



## Palladium solvent extraction process using a tertiary amine and isodecanol

### Proceso de extracción por solventes para paladio utilizando una amina terciaria e isodecanol

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#### Abstract

The recovery of platinum-group metals from secondary resources has attracted much attention due to their high demand and low concentration in the Earth's crust. Metals can be recycled through hydrometallurgical processes that consist of leaching followed by an aqueous concentration and purification process, such as solvent extraction. This study investigated the separation of palladium via solvent extraction using chlorinated leaching solutions from waste electronic cards. To determine the best conditions for palladium extraction, a tertiary amine extractant was used, varying its concentration in the organic phase (8, 10, and 12% v/v) and isodecanol modifier at 10% v/v. In the aqueous phase, the pH (0.1, 0.5, 1, 1.5, and 2) and phase ratio were varied (0.8/1, 1/1, and 1.2/1), obtaining greater than 95% palladium extraction at pH=1.5 and an aqueous/organic ratio of 1.2/1, followed by 72% gold, 43% silver, and 30% platinum.

**Keywords:** Palladium, Solvent Extraction, Tertiary Amine, Isodecanol, Chloride Ions.

#### Resumen

La recuperación de los metales del grupo del platino a partir de recursos secundarios ha atraído mucha atención debido a su alta demanda y la baja concentración que se encuentran en la corteza terrestre. Los metales pueden ser reciclados mediante procesos hidrometalúrgicos que consisten en una lixiviación seguida de un proceso de concentración y purificación acuosa como la extracción por solventes. En este estudio se investigó la separación de paladio mediante el proceso de extracción por solventes utilizando soluciones cloruradas de lixiviación de tarjetas electrónicas de desecho. Para determinar las mejores condiciones de extracción de paladio se utilizó un extractante de amina terciaria variando su concentración en la fase orgánica (8, 10 y 12 % v/v) y como modificador isodecanol al 10 % v/v, en la fase acuosa se varió el pH (0.1, 0.5, 1, 1.5 y 2) y la relación de fases se varió (0.8/1, 1/1 y 1.2/1), obteniéndose una extracción de paladio mayor al 95 % a un pH=1.5 y una relación acuoso/orgánico de 1.2/1, 72 % de oro, 43% de plata y 30% de platino.

**Palabras clave:** Paladio, Extracción por Solventes, Amina Terciaria, Isodecanol, Iones Cloruros.

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## 1 Introduction

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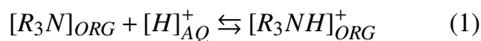
Platinum-group metals (PGMs) have high market value and low abundance in the Earth's crust (2.4%), attracting high popularity due to their unique physical and chemical properties: high chemical and thermal resistance, strong thermal and electrical conductivity, and resistance to corrosion and oxidation (Pianowska *et al.*, 2023). PGMs are primarily used in catalytic converters to decrease harmful emissions from automobiles; as catalysts for bulk chemical production and petroleum refining; in medical and dental devices; in electronic applications, such as computer hard drives, hybrid integrated circuits, and multilayer ceramic capacitors; and in glass manufacturing, investment, jewelry, and laboratory equipment (Survey, 2020).

Therefore, the recovery of PGMs from secondary resources has attracted much attention (Nguyen *et al.*, 2022). According to the United States Geological Survey in 2024, around 120,000 kg of palladium and platinum was recovered worldwide from the recycling of waste electronic equipment and automotive catalysts, proving the great importance of recycling in the recovery of PGMs (Survey, 2020). Several researchers have carried out studies on the recovery of these metals through hydrometallurgical processes, such as leaching with different reagents, a process consisting of dissolving metal ions (Birloaga *et al.*, 2013; Duan *et al.*, 2012; Jadhav & Hocheng, 2015; Lei *et al.*, 2020; Martínez-Ballesteros *et al.*, 2021; Segura-Bailón & Lapidus-Lavine; Torres & Lapidus, 2016). Hydrochloric acid is one of the most widely used and economically viable leaching reagents. In addition, the chemistry of the chloride ions that are formed from platinum-group metals has been extensively studied, providing sufficient vital information on subsequent processing stages (the concentration of the leach solution, the separation of the metals and their refining) (Bernardis *et al.*, 2005; Lee *et al.*, 2023; Pianowska *et al.*, 2023). Once the metals are in solution, the next stage consists of concentration and subsequent purification due to the wide range of metals contained in recycled materials. Solvent extraction is a process that combines these two stages because it enables the effective separation of metals from multi-component solutions, involving the transfer of components from one phase, usually aqueous, to a second organic phase, which is immiscible with the first phase. Once equilibrium is reached, the two phases separate, resulting in a loaded organic phase and an aqueous raffinate phase. The loaded organic undergoes re-extraction to recover the extracted metal ions at a higher concentration. The metals contained in the stripped solution can be reduced to transform them

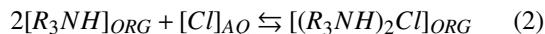
into a metallic form or into a specific chemical compound (precipitate). The stripped organic phase of the metal or metals of interest is sent back through the extraction process, hence its cyclical nature (Aguayo *et al.*, 2007; Pianowska *et al.*, 2023; Sole, 2008). The identification of metal ions is fundamental in metal extraction systems as the basis of classifying such systems. Here, it is important to consider the composition of the organic phase, featuring an extractant (which contains the active component that carries out the extraction reaction), a modifier (responsible for inhibiting the third phase and avoiding emulsions; it can affect the physical and chemical properties of the extractant), and a diluent (responsible for transporting the extractant and modifier) (Aguayo *et al.*, 2007). The improvement in extraction efficiency depends on the polarity and acidity of the modifier. Extraction improves with the addition of the modifier. The second application is in relation to hydroxyoximes and the formation of adapted mixtures where the extraction and stripping properties are adjusted to the aqueous phase, i.e. acidity and metal concentration, in such a way that the maximum transfer of metal ions is reached in the extraction and stripping cycle (Kordosky *et al.*, 1987). The production of new organic reactants to provide high selectivity of extraction metal anions is complex because extractors do not enter the sphere of internal coordination, and therefore it is difficult to take advantage of a metal's affinity for a particular coordination geometry or type of donor atom. The transfer of a metal anion to a non-polar, immiscible solvent in water requires the removal of most or all the hydration sphere, making it more difficult to extract small, highly charged anions (Wilson *et al.*, 2014). As solvent extraction is an economical and selective process, several researchers have studied various extractants for the concentration and purification of chlorinated leach solutions containing palladium (Cieszynska & Wiczorek, 2018; Lee *et al.*, 2010; Martínez *et al.*, 2024; Rane & Venugopal, 2006; Rovira *et al.*, 1999; Torrejos *et al.*, 2020; Uheida *et al.*, 2002; Xing *et al.*, 2018)

In this work, the purification of palladium from leaching solutions of electronic waste cards was investigated through solvent extraction, using a tertiary amine as the extractant, isodecanol as the modifier, and kerosene as the diluent. The study evaluated the effect of the phase ratio, the extractant concentration in the organic phase, and the aqueous solution's pH. The objective was to determine the most suitable conditions for selectively extracting palladium, separating it from the other metal ions present in the solution (platinum, gold, and silver), adding a modifier, because it allows a faster phase separation and in the selectivity of the extractant for the metal ion of interest. Tertiary

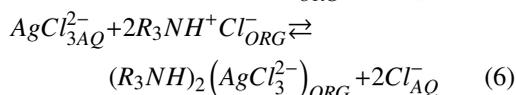
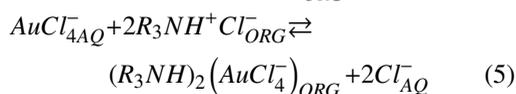
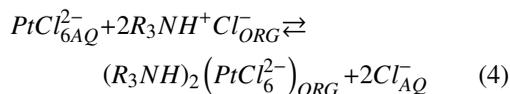
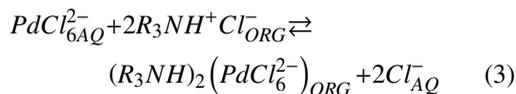
amine is an extractant of anionic character used commercially as an extractant. It is composed of a branched, unfunctional chain (containing only one ionizable group per molecule). Its ramifications are a mixture of n-octyle- and n-decyl, with 8-carbon chains predominating. In an acidic medium the amine reacts following the following reaction mechanism as shown by Eq. 1 (Ritcey & Ashbrook, 1984):



The second reaction that occurs is the formation of an amine salt as shown in the Eq. 2



Metals such as platinum, palladium and gold have a strong preference for aliphatic amines, which is why it is possible to use tertiary amine for the extraction of these metals (Cotton *et al.*, 1999). Therefore, the extraction reactions that will be carried out for each metal would be as follows (Eq. 3 - Eq.6):



## 2 Methodology

A leaching solution containing palladium, platinum, gold, and silver chlorides (Table 1) was concentrated using the solvent extraction process in a batch system using separation funnels, in which the leaching solution (aqueous phase) and the solvent (organic phase) were added, which is a mixture between the extractant, diluent and modifier. The funnels were shaken manually for 3 minutes, due to tests previously

carried out in which at this time equilibrium is reached (Martinez et al., 2024). Finally, they were left to rest to enable the separation of phases. A tertiary amine (ALAMINE® 336) was used as an extractant, for which we varied its concentration in the organic phase (8, 10, and 12% v/v); additionally, 10% isodecanol was used as a modifier (Table 2 shows the physical and chemical properties of the organic-phase components). The pH of the leaching solution varied (0.5, 1, 1.5, 2) in addition to the aqueous/organic-phase ratio (AQ/ORG) (0.8/1, 1/1, and 1.2/1). Each test was performed in triplicate and at room temperature (25 °C). The pH was adjusted using a 10 M solution of sodium hydroxide (NaOH). The concentration in the aqueous phase was determined using a microwave-induced plasma atomic emission spectrometer (Agilent 4210), to confirm that the team was analyzing well, a sample of 1 ppm of the metal being analyzed and for the analysis of platinum and palladium, lanthanum was added to the samples to suppress elements that may have an interference in the analysis of these metals, and in the organic phase its concentration was determined using a mass balance (see Eq.7):

$$V_{AQ}([Pd]_{AQin} - [Pd]_{AQout}) = V_{ORG}([Pd]_{ORGout} - [Pd]_{ORGin}) \quad (7)$$

where

$V_{AQ}$ : aqueous solution volume.

$V_{ORG}$ : organic solvent volume.

$[Pd]_{AQin}$ : concentration of palladium in the leaching solution.

$[Pd]_{AQout}$ : concentration of palladium in the raffinate.

$[Pd]_{ORGout}$ : concentration of palladium in the loaded organic phase.

$[Pd]_{ORGin}$ : concentration of palladium in the stripped organic phase.

Table 1. Concentration of metals in the aqueous phase.

Metals	Ag	Au	Pd	Pt
Concentration (mg/L)	10	10	1	3

Table 2. The physical and chemical properties of the organic phase.

Characteristic	Tertiary amine	Isodecanol	Kerosene
Molecular formula	R <sub>3</sub> N	C <sub>10</sub> H <sub>22</sub> O	C <sub>12</sub> H <sub>26</sub>
Molecular weight (g/mol)	392	158.28	170.132
Solubility in water (g/L)	0.005	0.037	0.02
Density (g/cm <sup>3</sup> ) to 20 °C	0.821	0.83	0.82
Appearance	Light yellow	Colorless	Colorless

### 3 Results and discussion

#### 3.1 Extraction experiments

All extraction experiments were performed with 10% v/v isodecanol and a stirring time of 3 minutes, varying the AQ/ORG ratio, the percentage of extractant, and the pH of the leaching solution, as described in the Methodology. The results are shown in Figures 1 to 4.

Figure 1 shows the extraction profiles (%) as a function of the extractant concentration (%) in the organic phase for the different metals present in the solution, using different phase ratios (0.8/1, 1/1, and 1.2/1) and pH= 0.5 in the aqueous phase. Figure 1(A) presents the extraction percentage at an AQ/ORG ratio of 0.8. The results indicate that the percentage of palladium extraction decreases as the extractant concentration increases; on the other hand, for the other metal ions present in solution, it increases. Figure 1(B) presents the extraction percentage at an AQ/ORG ratio of 1. The results indicate that the percentages of palladium, platinum, and silver extractions increase as the extractant concentration rises, on the other hand, gold extraction decreases. Figure 1(C) presents the extraction percentage at an AQ/ORG ratio of 1.2. The results indicate that the percentage of palladium extraction remains constant at any extractant concentration, whereas silver extraction increases along with the extractant concentration, on the other hand, platinum and gold extraction decreases. Therefore, under these conditions, the most appropriate parameters were an AQ/ORG ratio of 1.2 and an extractant concentration of 12 %, at which more than 97% of palladium was extracted alongside a 92% extraction of the other metal ions present in the solution, which fulfills the purpose of this process to extract the metal ions of interest. This is because there is a higher concentration of ammonia salts dissolved in the organic phase and this allows a greater capacity to extract the metal ions contained in the aqueous phase.

Figure 2 the percentage of extraction in the organic phase for gold, silver, platinum and palladium, using different phase ratios (0.8/1, 1/1 and 1.2/1), with pH = 1. Figure 2(A) presents the extraction percentage at an AQ/ORG ratio of 0.8. The results indicate that the percentages of palladium and platinum extractions increase as the extractant concentration rises, on the other hand, gold and silver extraction decreases. Figure 2(B) presents the extraction percentage at an AQ/ORG ratio of 1. The results indicate that the percentages of palladium and platinum extractions increase as the extractant concentration rises, on the other hand, gold and silver extraction decreases. Figure 2(C) presents the extraction percentage at an AQ/ORG ratio of 1.2. The results indicate that the percentage of palladium extraction remained nearly

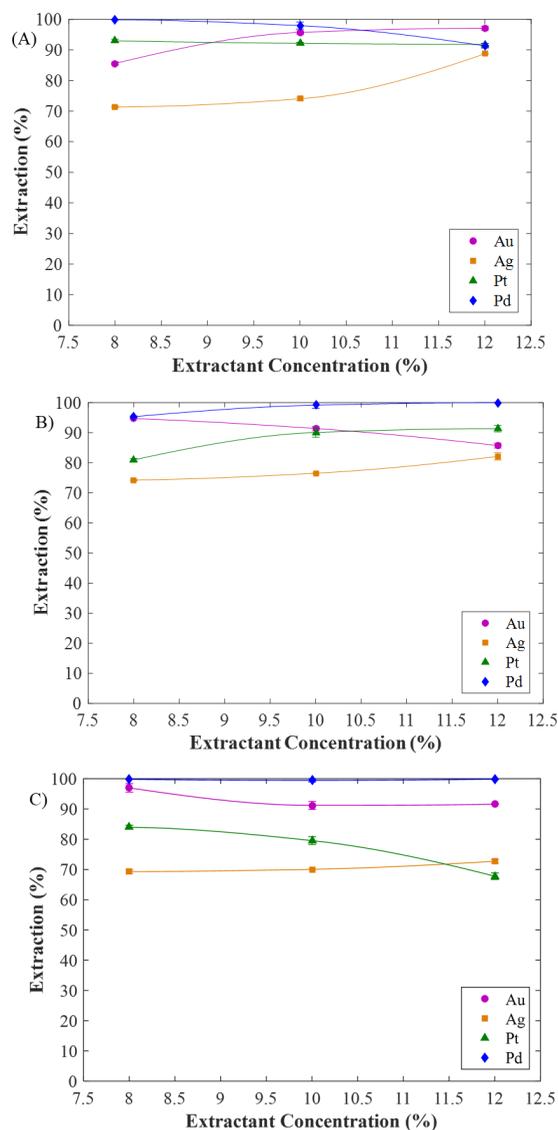


Figure 1. Percentage of extraction as a function of the extractant concentration (%) at different phase ratios: (A) AQ/ORG = 0.8, (B) AQ/ORG = 1, and (C) AQ/ORG = 1.2. Aqueous-phase pH = 0.5.

constant as the extractant concentration increased; however, a decrease was observed for the other metal ions present in the solution. Under these conditions, the most appropriate parameters were an AQ/ORG ratio of 1.2 and extractant concentration of 12%, at which more than 97% of palladium was extracted. However, the extraction percentages of other metal ions present in the solution were lower than 85% for gold, less than 70% in the case of platinum and silver which fulfills the purpose of this process: to extract the metal ion of interest. This is because there are more ammonia salts dissolved in the organic phase, that is, there are more active sites for the organometallic species to form with the metal ions of the aqueous solution.

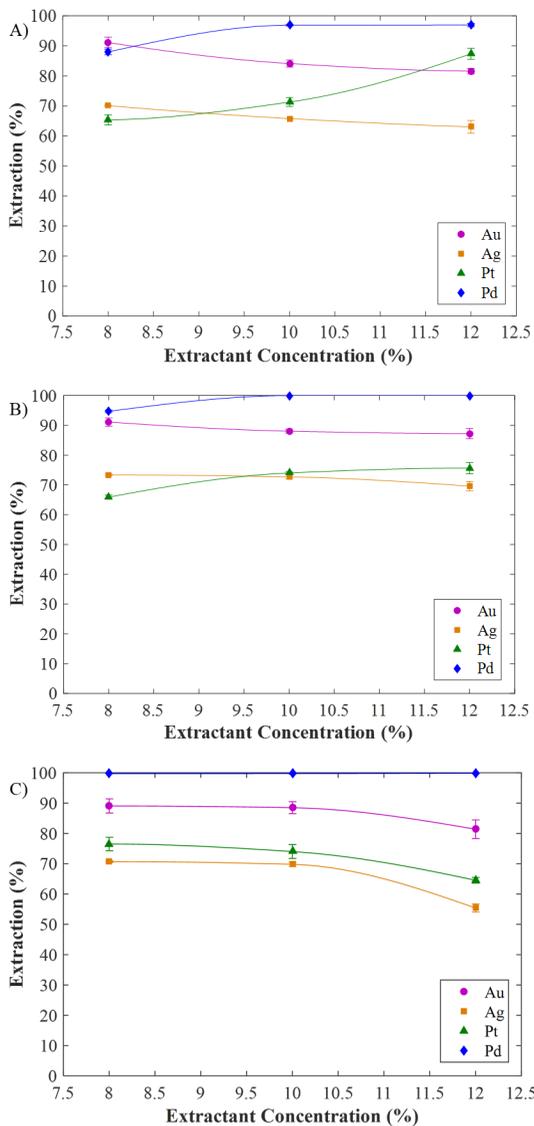


Figure 2. Percentage of extraction as a function of the extractant concentration (%) at different phase ratios: (A) AQ/ORG = 0.8, (B) AQ/ORG = 1, and (C) AQ/ORG = 1.2. Aqueous-phase pH = 1.

Figure 3 shows different phase ratios (0.8/1, 1/1 and 1.2/1) and a pH = 1.5 in the rich leach solution (aqueous phase). Figure 3(A) presents the extraction percentage at an AQ/ORG ratio of 0.8. The results indicate that the percentages of palladium, gold, and silver extractions increase with an increase in the extractant concentration, while platinum extraction decreases. Figure 3(B) presents the extraction percentage at an AQ/ORG ratio of 1. The results indicate that the percentages of palladium, platinum, silver, and gold extractions increase as the extractant concentration rises. Figure 3(C) presents the extraction percentage at an AQ/ORG ratio of 1.2. The results indicate that the percentage of palladium extraction increases as the extractant concentration rises; however, for the other metal ions present in the solution, it decreases. Under these conditions, the

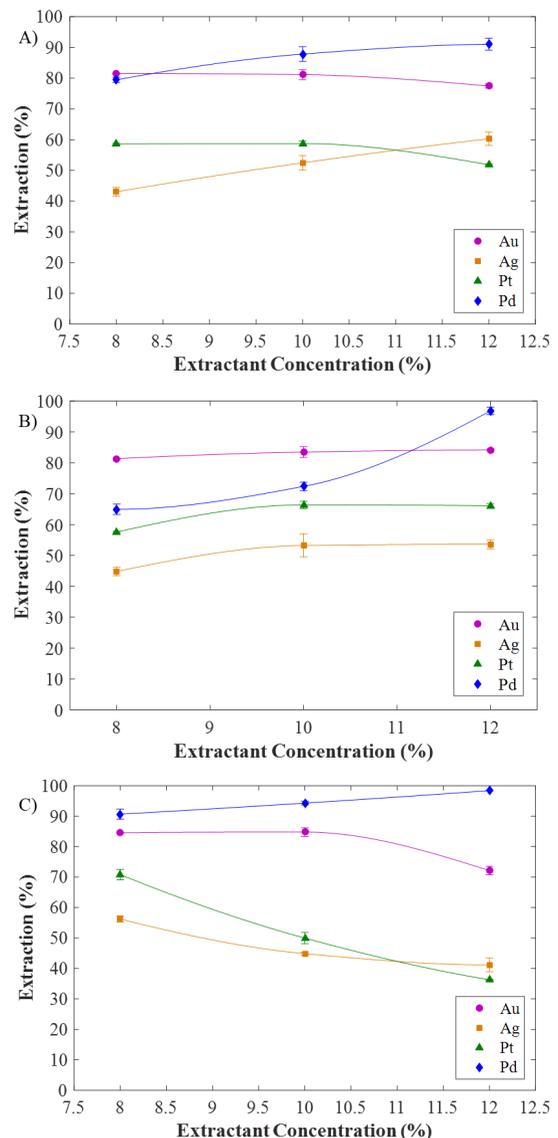


Figure 3. Percentage of extraction as a function of the extractant concentration (%) at different phase ratios: (A) AQ/ORG = 0.8, (B) AQ/ORG = 1, and (C) AQ/ORG = 1.2. Aqueous-phase pH = 1.5.

most appropriate parameters are an AQ/ORG ratio of 1.2 and extractant concentration of 12%, at which more than 97% of palladium is extracted. However, the other metal ions present in solution have lower extraction percentages less than 75% for gold and less than 45% in the case of platinum and silver thus fulfilling the purpose of this process in extracting the metal ions of interest. This is because the higher the concentration of extractant, the more active spaces for the extraction of the metal ions of interest. By increasing the pH in the solution, there are fewer hydrogens present in solution that are required for the extraction mechanism observed in equation 1 to be carried out, so a lower percentage of extraction is observed for silver, platinum and gold.

Figure 4 shows the extraction profiles (%) as a function of the extractant concentration (%) in the

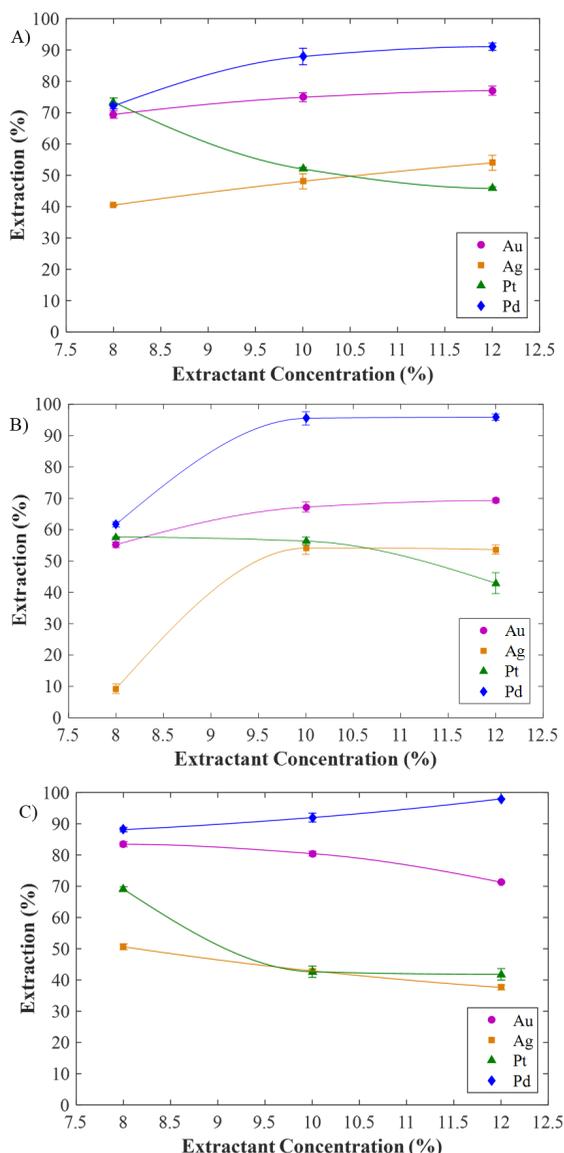


Figure 4. Percentage of extraction as a function of extractant concentration (%) in the organic phase at different phase ratios: (A) AQ/ORG = 0.8, (B) AQ/ORG = 1, and (C) AQ/ORG = 1.2. Aqueous-phase pH = 2.

organic phase for the different metals present in the solution, using different phase ratios (0.8/1, 1/1, and 1.2/1) and pH = 2 in the aqueous phase. Figure 4(A) presents the extraction percentage at an AQ/ORG ratio of 0.8. The results indicate that the percentages of palladium, gold, and silver extractions rise with an increase in the extractant concentration, on the other hand, the extraction of platinum decreases as the concentration increases. Figure 4(B) presents the extraction percentage at an AQ/ORG ratio of 1. The results indicate that the percentages of palladium, gold, and silver extractions increase and subsequently remain stable as the concentration of the extractant increases, on the other hand, the extraction of platinum decreases as the concentration increases.

Figure 4(C) presents the extraction percentage at an AQ/ORG ratio of 1.2. The results indicate that the percentage of palladium extraction rises as the extractant concentration increases; however, a decrease is observed for the other metal ions present in the solution. Under these conditions, the most appropriate parameters are an AQ/ORG ratio of 1.2 and an extractant concentration of 12%, at which more than 95% of palladium is extracted. Here, the extraction percentages of the other metal ions present in solution are lower, less than 72% for gold and less than 45% in the case of platinum and silver; therefore, the purpose of this process to extract the metal ion of interest is fulfilled. This is because there are more active spaces in the organic phase for the extraction of the metal ions found in the aqueous phase to take place. As the pH in the solution increases, there are fewer hydrogens present in the solution that are necessary for the extraction mechanism observed in equation 1 to take place, so a lower percentage of extraction is observed for silver, platinum and gold at a pH = 2 and at a pH = 0.5 a higher percentage of extraction is observed for all metal ions present in the aqueous solution.

### 3.2 Selectivity of tertiary amine

To calculate the distribution coefficients and the selectivity for metal chlorides, we used an aqueous solution containing Pd, Pt, Au, and Ag chlorides and an organic solvent with a 12% extractant v/v and a phase ratio of 1.2/1.

The distribution coefficients were calculated using Eq. 8.

$$D_M = \frac{[M]_{ORG}}{[M]_{AQ}} \quad (8)$$

where

$D_M$  = distribution coefficient of the metal

$[M]_{ORG}$  = concentration of the metal in the organic phase.

$[M]_{AQ}$  = concentration of the metal in the aqueous phase.

Selectivity factors ( $S_M^{Pd}$ ) for these metal chlorides were calculated using Eq. 9.

$$S_M^{Pd} = \text{Selectivity} = \frac{D_{Pd}}{D_M} \quad (9)$$

where

$D_{Pd}$  = distribution coefficient of palladium.

$D_M$  = distribution coefficient of the metal that is compared with palladium.

Based on these calculations, Table 3 summarizes the distribution coefficients.

The extractant exhibited the following selectivity order:

$$Pd > Au > Ag > Pt$$

Table 3. Extraction distribution coefficients and selectivity.

Metal	$[M]_{AQ}$ (mg/L)	$[M]_{ORG}$ (mg/L)	$D_M$	$S_M^{Pd}$
Pd	0.016	1.18	71.688	1
Pt	1.914	1.303	0.681	105.27
Au	2.689	8.773	3.262	21.98
Ag	6.044	4.747	0.785	91.32

The preference of tertiary amine for palladium over platinum even though both metals are transitional and form similar complexes. This is mainly because palladium complexes are about five orders of magnitude more labile than platinum complexes. This means that palladium binds to and separates from ligands, including tertiary amines, much faster than platinum, resulting in an apparent "higher affinity" in terms of reaction rate and bond formation (MacDonald *et al.*, 2024; Shoukry & van Eldik, 2023).

The selectivity of palladium tertiary amine over gold and silver is mainly due to differences in coordination chemistry and metal hardness (according to the HSAB theory), palladium is classified as a Lewis acid of intermediate hardness (borderline), meaning that it has a significant affinity for both "hard" bases such as oxygen, nitrogen, and for "soft" bases such as sulfur, phosphorus. Tertiary amines are Lewis bases that donate nitrogen, which form very stable complexes with palladium; for which they are often used in catalysis. The gold-ion is a "soft" Lewis acid; therefore, they prefer soft ligands such as sulfur, phosphorus, or cyanide. Silver-ion is considered a soft acid, so it forms much more stable complexes with soft ligands such as cyanide, sulfur, and phosphorus. Although gold and silver can bind to nitrogen, binding with amines is not as thermodynamically favorable as with palladium (Galdi *et al.*, 2026; Shoukry & van Eldik, 2023).

### 3.3 Modifier effect on extraction

In this section, we present the extraction results obtained using only the tertiary amine (Martínez *et al.*, 2024) and compare them with those obtained when 10% isodecanol is added. The experiments were conducted at AQ/ORG = 1.2 and pH 1.5, with varying extractant concentrations. The corresponding results are shown in Figures 5 and 6.

Figure 5 presents the extraction profiles (%) as a function of the extractant concentration in the organic phase (% v/v) for palladium and platinum, both in the absence and presence of isodecanol as a modifier. The experiments were carried out at a phase ratio of 1.2/1 and an aqueous phase pH of 1.5. The results show that palladium extraction is not significantly influenced by the presence of the modifier. In contrast, platinum extraction consistently decreases when isodecanol is added, regardless of the extractant concentration in the organic phase.

Figure 6 presents the extraction profiles (%) as a function of the extractant concentration in the organic phase (% v/v) for gold and silver, both in the absence and presence of isodecanol as a modifier. The experiments were carried out at a phase ratio of 1/1.2 and an aqueous phase pH of 1.5. The results show that the percentage of gold extraction is not significantly influenced by the presence of the modifier; in contrast, silver extraction decreases when isodecanol is added, regardless of the extractant concentration in the organic phase.

Tables 4 and 5 show the extraction percentages for each metal ion present in the solution when only the tertiary amine is used and when 10% isodecanol is added; there is no effect on the extraction of palladium and gold when the modifier is added to the solvent extraction process. On the other hand, the extraction of platinum and silver is reduced, a positive result in the context of this study on the extraction of palladium chloride ions. In the separation time, it is observed that the phase separation is faster when the modifier is used, which is one of the objectives when using it in the process.

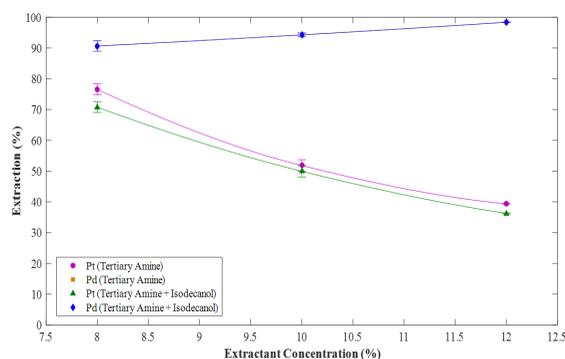


Figure 5. Comparison of the percentage of extraction as a function of the extractant concentration (%). Effect of the modifier, isodecanol, on Pd and Pt extraction.

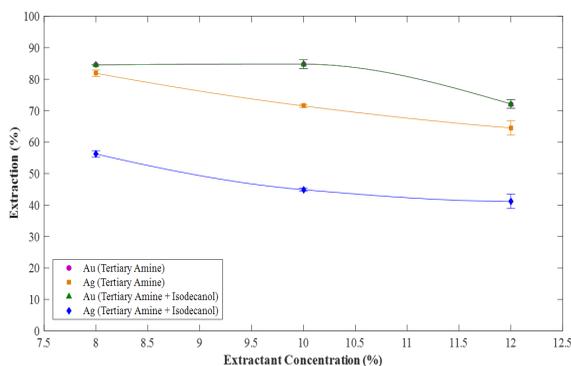


Figure 6. Comparison of the percentage of extraction as a function of the concentration of the extractant (% v/v). Effect of the modifier, isodecanol, on Au and Ag extraction.

Table 4. Extraction percentages for each metal ion present in solution when only the tertiary amine is used.

Extractant Concentration (% v/v)	Extraction (%)				Separation Time Sec
	Pd	Pt	Au	Ag	
8	90.7	76.6	84.5	81.9	75
10	94.3	51.9	84.8	71.5	75
12	98.4	39.4	72.1	64.5	75

Table 5. Extraction percentages for each metal ion present in solution when the tertiary amine and isodecanol are used.

Extractant Concentration (% v/v)	Extraction (%)				Separation Time Sec
	Pd	Pt	Au	Ag	
8	90.7	70.8	84.5	56.2	30
10	94.3	50.0	84.8	44.9	30
12	98.4	36.2	72.1	41.2	30

It is observed that the percentages of palladium and gold extractions with a tertiary amine do not show significant changes. In contrast, platinum and silver extraction is affected, decreasing by up to 26% in the case of silver and up to 5% in the case of platinum. This is because the modifier improves the efficiency and selectivity of the extractant by influencing the solubility or modifying the polarity of the system, thus facilitating the passage of the metal ion of interest from the aqueous phase to the organic phase.

The distribution coefficient of a solute is related to the difference between its solvation energies in the aqueous medium and in the solvent; consequently, it is affected by changes in the solvent. The fact that the addition of isodecanol affects the base concentration, extraction power, and extraction mechanism indicates that there is some interaction between isodecanol and the extractant (Ritcey & Ashbrook, 1984). The addition of alcohol to a solvent changes its physical nature, which, in turn, produces changes in the extraction system.

It is also observed that the tertiary amine exhibits greater selectivity towards palladium chloride ions than towards platinum chloride ions, especially when a modifier such as isodecanol is used. In the case of gold chloride ions, selectivity is not affected using isodecanol. However, the tertiary amine still shows a preference for palladium chloride ions over gold ones. Consequently, the use of isodecanol has a positive effect, as it enhances the selectivity of the extractant towards palladium chloride ions compared with the other metal ions present in the solution. This is because the presence of an alcohol increases the solubility of the ammonia complexes in the organic phase, which influences the extraction of metal ions present in the solution. In addition, as can be seen in the extraction mechanism, a hydrogen ion is necessary for the activation of the amine to take place, so at lower pH, which is where more hydrogen ions a greater extraction was obtained of all the metals studied in this work. Viscosity decreases when a modifier is added,

which has a beneficial effect on the process, as it inhibits the formation of the third phase. By avoiding the formation of the third phase, there is a faster separation time, without having a side effect on the loading of the  $PdCl_6^{2-}$  of the organic phase.

The technical aspects that have been used have been discussed by Kordosky for first generation reagents hydroxyoximes these have been modified with nonylphenol and tridecanol, the problem of the industrial application of continuous suitable mixtures is easier and cheaper to optimize the composition of a mixture than to invent and produce a new reagent with an active substance. In the case of amines, these can be modified with isodecanol to obtain better results (Kordosky *et al.*, 1987).

## Conclusions

The best conditions for palladium extraction were achieved using 12% v/v of the extractant, a phase ratio (AQ/ORG) of 1.2/1, and a pH of 1.5. Under these conditions, more than 98% of palladium was extracted, while the extraction of gold remained below 80% and that of silver and platinum stayed below 45%.

The extraction of metal ions in solution is affected by the concentration of the extractant and the phase ratio. As the metal of interest in this study, the percentage of palladium extraction is favored by increasing the concentration of the extractant at any phase ratio. At pH = 1.5 and AQ/ORG = 1.2/1, the extraction percentages of platinum and silver decrease as the concentration of the extractant increases. Overall, the extractant exhibited higher selectivity for palladium compared with the other metals present in the solution. This is because the higher the concentration of extractant, the more active spaces for the extraction of the metal ions of interest. By increasing the pH in the solution, there are fewer hydrogens present in solution that are required for

the extraction mechanism observed in equation 1 to be carried out, so a lower percentage of extraction is observed for silver, platinum and gold.

By using tertiary amine as an extractant, adding isodecanol as a modifier increases the solubility of the ammonia complexes in the organic phase, which influences the extraction of metal ions present in the solution, in addition to avoiding the formation of third phases and facilitating the faster separation of phases.

This study shows that the addition of a modifier, which aims to enhance phase decoupling by increasing the solubility of ammonium salts in the organic phase, influences the extraction of metal ions by the amine extractant to different extents. The presence of alcohol increases the solubility of the ammonia complexes in the organic phase, which influences the extraction of metal ions present in the solution.

This solution offers suitable conditions for the precipitation of palladium in the final stage of the recovery process.

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