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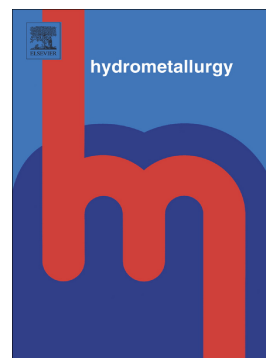
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Hoai Thanh Truong, Man Seung Lee, Gamini Senanayake



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**Separation of Pt(IV), Rh(III) and Fe(III) in acid chloride
leach solutions of glass scraps by solvent extraction with
various extractants**

Hoai Thanh Truong^a, Man Seung Lee^{a*} and Gamini Senanayake^b

^aDepartment of Advanced Materials Science & Engineering, Institute of Rare Metal,

Mokpo National University, Jeollanamdo 534-729, Korea

*^bChemical & Metallurgical Engineering & Chemistry, School of Engineering & Information
Technology, Murdoch University, 90 South Street, Murdoch, WA 6150, Australia*

*Corresponding author. Tel: +82 61 450 2492; fax: +82 61 450 2498.

E-mail address: mslee@mokpo.ac.kr (M.S. Lee).

Abstract

Solvent extraction experiments were conducted to recover pure Pt(IV) and Rh(III) from the chloride leach liquor of glass industry scraps containing a small amount of Fe(III) using Alamine 336, TOPO, TBP and Cyanex 923. The Pt(IV) and Fe(III) were selectively extracted by Cyanex 923 leaving Rh(III) in the raffinate, while only Fe(III) was extracted by TBP. The Pt(IV) in the loaded Cyanex 923 phase was first selectively stripped over Fe(III) by NaSCN and then the remaining Fe(III) was stripped by HCl solution. The Fe(III) in the loaded TBP phase was easily stripped by dilute HCl solution. The McCabe-Thiele diagrams for the extraction of Pt(IV) by Cyanex 923 and of Fe(III) by TBP were constructed. Based on the obtained results, a flowsheet for the separation of three metals from the real leaching solution of glass industry scraps was proposed.

Keywords: Glass industry scrap, Recovery, Platinum, Rhodium, Cyanex 923, Solvent Extraction.

1. Introduction

Platinum group metals (PGMs) have specific physical and chemical properties and thus the demand for PGMs is increasing (Rovira et al., 1998; Gupta et al., 2014). Since the ores containing PGMs become exhausted, it is desirable to develop an efficient process to recover PGMs with high purity from secondary resources such as spent catalysts, and glass industry scraps. In glass industry, platinum and rhodium are used in some glass melting equipment, such as crucibles, tank linings, plungers, and thermocouple owing to their high melting points and resistance to corrosion (Fischer et al., 1999; Worrell and Reuter, 2014). Since pure platinum metal cannot keep its mechanical properties at high temperature, 10% of rhodium is added to platinum to improve the properties of the resulting alloys and thus to expand their service life at high temperature (Stokes, 1987).

In order to recover pure Pt and Rh from the glass industry scraps, the scraps are generally treated by aqua regia and then the nitric acid is recovered from the leach liquor. A small amount of iron(III) is contained in the leach liquor (Nowotny et al., 1997; Schreier and Edtmaier, 2003; Maeda et al., 2017). The purity of Pt and Rh should be higher than 99.9% for them to be reused in the manufacture of crucibles for glass industry. Therefore, Pt(IV), Rh(III) and iron(III) in the leach liquor should be separated. Solvent extraction is widely employed for the separation of these ions from concentrated acidic solutions (Cieszynska and Wisniewski, 2011; Lee et al., 2008, 2009; Mavhungu et al., 2013).

In hydrochloric acid solution, Pt(IV) exists as PtCl_6^{2-} , while it has been reported that aging has some effect on the stable species of Rh(III) as ionic Rh(III) is very labile (Benguerel et al., 1996). The RhCl_6^{3-} species can be transformed to $\text{RhCl}_5(\text{H}_2\text{O})^{2-}$ at high chloride concentration (Levitin and Schmuckler, 2003; Nguyen et al., 2016a). The reported values of relevant stability

constants for the chloro-complexes are listed in Table 1. Since both Pt(IV) and Rh(III) exist as anionic species in concentrated hydrochloric acid solutions, either amines or neutral extractants are employed to separate Pt(IV) and Rh(III) in the presence of other metal ions (Sun et al., 2011; Raju et al., 2012). Application of Kelex 100 to the concentrated hydrochloric acid solutions containing tin(IV) results in selective extraction of Rh(III) over Pt(IV) and Pd(II) but stripping of Rh(III) from the loaded organic phase is difficult (Shafiqul Alam and Katsutoshi Inoue, 1997). Although Alamine 308 is reported to be suitable for the separation of Pt(IV) and Rh(III), co-extraction of Rh(III) leads to a decrease in the purity of Pt(IV) thus separated (Lee et al., 2009). A combination of precipitation and solvent extraction has been tested to recover Pt(II) and Rh(III) from the synthetic chloride solution with the following composition: 364 mg/L Pt(II), 62 mg/L Rh(III), 13880 mg/L Al(III), 6980 mg/L Mg(II), and 1308 mg/L Fe(III) (Raju et al., 2012). First, Al(III) and Fe(III) were precipitated with Na_3PO_4 and then Pt(II) was selectively extracted over Rh(III) and Mg(II) using Aliquat 336 (Raju et al., 2012). In a study to separate Pt(IV), Pd(II), Rh(III) and Ir(IV) from hydrochloric acid solutions, TBP has been used to selectively extract Pt(IV) over Ir(IV) and Rh(III) from the raffinate after extraction of Pd(II) by LIX 63 (Nguyen et al., 2016a). Compared to the number of studies devoted to the recovery of Pt(IV) and Pd(II) described above, the separation and recovery of pure Pt and Rh from the glass industry scraps has been limited (Schreier and Edtmaier, 2003).

In solvent extraction with amines or solvating extractants, Fe(III) is selectively extracted over Pt(IV) from hydrochloric acid solution. This work reports the results from solvent extraction experiments conducted to separate Pt(IV) and Rh(III) from the leach liquor of glass industry scraps which contained macro amount of Pt(IV) and Rh(III) in addition to the small amount of Fe(III). The three extractant Alamine 336, TOA, TBP and Cyanex 923 (Appendix 1)

were employed to determine the most suitable conditions to separate the three metal ions. Moreover, McCabe-Thiele diagrams for the extraction were constructed and a flowsheet for treating the leach liquor from glass industry scrap proposed.

2. Experimental

2.1. Chemicals and reagents

Alamine 336 and TOA were purchased from BASF Co. Korea and TBP was a product of Yakuri Pure Chemical Co. Japan. Cyanex 923 was purchased from Cytec Industries, Canada. These reagents were used without further purification. Toluene and kerosene were supplied by Daejung Chemicals & Metals Co. Korea and used as the diluents. The leach liquor of glass industry scrap digested by aqua regia was provided by DSM corp. in Korea, after removing nitric acid.

2.2. Solvent extraction procedure

The extraction and stripping experiments were carried out by mixing equal volumes (10 mL) of organic and aqueous phases in a screwed cap bottle. The mixed phases were shaken for 30 mins with a Burrell wrist action shaker (model 75 USA) and the two phases were separated using a separating funnel. All the experiments were performed at room temperature. The metal ion concentration in the aqueous phase was determined using ICP-AES (OPTIMA 4300 DV). The concentration of metal ions in the loaded organic phase was calculated by mass balance. The errors correlated with the extraction and stripping percentage of metals were within $\pm 5\%$.

In general, either amines or solvating extractants can extract Pt(IV) from concentrated hydrochloric acid solution. In order to investigate the extraction and separation behavior of the metal ions in the leach liquor, amines (TOA or Alamine 336) and solvating extractants (TBP or

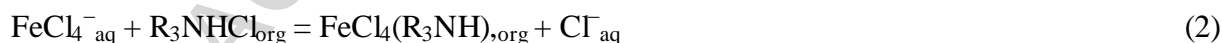
Cyanex 923) of structures shown in Appendix 1 were employed in this work. The concentration of TOA and Alamine 336 was varied from 0.1 to 1 M, while that of TBP and Cyanex 923 was varied from 0.01 to 0.1 M. The volume ratio of aqueous to organic phase was unity.

3. Results and discussion

3.1. Effect of different types of extractants

3.1.1 Extraction by Alamine 336 and TOA via anion exchange

The HCl concentration of as supplied leach liquor was higher than 8.5 M and the Fe(III), Pt(IV), and Rh(III) concentrations of the leach liquor are listed in Table 2. Figs. 1a and b show the variation in the extraction of Fe(III), Pt(IV), and Rh(III) with extractant concentration. While Fe(III) and Pt(IV) ions were completely extracted by Alamine 336 (Fig. 1a) and TOA (Fig. 1b) irrespective of the difference in their concentration (Table 2), the extraction percentage of Rh(III) was very low. The solvent extraction reaction of Pt(IV) and Fe(III) by tertiary amines has been generally represented by Eqs. (1) and (2) (Levitin and Schmuckler, 2003; Lee et al., 2009; Sun et al., 2011; Maeda et al., 2017), where R_3N represents the tertiary amine and the subscript *aq* and *org* represent the aqueous and organic phase, respectively.



Benguereel et al. (1996) reported that the predominant species of Rh(III) depend on the chloride concentration as shown in Appendix 2 and $RhCl_5(H_2O)^{2-}$ would not be extracted by amines. Selective extraction of Pt(IV) over Rh(III) by TOA and Alamine 336 agrees well with the extractability of chloro complexes of platinum group metal ions (PGMs) by amines, MCl_6^{2-}

>> MCl_6^{3-} (Nguyen et al., 2016b). During the extraction, the formation of a third phase was observed.

The purity of Pt metal should be higher than 99.9% to be recycled to the glass industry. This means that there should be no Fe(III) in Pt(IV) solution. Since Fe(III) is co-extracted with Pt(IV) by amines, the extraction and separation behavior of the metal ions in the leach liquor was investigated by employing solvating extractants, TBP and Cyanex 923.

3.1.2 Extraction by Cyanex 923 and TBP via solvation

Fig. 2a shows that as Cyanex 923 concentration increased from 0.01 to 0.05 M, the extraction of Fe(III) and Pt(IV) increased from 42 and 18% to 100 and 85%, respectively, and then was constant with the further increase of Cyanex 923 up to 0.1 M. However, no Rh(III) was extracted. The selective extraction of Pt(IV) over Rh(III) by Cyanex 923 can also be ascribed to the difference in their charge density. The charge density of RhCl_6^{3-} (54.2) is higher than that of PtCl_6^{2-} (38.2) (Nguyen et al., 2016a). In the course of solvent extraction by solvation reaction, the metal ion with higher charge density has a stronger tendency to be solvated by more water, resulting in less interaction with other species (Michael, 2012). Therefore, the extraction of Pt(IV) is higher than that of Rh(III).

Fig. 3 indicates that only Fe(III) was selectively extracted over Pt(IV) and Rh(III) by TBP and extraction efficiency increased at higher TBP concentrations. The solvent extraction reaction of Pt(IV) and/or Fe(III) with Cyanex 923 (Fig. 2a) or TBP (Fig. 3) may be represented as follows (Sun et al., 2011; Nguyen et al., 2017), where L represents the solvating extractant TBP/Cyanex 923.





Fig. 2b shows a Log-Log plot of the distribution ratio (D) as a function of Cyanex 923 concentration, where D is the ratio of the concentration of Pt(IV) in organic phase to aqueous phase at equilibrium obtained in this study. A slope of 2.1 in Fig. 2b suggests a value of m equal to 2 in Eq. (3). The results in Figs. 1-3 clearly show that both Fe(III) and Pt(IV) ions were co-extracted by TOA, Alamine 336 and Cyanex 923, while only Fe(III) was extracted by TBP. The difference in the extraction behavior for Pt(IV) and Fe(III) between Cyanex 923 (Fig. 2a) and TBP (Fig. 3) might be ascribed to the fact that the interaction between hydrogen ion and Cyanex 923 is much stronger than TBP (Sarangi et al., 2006). Therefore, Pt(IV) can be readily extracted from concentrated HCl solutions by Cyanex 923.

3.2. Third phase formation and effect of diluents

Third phase formation occurred during the extraction with Cyanex 923. Addition of 1-decanol as a modifier could not depress the formation of a third phase. Therefore, other diluents, such as toluene, benzene, xylene, and *n*-hexane of different dielectric constants listed in Table 3 were tested. The leach liquor was contacted with 0.05 M Cyanex 923 at an organic/aqueous phase volume ratio (O/A ratio) of 1. Results listed in Table 3 indicate that the extraction of Pt(IV) (20-90%) depended on the nature of the diluent, while there was no change in the extraction behavior of Fe(III) (100%) and Rh(III) (0%). The extraction percentage of Pt(IV) increased as the dielectric constant of the diluents decreased and the extraction order of Pt(IV) was benzene < toluene < xylene < kerosene < *n*-hexane. Although the extraction percentage of Pt(IV) was high with *n*-hexane, kerosene, and xylene as diluents, a third phase was formed during the extraction. However, no third phase was formed when toluene was employed as a diluent. Thus, toluene was used in further studies.

3.3. Effect of Cyanex 923 concentration in toluene

The effect of Cyanex 923 concentration on the extraction of the metal chloride complexes was investigated by varying its concentration from 0.01 to 0.1 M in toluene. Fig. 4a shows that Fe(III) was completely extracted by Cyanex 923 and the extraction percentage of Pt(IV) rose from 0.3 to 63.3% as Cyanex 923 concentration was increased from 0.01 to 0.1 M. Thus, Fe(III) was selectively extracted over Pt(IV) by Cyanex 923 in toluene. Meanwhile, the extraction of Rh(III) by Cyanex 923 was negligible in the tested range of experimental conditions. When Cyanex 923 concentration was 0.1 M, a third phase was formed and thus 0.07 M Cyanex 923 was chosen as the best concentration for the selective extraction of Pt(IV) and Fe(III) over Rh(III) from the leach liquor. Fig. 4b shows a Log-Log plot of D as a function of [Cyanex 923] in toluene. The slope of the linear relationship indicates that the value of m in Eq. (3) is equal to 3. The difference in the value of m of Eq. (3) between kerosene ($m=2$) and toluene ($m=3$) agrees well with the higher extraction percentage of Pt(IV) from kerosene than that from toluene due to stronger solvation of the Pt(IV) species by Cyanex 923 in toluene.

3.4. McCabe Thiele diagrams

3.4.1 Pt(IV) extraction by Cyanex in toluene

To determine the number of theoretical stages required for the complete extraction of Pt(IV) from the leach liquor, McCabe-Thiele diagram for the extraction of Pt(IV) was constructed by varying the O/A ratio using 0.07 M Cyanex 923 in toluene. The extraction percentage of Pt(IV) increased from 10 to 84% with an increase of O/A ratio from 1:3 to 5:1, while Fe(III) was completely extracted at any O/A ratio. On the other hand, no Rh(III) was

extracted into Cyanex 923. Fig. 5 indicates that four counter-current extraction stages are required for the complete extraction of Pt(IV) from the initial 1514 mg/L feed solution (Table 2) at an O/A ratio of 3.5 and the concentration of Pt(IV) in the loaded organic phase is 422 mg/L.

3.4.2 Fe(III) extraction by TBP in kerosene

Unlike TOA, Alamine 336 and Cyanex 923, TBP selectively extracted Fe(III) over Pt(IV) and Rh(III) from the leach liquor (Fig. 3). Therefore, to estimate the theoretical number of stages for the extraction of Fe(III) from leach liquor, extraction isotherm for Fe(III) was obtained by employing 0.1 M TBP in kerosene. In these experiments, the volume ratio of organic to aqueous was varied from 1:3 to 3:1. The extraction percentage of Fe(III) increased from 50 to 94% as the O/A ratio was increased from 1:3 to 3:1, while no Pt(IV) and Rh(III) was extracted. Fig. 6 shows that three counter-current extraction stages are needed to extract Fe(III) from the feed solution of 1.6 mg/L (Table 2) at an O/A ratio of 1 and the concentration of Fe(III) in the loaded organic phase is 1.47 mg/L.

3.5. Stripping of loaded organic phase

It has been reported that NaSCN and dilute HCl are two solutions which can strip Pt(IV) and Fe(III) from the loaded Cyanex 923 phase (Nguyen et al., 2016; Nguyen et al., 2017). As shown in Table 1, the stability constants of $\text{Pt}(\text{SCN})_6^{2-}$ ($10^{33.6}$) and $\text{Fe}(\text{SCN})_6^{3-}$ ($10^{3.51}$) are much larger than their chloride counterparts, which will facilitate the stripping of these metal ions from the loaded organic phase. A solution of dilute HCl of low H^+ and Cl^- concentration will favor the reverse reactions of Eqs. 3 and 4 and facilitate stripping due to the low stability constants of the chloro-complexes of Pt(IV) and Fe(III). Selective stripping was tested with the two stripping agents as described below.

The loaded organic phase was prepared by contacting the real leach liquor with 0.07 M Cyanex 923 in toluene. The concentration of Pt(IV) and Fe(III) in the loaded organic phase was 422 and 1.47 mg/L, respectively, to be consistent with the McCabe Thiele diagrams in Figs. 5 and 6, respectively. The O/A volume ratio was unity. In order to investigate the stripping behavior of Fe(III) and Pt(IV), the concentrations of NaSCN and HCl solutions were varied from 0.05 to 0.5 M and 0.01 to 1 M, respectively. The stripping percentage of Pt(IV) increased from 80 to 100% with increasing NaSCN concentration from 0.05 to 0.1 M and then remained unchanged with further increase of NaSCN concentration up to 0.5 M. However, the stripping efficiency of Fe(III) was nearly zero (see Fig. 7). Therefore, the higher stability of $[\text{Pt}(\text{SCN})_6]^{2-}$ favors the selective stripping of Pt(IV) over Fe(III) (Ginzburg et al., 1975). Further, in terms of Hard and Soft Acid Base (HSAB) theory, Pt(IV) is a soft acid and thus has a strong tendency to form complexes with a soft base like SCN^- , while Fe(III) is a borderline acid (Pearson, 1963).

Fig. 8 shows that the stripping percentage of Fe(III) increased from 50 to 85% as HCl concentration was increased from 0.01 to 1.0 M, whereas Pt(IV) was completely stripped irrespective of HCl concentration. According to Fig. 8 the stripping of loaded Cyanex 923 phase with NaSCN solution resulted in selective stripping of Pt(IV) over Fe(III) and thus it was possible to separate the two metal ions from the loaded Cyanex 923 phase.

Fig. 9 shows that the stripping percentage of Fe(III) from loaded TBP phase in kerosene increased from 80 to 100% as HCl concentration increased from 0.01 to 0.1 M HCl and then remained more or less constant with a further increase of HCl concentration up to 1.0 M.

3.6. Summary and proposed flowsheet

Based on the extraction and stripping results obtained, a proposed process for the separation of Pt(IV), Rh(III) and Fe(III) from the leach liquor of glass industry scraps is shown in Fig. 10. First, Fe(III) and Pt(IV) from leach liquor were completely extracted by Cyanex 923, leaving Rh(III) in the raffinate. Second, Pt(IV) was selectively stripped from the loaded Cyanex 923 phase by using NaSCN solution. The remaining Fe(III) in the loaded Cyanex 923 phase can be stripped by using HCl solution. The purity of final Pt(IV) solutions were higher than 99.9% and thus these metals can be recycled to the glass industry.

4. Conclusions

The leaching of glass industry scraps with aqua regia results in concentrated hydrochloric acid solution containing 1514 mg/L Pt(IV) and 178 mg/L Rh(III) together with a small amount of 1.6 mg/L Fe(III). The Fe(III) and Pt(IV) ions were simultaneously extracted by TOA, Alamine 336 and Cyanex 923, while only Fe(III) was extracted by TBP. The extraction percentage of Rh(III) by these 4 extractants was negligible. The Pt(IV) and Fe(III) in the loaded Cyanex 923 phase can be separated by selective stripping of Pt(IV) by NaSCN solution. The remaining Fe(III) in the loaded Cyanex 923 phase after stripping by NaSCN can be stripped by HCl solution. McCabe-Thiele diagrams for the extraction of Pt(IV) with Cyanex 923 and of Fe(III) by TBP were constructed. A process for the recovery of pure Pt(IV) and Rh(III) solutions from the leaching solution using solvent extraction was proposed.

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Table 1 Stability constants for the formation of complexes of Pt(IV), Rh(III), and Fe(III) with chloride and thiocyanate.

Reaction	Equilibrium constant		Reference
	(log K)		
$\text{Fe}^{3+} + 4\text{Cl}^- = \text{FeCl}_4^-$	-1.31		Belaustegi et al., 1999.
$\text{Pt}^{4+} + 6\text{Cl}^- = \text{PtCl}_6^{2-}$	2.36		Hogfeldt, 1983
$\text{PtCl}_4 + \text{Cl}^- = \text{PtCl}_5^-$	2.02		Lee et al., 2008.
$\text{PtCl}_5^- + \text{Cl}^- = \text{PtCl}_6^{2-}$	2.01		Lee et al., 2008.
$\text{Rh}^{3+} + 6\text{Cl}^- = \text{RhCl}_6^{3-}$	8.43		Cozzi and Pantani, 1958.
$\text{RhCl}_6^{3-} + \text{H}_2\text{O} = \text{RhCl}_5(\text{H}_2\text{O})^{2-} + \text{Cl}^-$	8.76		Read et al., 1994.
$\text{Fe}^{3+} + 6\text{SCN}^- = \text{Fe}(\text{SCN})_6^{3-}$	3.51		Theopold et al., 2015.
$\text{Pt}^{4+} + 6\text{SCN}^- = \text{Pt}(\text{SCN})_6^{2-}$	33.6		Mountain and Wood, 1988.
$\text{Rh}^{3+} + 6\text{SCN}^- = \text{Rh}(\text{SCN})_6^{3-}$	35.0		Read et al., 1994.

thiocyanate ion (SCN^-); tetrachloroferrate(III) ion (FeCl_4^-); hexathiocyanatoferrate(III) ion ($\text{Fe}(\text{SCN})_6^{3-}$); hexachloroplatinate(IV) ion (PtCl_6^{2-}); pentachloroplatinate(IV) ion (PtCl_5^-); hexathiocyanatoplatinate(IV) ion ($\text{Pt}(\text{SCN})_6^{2-}$); hexachlororhodate(III) ion (RhCl_6^{3-}); hexathiocyanatorhodate(III) ion ($\text{Rh}(\text{SCN})_6^{3-}$); aquopentachlororhodate(III) ion ($\text{RhCl}_5(\text{H}_2\text{O})^{2-}$).

Table 2 The composition of real leach liquor of glass industry scraps in aqua regia.

Element	Fe(III)	Pt(IV)	Rh(III)
mg/L	1.6	1514	178
mmol/L	0.03	7.76	1.73

Table 3 Effect of diluents on the extraction of Fe(III), Pt(IV), and Rh(III) by Cyanex 923.

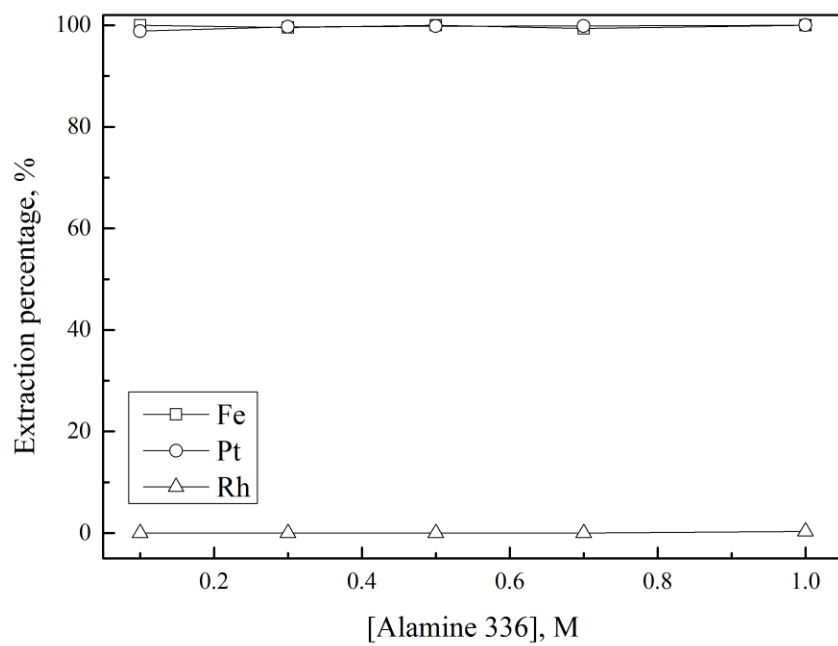
Diluent	Dielectric constant	Extraction percentage, %			Formation of a third phase
		Pt(IV)	Fe(III)	Rh(III) ^a	
Toluene	2.38	13.9	100	0	No
Benzene	2.28	12.6	100	0	No
Xylene	2.27	23.5	100	0	Yes
Kerosene	2.0	88.6	100	0	Yes
<i>n</i> -Hexane	1.88	89.9	100	0	Yes

a. Concentration was too low to measure

Experiment conditions: leach liquor: [Fe]=1.6 mg/L, [Pt]=1514 mg/L, [Rh]=178 mg/L;

organic phase: [Cyanex 923]=0.05 M, O/A=1.

(a)



(b)

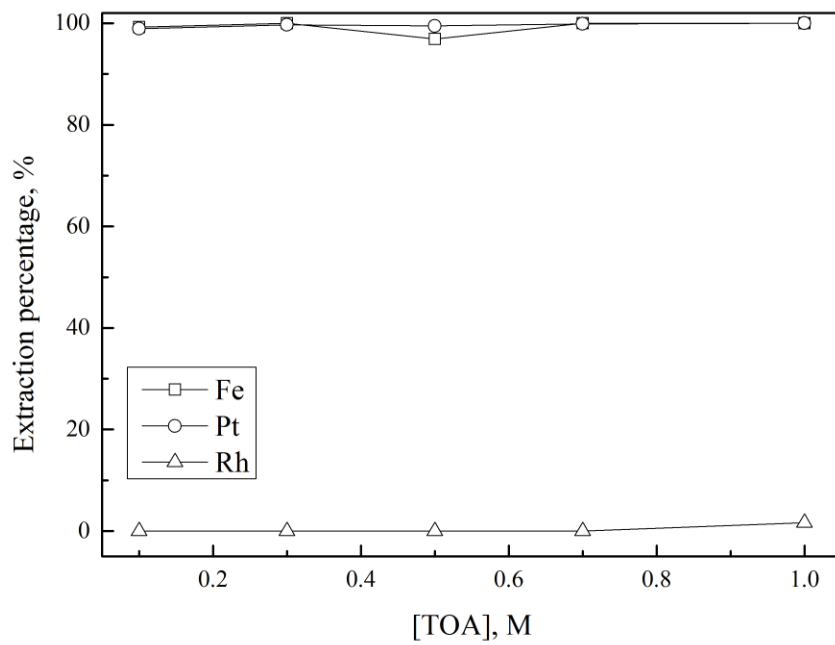


Fig. 1. Effect of Alamine 336 (a) or TOA (b) concentration on the extraction of Fe(III), Pt(IV), and Rh(III). Leach liquor: [Fe]=1.6 mg/L, [Pt]=1514 mg/L, [Rh]=178 mg/L. [Alamine 336] or [TOA]=0.1-1.0 M. O/A=1. Diluent: kerosene.

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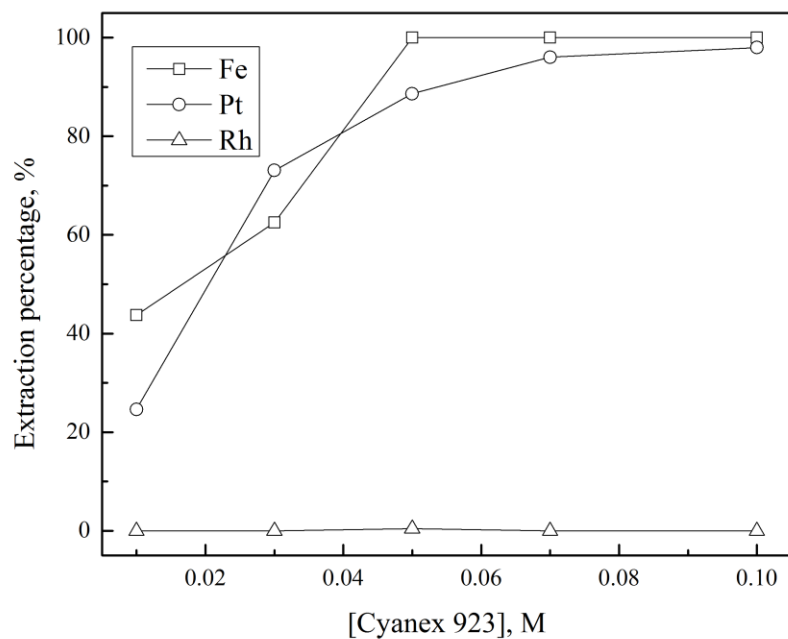


Fig. 2a. Effect of Cyanex 923 concentration on the extraction of Fe(III), Pt(IV), and Rh(III).

Leach liquor: [Fe]=1.6 mg/L, [Pt]=1514 mg/L; [Rh]=178 mg/L. [Cyanex 923]=0.01-0.1 M.

O/A=1. Diluent: kerosene.

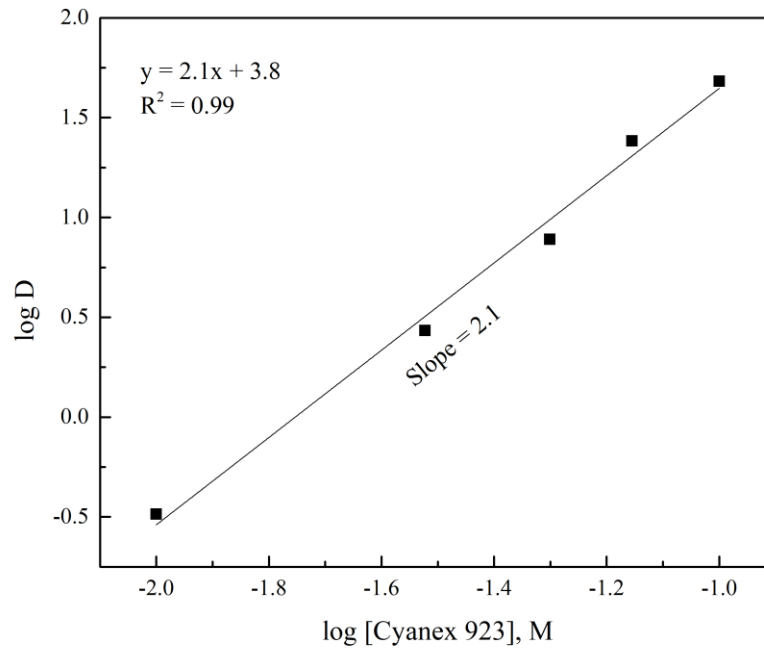


Fig. 2b. Plot of log D of Pt(IV) as a function of log [Cyanex 923]. Leach liquor: [Fe]=1.6 mg/L, [Pt]=1514 mg/L; [Rh]=178 mg/L; [Cyanex 923]=0.01-0.1 M. O/A=1. Diluent: kerosene.

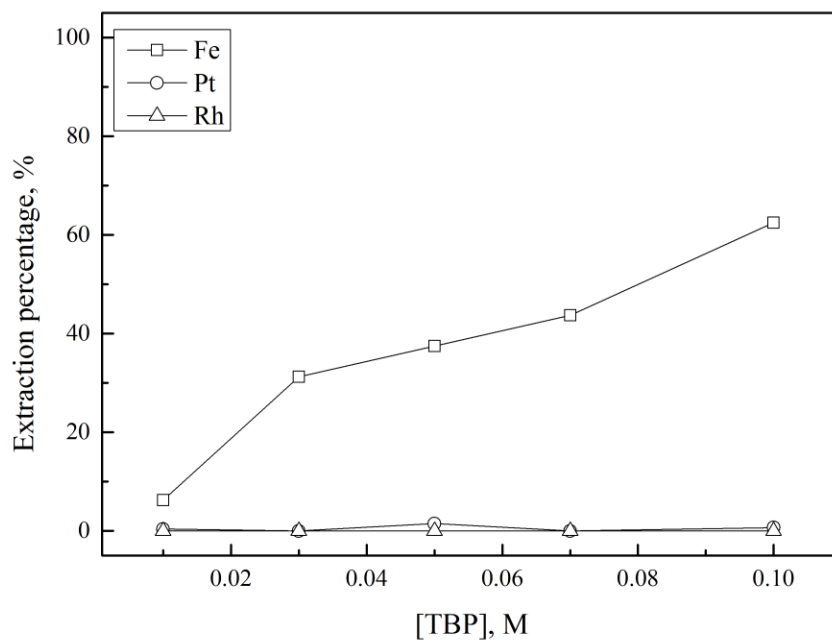


Fig. 3. Effect of TBP concentration on the extraction of Fe(III), Pt(IV), and Rh(III). Leach liquor: [Fe]=1.6 mg/L, [Pt]=1514 mg/L; [Rh]=178 mg/L. [TBP]=0.01-0.1 M. O/A=1. Diluent: kerosene.

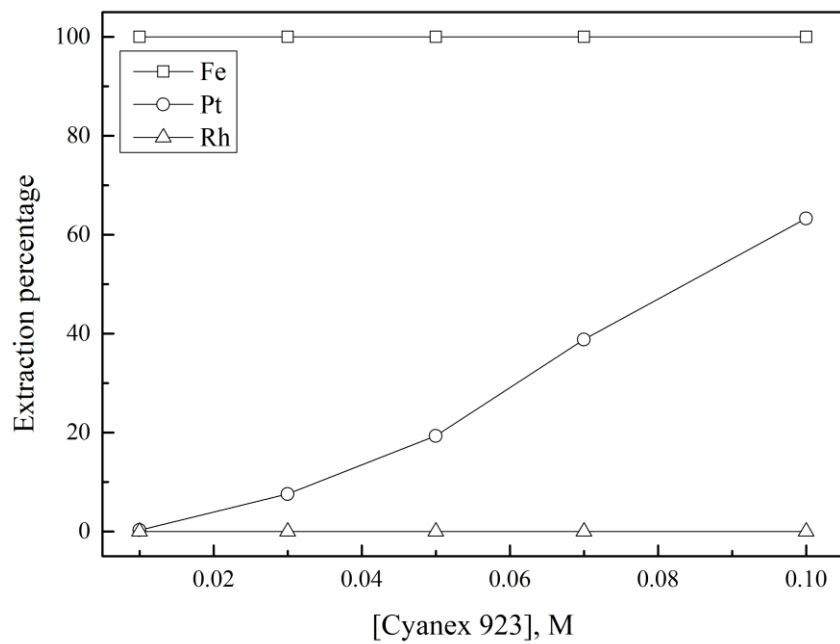


Fig. 4a. Effect of Cyanex 923 on the extraction of Fe(III), Pt(IV), and Rh(III). Leach liquor: [Fe]=1.6 mg/L, [Pt]=1466 mg/L, [Rh(III)]=178 mg/L. Organic: [Cyanex 923]=0.01-0.1 M. O/A=1. Diluent: toluene.

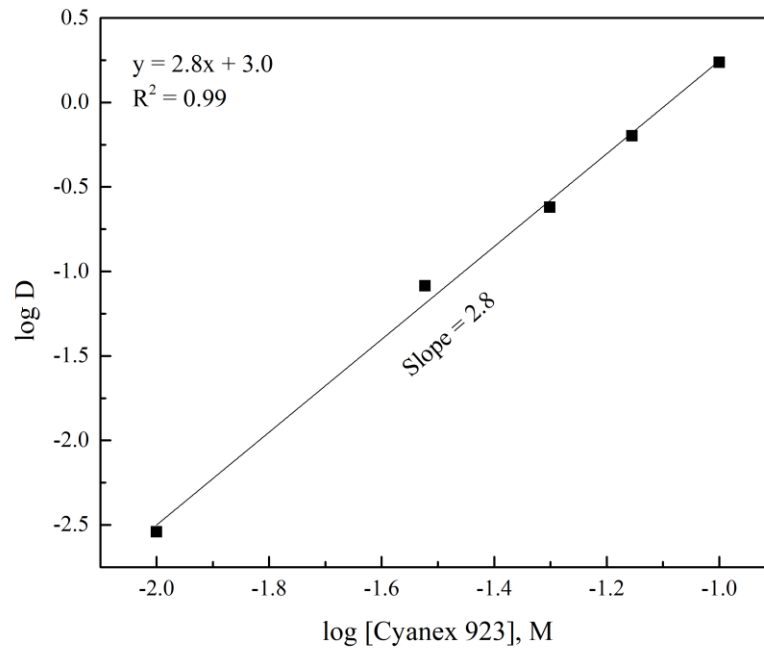


Fig. 4b. Plot of log D of Pt(IV) as a function of log [Cyanex 923]. Leach liquor: [Fe]=1.6 mg/L, [Pt]=1466 mg/L; [Rh]=178 mg/L. [Cyanex 923]=0.01-0.1 M. O/A=1. Diluent: toluene.

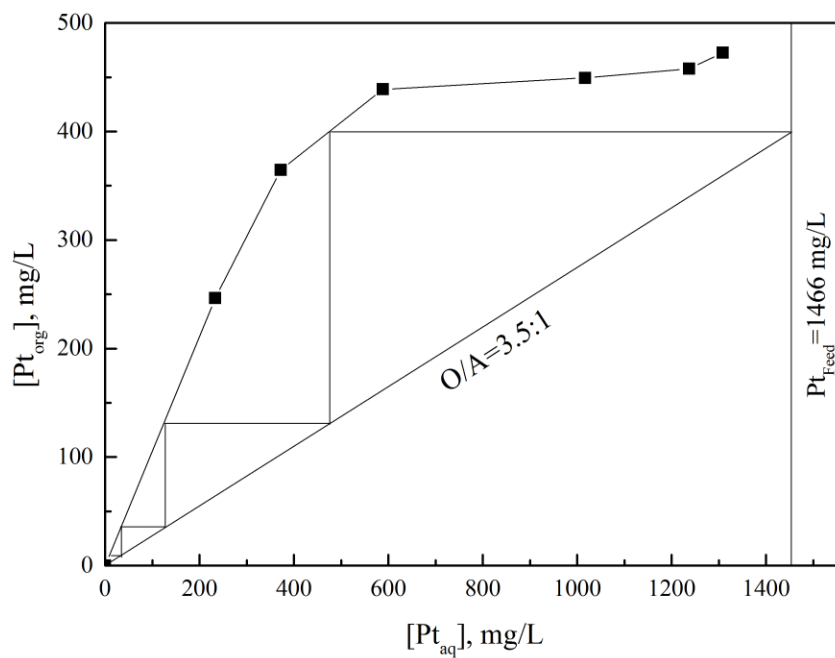


Fig. 5. McCabe-Thiele diagram for the extraction of Pt(IV). Leach liquor: $[Fe]=1.6$ mg/L, $[Pt]=1466$ mg/L, $[Rh]=178$ mg/L. Organic, $[Cyanex\ 923]=0.07$ M. O/A=1:3-5:1. Diluent: toluene.

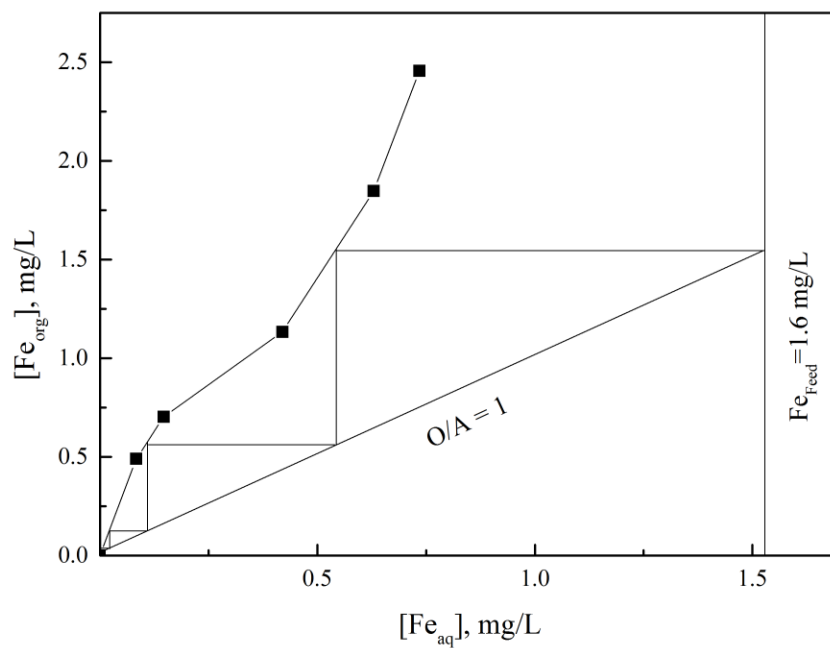


Fig. 6. McCabe-Thiele diagram for the extraction of Fe(III). Leach liquor: $[Fe]=1.6$ mg/L, $[Pt]=1466$ mg/L, $[Rh]=178$ mg/L. Organic: $[TBP]=0.1$ M. $O/A=1:3-3:1$. Diluent: kerosene.

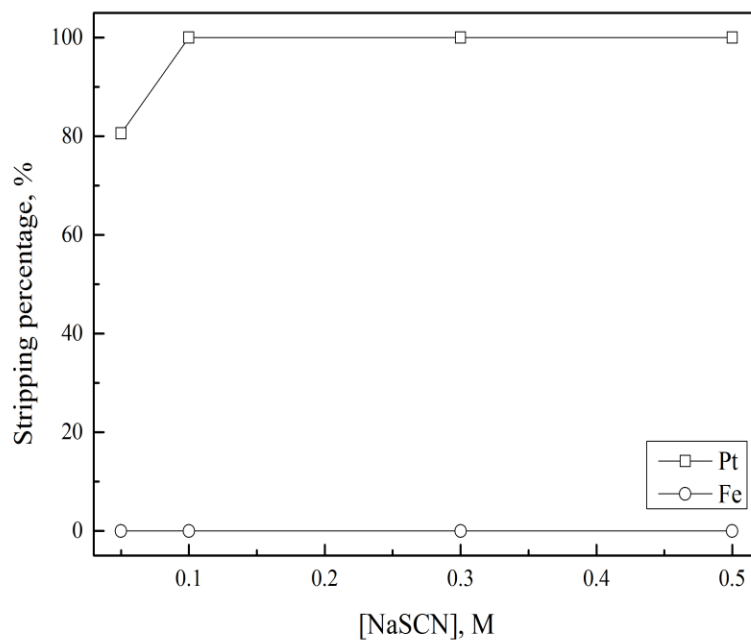


Fig. 7. Effect of NaSCN concentration on the stripping of Fe(III) and Pt(IV). Loaded Cyanex 923 in toluene phase: [Fe]=1.47 mg/L, [Pt]=422 mg/L. Stripping agent, [NaSCN]=0.05-0.5 M. O/A=1.

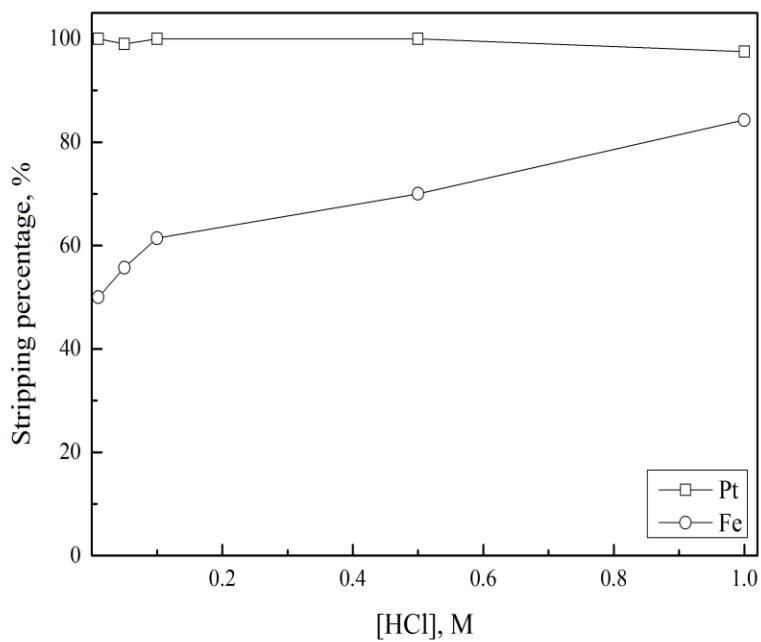


Fig. 8. Effect of HCl concentration on the stripping of Fe(III) and Pt(IV). Loaded Cyanex 923 in toluene phase: [Fe]=1.47 mg/L, [Pt]=422 mg/L. Stripping agent: [HCl]=0.01-1.0 M. O/A=1.

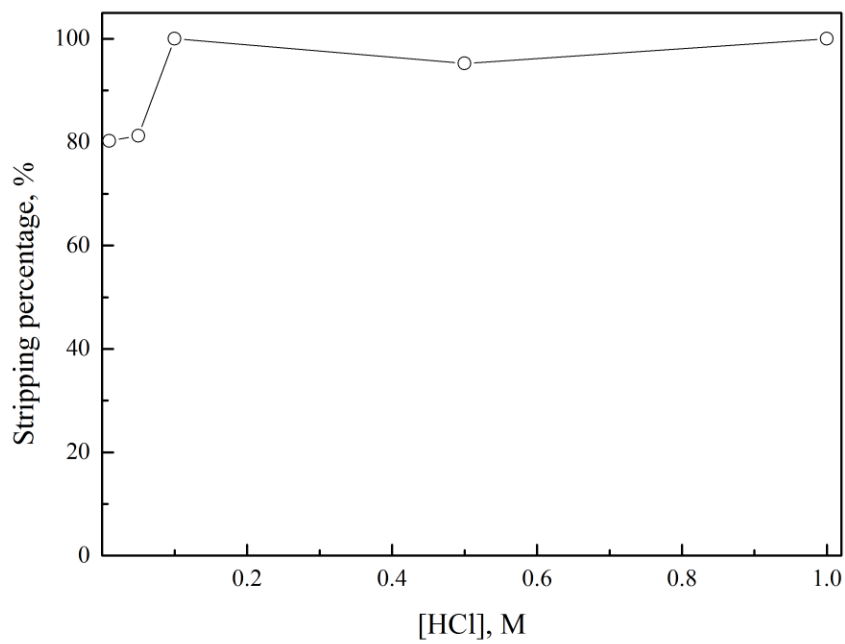


Fig. 9. Effect of HCl concentration on the stripping of Fe(III). Loaded TBP in kerosene phase:

[Fe]=1.47 mg/L. Stripping agent, [HCl]=0.01-1.0 M. O/A=1.

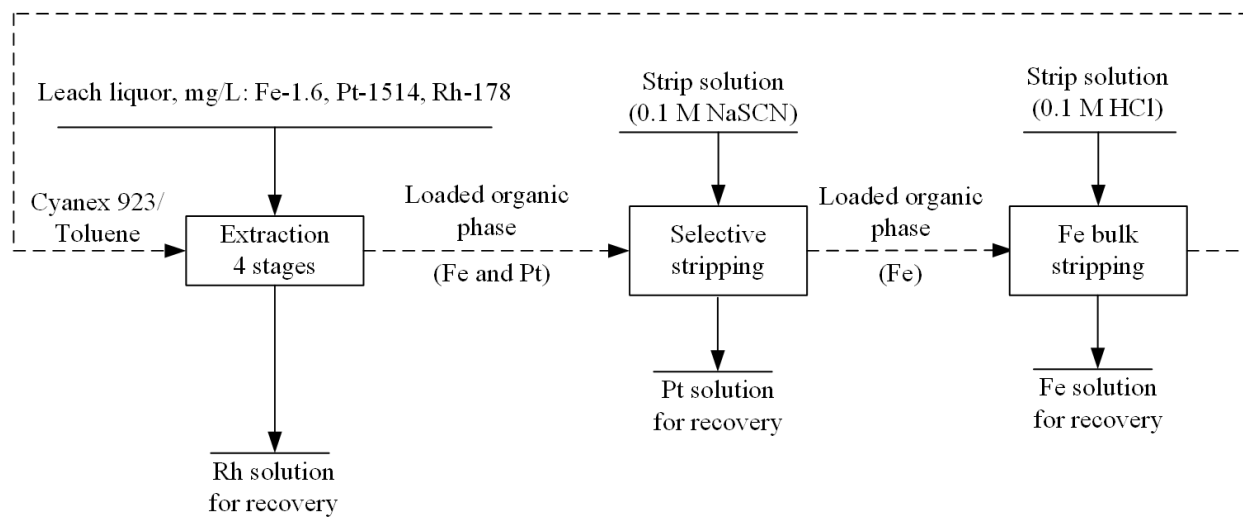


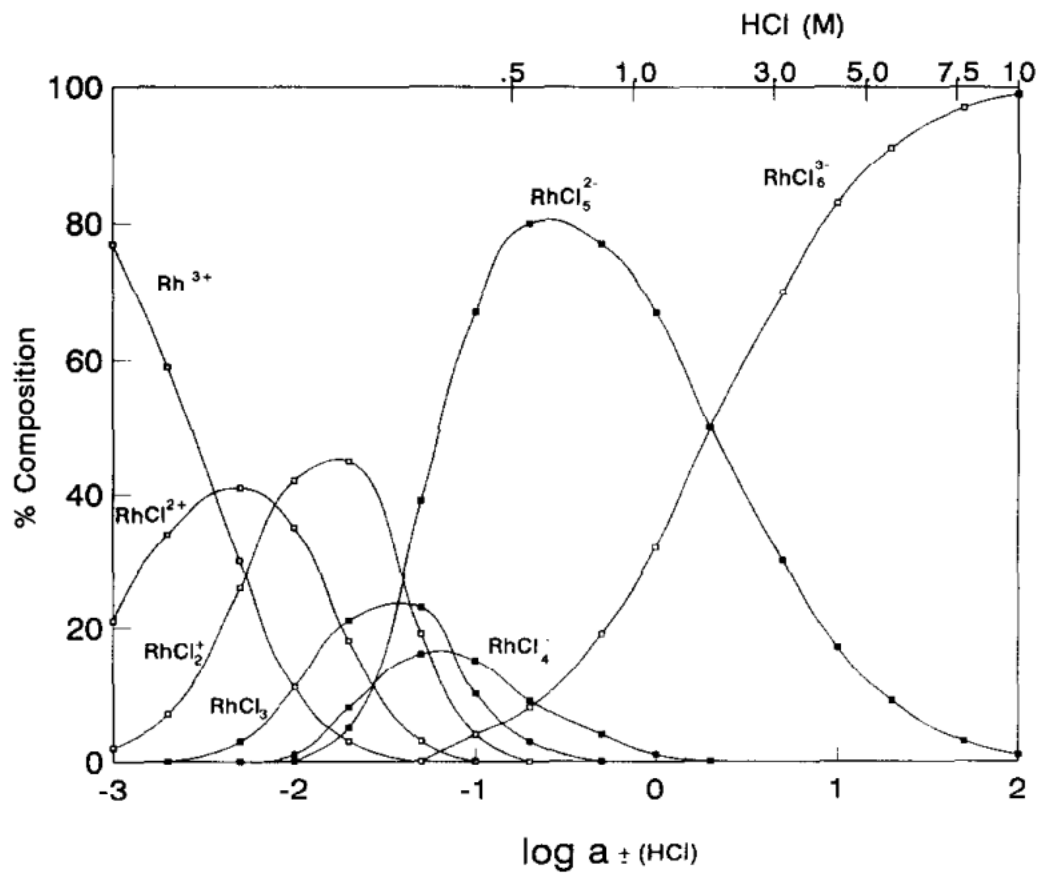
Fig. 10. Proposed flowsheet for recovery of Fe(III), Pt(IV), and Rh(III) from acid leaching solution of glass industry scarp by solvent extraction.

Appendix 1. Chemical formula and structure of extractants used in this study

Extractant	Structure	R or R' group
TBP		R = <i>n</i> -butyl
Cyanex 923		R = <i>n</i> -octyl R' = <i>n</i> -hexyl
TOA		R = <i>n</i> -octyl
Alamine 336		R = <i>n</i> -octyl/ <i>n</i> -decyl

TBP (tri-*n*-butyl phosphate), Cyanex 923 (a mixture of four trialkyl phosphine oxides), TOA (tri-*n*-octyl amine), Alamine 336 (tricaprylamine).

Appendix 2. Distribution diagram of Rh(III) in hydrochloric acid solutions (Benguere1 et al., 1996).



Highlights

- A process was proposed to recover Pt(IV) and Rh(III) from glass scraps.
- The Pt(IV), Rh(III) and Fe(III) in leachate was separated by solvent extraction.
- Fe(III) was selectively extracted over Pt(IV) and Rh(III) by TBP. .
- Selective extraction of Pt(IV) and Fe(III) over Rh(III) by Cyanex 923.
- Pt(IV) and Fe(III) in loaded Cyanex 923 was stripped by NaSCN and HCl.