhasin, K. K., Chauhan, R., and Dham, S. (2005). Effect of Temperature on Critical Micelle Concentration and Thermodynamic Behavior of Dodecyldimethylethylammonium Bromide and Dodecyltrimethylammonium Chloride in Aqueous Media. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 255, 153–157.

Melo, R. P. F., Barros Neto, E. L., Moura, M. C. P. a., Castro Dantas, T. N., Dantas Neto, A. A., and Oliveira, H. N. M. (2014). Removal of Reactive Blue 19 using Nonionic Surfactant in Cloud Point Extraction. *Separation and Purification Technology*, 138, 71–76.

Moghaddam, S. S., Moghaddam, M. R. A., and Arami, M. (2010). Coagulation / Flocculation Process for Dye Removal using Sludge from Water Treatment Plant : Optimization through Response Surface Methodology. *Journal of Hazardous Materials*, 175, 651–657.

Morf, L. S., Gloor, R., Haag, O., Haupt, M., Skutan, S., Di, F., and Böni, D. (2013). Precious Metals and Rare Earth Elements in Municipal Solid Waste – Sources and Fate in A Swiss Incineration Plant. *Waste Management*, 33(3), 634–644.

Nikoloski, A. N., and Ang, K.-L. (2014). Review of the Application of Ion Exchange Resins for the Recovery of Platinum-Group Metals From Hydrochloric Acid Solutions. *Mineral Processing and Extractive Metallurgy Review: An International Journal*, 35, 369–389.

Ojeda, M. W., Perino, E., and Ruiz, M. D. C. (2009). Gold Extraction by Chlorination using A Pyrometallurgical Process. *Minerals Engineering*, 22(4), 409–411.

Pakarinen, J., and Paatero, E. (2011). Recovery of Manganese from Iron Containing Sulfate Solutions by Precipitation. *Minerals Engineering*, 24(13), 1421–1429.

Paleologos, E. K., Giokas, D. L., and Karayannis, M. I. (2005). Micelle-Mediated Separation and Cloud-Point Extraction. *Trends in Analytical Chemistry*, 24(5), 426–436.

Pan, L., Bao, X., and Gu, G. (2013). Solvent Extraction of Palladium (II) and Effective Separation of Palladium (II) and Platinum (IV) with Synthetic Sulfoxide MSO. *Journal of Mining and Metallurgy, Section B:Metallurgy*, 49(1), 57–63.

Parajuli, D., and Hirota, K. (2009). Recovery of Palladium using Chemically Modified Cedar Wood Powder. *Journal of Colloid and Interface Science*, 338(2), 371–375.

Parajuli, D., Kawakita, H., Inoue, K., and Funaoka, M. (2006). Recovery of Gold (III), Palladium (II), and Platinum (IV) by Aminated Lignin Derivatives. *Industrial & Engineering Chemistry Research*, 45(19), 6405–6412.

Park, S., Seob, I., Wook, S., and Yun, Y. (2013). Glutaraldehyde-Crosslinked Chitosan Beads for Sorptive Separation of Au (III) and Pd (II): Opening A Way to Design Reduction-Coupled Selectivity-Tunable Sorbents For Separation of Precious Metals. *Journal of Hazardous Materials*, 248-249, 211–218.

Patrushev, V. (1998). Reduction of Platinum Group Metals in Phosphoric Acid Solutions by Formalin. *Hydrometallurgy*, 50(1), 89–101.

Peng, C.-Y., and Tsai, T.-H. (2012). Recovery of Palladium(II) from Acidic Chloride Solution using Kerosene Containing Tri-N-Octyl/Decyl Amine (Alamine 336). *Desalination and Water Treatment*, 47(1-3), 105–111.

Pierre, J. A., Demopoulos, G. P., and Pouskouleli, G. (1987). Direct Recovery of Precious Metals by Solvent Extraction and Selective Removal. *United States Patent*.

Pradhan, D., Kumar, A., Kim, D., Chung, H., and Lee, S. (2013). A Novel Sequential Process of Bioleaching and Chemical Leaching for Dissolving Ni , V , and Mo from Spent Petroleum Refinery Catalyst. *Hydrometallurgy*, 131-132, 114–119.

Praipruke, S., Kriausakul, K., and Tantayanon, S. (2012). Extraction of Palladium from Acidic Chloride Media into Emulsion Liquid Membranes using LIX 984N-C ®. *International Journal of Nonferrous Metallurgy*, 1, 13–22.

Purkait, M. ., Vijay, S. ., DasGupta, S., and De, S. (2004). Separation of Congo Red by Surfactant Mediated Cloud Point Extraction. *Dyes and Pigments*, 63(2), 151–159.

Purkait, M. K., and Dasgupta, S. (2005). Separation of Aromatic Alcohols using Micellar-Enhanced Ultrafiltration and Recovery of Surfactant. *Journal of Membrane Science*, 250, 47–59.

Pytlakowska, K., Kozik, V., and Dabioch, M. (2013). Complex-forming Organic Ligands in Cloud-Point Extraction of Metal Ions: A Review. *Talanta*, 110, 202–28.

Qin, J.-J., Wai, M.-N., Oo, M.-H., and Wong, F.-S. (2002). A Feasibility Study on The Treatment and Recycling of A Wastewater from Metal Plating. *Journal of Membrane Science*, 208(1-2), 213–221.

Rafatullah, M., Sulaiman, O., Hashim, R., and Amini, M. H. M. (2011). Adsorption of Copper (II) Ions onto Surfactant-Modified Oil Palm Leaf Powder. *Journal of Dispersion Science and Technology*, 32, 1641–1648.

Raju, B., Kumar, J. R., Lee, J., Kwonc, H., Kantam, M. L., and Reddy, B. R. (2012). Separation of Platinum and Rhodium from Chloride Solutions Containing Aluminum , Magnesium and Iron using Solvent Extraction and Precipitation Methods. *Journal of Hazardous Materials*, 227-228, 142–147.

Reddy, B. R., Raju, B., Lee, J. Y., and Park, H. K. (2010). Process for The Separation and Recovery of Palladium and Platinum from Spent Automobile Catalyst Leach Liquor using LIX 84I and Alamine 336. *Journal of Hazardous Materials*, 180(1-3), 253–258.

Regel-rosocka, M., Wisniewski, M., Borowiak-resterna, A., Cieszynska, A., and Sastre, A. M. (2007). Selective Extraction of Palladium (II) from Hydrochloric Acid Solutions with Pyridinecarboxamides and ACORGA ® CLX50. *Separation and Purification Technology*, 53, 337–341.

Rumpold, R., and Antrekowitsch, J. (2012). Recycling of Platinum Group Metals from Automotive Catalysts by An Acidic Leaching Process. *The Southern Institute of Mining and Metallurgy*, 695–714.

Samper, E., Rodríguez, M., De la Rubia, M. a., and Prats, D. (2009). Removal of Metal Ions at Low Concentration by Micellar-Enhanced Ultrafiltration (MEUF) using Sodium Dodecyl Sulfate (SDS) and Linear Alkylbenzene Sulfonate (LAS). *Separation and Purification Technology*, 65(3), 337–342.

Schramm, L. L., Stasiuk, E. N., and Marangoni, D. G. (2003). Surfactants and Their Applications. *Annual Reports Program Chemistry*, 99, 3–48.

Senanayake, G. (2005). Kinetics and Reaction Mechanism of Gold Cyanidation: Surface Reaction Model Via Au(I)–OH–CN Complexes. *Hydrometallurgy*, 80(1-2), 1–12.

Senanayake, G. (2005). The Role of Ligands and Oxidants in Thiosulfate Leaching of Gold. *Gold Bulletin*, 38(4), 170–179.

Shafiqul Alam, M., and Inoue, K. (1997). Extraction of Rhodium from Other Platinum Group Metals with Kelex 100 from Chloride Media Containing Tin. *Hydrometallurgy*, 46(3), 373–382.

Shen, S., Pan, T., Liu, X., Yuan, L., Zhang, Y., Wang, J., and Guo, Z. (2010). Adsorption of Pd(II) Complexes from Chloride Solutions obtained by Leaching Chlorinated Spent Automotive Catalysts on Ion Exchange Resin Diaion WA21J. *Journal of Colloid and Interface Science*, 345(1), 12–18.

Sopena, L. A. S., Ruiz, M., Pestov, A. V, Sastre, A. M., Yatluk, Y., and Guibal, E. (2011). N - (2- (2-Pyridyl) ethyl) Chitosan (PEC) for Pd (II) and Pt (IV) Sorption from HCl solutions. *Cellulose*, 18, 309–325.

Stalikas, C. D. (2002). Micelle-Mediated Extraction as a Tool for Separation and Preconcentration in Metal Analysis. *Trends in Analytical Chemistry*, 21(5), 343–355.

Sun, C., Xie, Y., Tian, Q., and Liu, H. (2007). Separation of Glycyrrhizic Acid and Liquiritin from Licorice Root by Aqueous Nonionic Surfactant Mediated Extraction. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 305, 42–47.

Suzuki, Y., and Maruyama, T. (2005). Removal of Emulsified Oil from Water by Coagulation and Foam Separation. *Separation Science and Technology*, 40(16), 3407–3418.

Swain, B., Jeong, J., Kim, S., and Lee, J. (2010). Separation of Platinum and Palladium from Chloride Solution by Solvent Extraction using Alamine 300. *Hydrometallurgy*, 104(1), 1–7.

Syed, S. (2012). Recovery of Gold from Secondary Sources — A Review. *Hydrometallurgy*, 115-116, 30–51.

Taffarel, S. R., and Rubio, J. (2010). Adsorption of Sodium Dodecyl Benzene Sulfonate from Aqueous Solution using A Modified Natural Zeolite with CTAB. *Minerals Engineering*, 23(10), 771–779.

Talens-alesson, F. I. (1999). Removal of 2 , 4-Dichlorophenoxyacetic Acid from Water by Adsorptive Micellar Flocculation. *Environmental Science and Technology*, 33(18), 3206–3209.

Thorsteinsson, T., Másson, M., Kristinsson, K. G., Hjálmarsdóttir, M. A., Hilmarsson, H., and Loftsson, T. (2003). Soft Antimicrobial Agents: Synthesis and Activity of Labile Environmentally Friendly Long Chain Quaternary Ammonium Compounds. *Journal of Medicinal Chemistry*, 46, 4173–4181.

Tuncuk, A., Stazi, V., Akcil, A., Yazici, E. Y., and Deveci, H. (2012). Aqueous Metal Recovery Techniques from e-scrap: Hydrometallurgy in Recycling. *Minerals Engineering*, 25(1), 28–37.

Villa-Gomez, D. K., Papirio, S., van Hullebusch, E. D., Farges, F., Nikitenko, S., Kramer, H., and Lens, P. N. L. (2012). Influence of Sulfide Concentration and Macronutrients on The Characteristics of Metal Precipitates Relevant to Metal Recovery in Bioreactors. *Bioresource Technology*, 110, 26–34.

Vyas, A. H., Jauhari, S., and Murthy, Z. V. P. (2013). Chemically Modified Rice Husk Adsorbents , Characterization and Removal of Palladium (II) From Aqueous Solutions. *Journal of Dispersion Science and Technology*, 34, 369–380.

Wang, S., Li, Y., Bai, J., Yang, Q., Song, Y., and Zhang, C. (2009). Characterization and Photoluminescence Studies of Cdte Nanoparticles Before and After Transfer from Liquid Phase to Polystyrene. *Bulletin of Materials Science*, 32(5), 487–491.

Won, S. W., Kotte, P., Wei, W., Lim, A., and Yun, Y. S. (2014). Biosorbents for Recovery of Precious Metals. *Bioresource Technology*, 160, 203–212.

Wook, S., and Yun, Y. (2013). Recovery of Metallic Palladium from Hydrochloric Acid Solutions by A Combined Method of Adsorption and Incineration. *Chemical Engineering Journal*, 218, 303–308.

Xiao, Z., and Laplante, R. (2004). Characterizing and Recovering The Platinum Group Minerals—A Review. *Minerals Engineering*, *17*(9-10), 961–979.

Xiong, Y., Adhikari, C. R., Kawakita, H., Ohto, K., Inoue, K., and Harada, H. (2009). Selective Recovery of Precious Metals by Persimmon Waste Chemically Modified with Dimethylamine. *Bioresource Technology*, 100(18), 4083–4089.

Yakout, S. M., and Nayl, A. A. (2009). Removal of Cationic Surfactant (CTAB) from Aqueous Solution on to Activated Carbon obtained from Corncob. *Carbon-Science Technology*, 2, 107–116.

Yi-Jun, Y., Guan-Yong, S., Lam, M. H. W., Lam, P. K. S., and Hong-Xia, Y. (2009). Cloud Point Extraction of Bisphenol A from Water Utilizing Cationic Surfactant Aliquat 336. *Chinese Journal of Analytical Chemistry*, 37(12), 1717–1721.

Yin, P., Wang, Z., Qu, R., Liu, X., Zhang, J., and Xu, Q. (2012). Biosorption of Heavy Metal Ions onto Agricultural Residues. *Journal of Agricultural and Food Chemistry*, 60, 11664–11674.

Yin, P., Xu, M., Qu, R., Chen, H., Liu, X., Zhang, J., and Xu, Q. (2013). Uptake of Gold (III) from Waste Gold Solution onto Biomass-Based Adsorbents Organophosphonic Acid Functionalized Spent Buckwheat Hulls. *Bioresource Technology*, 128, 36–43.

Yong, P., Rowson, N. a., Farr, J. P. G., Harris, I. R., and Macaskie, L. E. (2002). Bioreduction and Biocrystallization of Palladium by Desulfovibrio Desulfuricans NCIMB 8307. *Biotechnology and Bioengineering*, 80, 369–379.

Young, J., Raju, B., Kumar, B. N., Kumar, J. R., Kyu, H., and Reddy, B. R. (2010). Solvent Extraction Separation and Recovery of Palladium and Platinum from Chloride Leach Liquors of Spent Automobile Catalyst. *Separation and Purification Technology*, 73(2), 213–218.

Zanjani, A., and Baghalha, M. (2009). Factors Affecting Platinum Extraction from Used Reforming Catalysts in Iodine Solutions at Temperatures Up to 95 °C. *Hydrometallurgy*, 97(1-2), 119–125.

Zeng, G. M., Xu, K., Huang, J. H., Li, X., Fang, Y. Y., and Qu, Y. H. (2008). Micellar Enhanced Ultrafiltration of Phenol in Synthetic Wastewater using Polysulfone Spiral Membrane. *Journal of Membrane Science*, 310, 149–160.

Zeng, L., and Cheng, C. Y. (2009). A Literature Review of The Recovery of Molybdenum and Vanadium from Spent Hydrodesulphurisation Catalysts. *Hydrometallurgy*, 98(1-2), 1–9.

Zhang, S., and Nicol, M. J. (2003). An Electrochemical Study of The Dissolution of Gold in Thiosulfate Solutions Part I : Alkaline Solutions. *Journal of Applied Electrochemistry*, 33, 767–775.

Zhang, Y., Liu, S., Xie, H., Zeng, X., and Li, J. (2012). Current Status on Leaching Precious Metals from Waste Printed Circuit Boards. *Procedia Environmental Sciences*, 16, 560–568.

Zhao, J. I. N., Wu, Z., and Chen, J. C. (1999). Separation of Gold from Other Metals in Thiosulfate Solutions by Solvent Extraction. *Separation Science and Technology*, 34(10), 2061–2068.

Zdziennicka, A., Szymczyk, K., Krawczyk, J., and Jańczuk, B. (2012). Critical Micelle Concentration of Some Surfactants and Thermodynamic Parameters of Their Micellization. *Fluid Phase Equilibria*, 322-323, 126–134.