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Valorization of a mining effluent by selective recovery of Zn using solvent extraction

Marta Avila, Gustavo Perez and Manuel Valiente

Universitat Autònoma de Barcelona, Spain

Abstract. Zn is a typical metal component of acidic mining waters. Its selective recovery is a goal to valorize such effluents and also to minimize the cost for the mandatory treatment of such effluents. To this purpose, a solvent extraction process was developed successfully in our laboratories after comparing the results of applying different organophosphorous acids such as di-(2-ethylhexyl)-phosphoric acid (D2EHPA) and bis-(2,4,4-trimethylpentyl)-phosphinic acid (CYANEX 272 and IONQUEST 290) to a specific acidic mine effluent of South Spain (Aznalcollar Mine). Results showed that kinetics is faster with CYANEX 272 (CY) and IONQUEST 290 (IQ) than with DEHPA, reaching a 95% of the Zn recovery at less than 5 minutes for CY and IQ and 10 min for DEHPA. Regarding the selectivity, DEHPA extracts more efficiently Al and Ca than Zn. Ca is re-extracted from the organic phase to the stripping phase, providing an effluent almost saturated with gypsum, that will interfere in the EW process. In addition, Al is not re-extracted from the organic phase causing poisoning of DEHPA and avoiding their future reutilizations. On the other hand, neither IQ nor CY indicates Al, Cu, Mn or Ca enrichment in the stripping solution thus there is no need for scrubbing the organic phase. IQ recovery of Zn is 5-10% higher than for CY. Taking into account all these results, the best solvent considered for the extraction of Zn was IONQUEST 290.

Keywords. Mining effluent – Solvent extraction – Zinc –DEHPA - IONQUEST 290 – CYANEX 272.

Valorisation des effluents miniers par récupération sélective du Zn utilisant l'extraction par solvant

Résumé. Le zinc est un composant métallique typique des eaux acides minières. Sa récupération sélective est une étape fondamentale pour valoriser ces effluents et minimiser les coûts de leur traitement obligatoire. A cette fin, un processus d'extraction par solvant a été mis au point avec succès dans nos laboratoires après avoir comparé les résultats de l'application des différents composés organophosphorés tels l'acide phosphorique di(2-éthylhexyl) (D2EHPA) et l'acide bis-(2,4,4-triméthylpentyl)-phosphinique (CYANEX 272 et IONQUEST 290) à des effluents acides minières dans le sud de l'Espagne (mine d'Aznalcollar). Les résultats ont montré que la cinétique est plus rapide avec le CYANEX 272 (CY) et l'IONQUEST 290 (IQ) qu'avec le DEHPA, permettant de récupérer 95% de Zn en moins de 5 minutes dans le cas du CY et de l'IQ et de 10 minutes dans le cas du DEHPA. S'agissant de la sélectivité, le DEHPA extrait plus efficacement l'Al et le Ca que le Zn. Le Ca est ré-extrait de la phase organique à la phase d'extraction, produisant ainsi des effluents presque saturés en gypse, qui vont interférer dans le processus d'EW. En plus, l'Al n'est pas ré-extrait de la phase organique provoquant une contamination du DEHPA et évitant une réutilisation future. Par ailleurs, ni l'IQ, ni le CY n'indiquent un enrichissement en Al, Cu, Mn ou Ca dans la solution d'extraction pas plus que dans la solution organique rendant ainsi nécessaire le scrubbing de la phase organique. La récupération du zinc avec l'IQ est 5 à 10% plus élevée qu'avec le CY. A la lumière de ces résultats, l'IONQUEST 290 s'avère être le meilleur solvant pour l'extraction du zinc.

Mots-clés. Effluent minier – Extraction par solvant – Zinc – DEHPA – IONQUEST 290 – CYANEX 272.

I – Introduction

Developing viable ways of recycling industrial waters such as mining effluents rather than the simple disposal of the effluents and their derivate sludge as a hazardous waste in specially controlled landfills is extremely important from an environmental and economical point of view. In a currently abandoned mine in Andalusia, Spain, huge streams of effluents, containing about 1 g/l Zn and significant amount of calcium, copper, aluminium and manganese cations were treated in order to obtain pure Zn. Zinc is the fourth most commonly used metal in the world trailing only

iron, aluminum and copper in annual production. Over 7 million tons of zinc are produced annually worldwide. Nearly 50% of the amount is used for galvanizing to protect steel from corrosion, approximately 19% is used to produce brass and 16% goes into the production of zinc base alloys to supply the die casting industry. Significant amounts are also utilized for compounds such as zinc oxide and zinc sulfate and semi-manufactures including roofing, gutters and down-pipes. These first-use suppliers then convert zinc into a broad range of products such as rubber in tyres, ointments to prevent bacteria and fungi from reproducing, in sunscreen, TV screens and luminous dials amongst others. These broad types of uses give zinc high economic value (Adriano, 2000).

Conventional treatment methods for zinc extraction and purification included precipitation, ion exchange, adsorption, electrochemical recovery, membrane separation and solvent extraction. Amongst those, solvent extraction (SX) has been widely proposed as one of the best ways to extract Zn from waters containing Zn and other impurities for being one of the most economical and practical processes (Devi, 1997). This is a very-well established process in hydrometallurgy used for the recovery of a large number of metals from aqueous sources. This process involves the use of an extractant usually diluted in an organic solvent. In this process, the solution containing the metal/s of interest is contacted with the extractant solution where the target elements are extracted from the initial solution. Once the extraction process has taken place, a re-extraction process or strip from the organic phase that contains the extractants “bonded” with the metals is necessary to get a clean solution with the target metals. Usually this re-extraction step is carried out with some acidic solution (strip solution) with higher affinity with the target metals than the extractant. Sometimes, when the organic phase has higher affinity for some metal/s than the strip solution, further steps may be necessary, i.e. scrubbing of the solvent, previous to the strip of the target elements or regeneration of the extractant after the stripping phase for further applications. The latter steps involve an increase in the cost due to spent in reactants as well as in time. These steps are summarized in Nowadays, a wide number of extractants are available for use in solvent extraction for the recovery of metals. Some of them are suitable for a specific metal; others must be used at certain conditions to avoid extraction of impurities. The most widely used extractants for Zn recovery are those corresponding to the organophosphorous acids group, i.e. DEHPA and CYANEX, commonly used in SX. In this study, a new commercial extractant never tested before, IONQUEST 290, is compared with the results of DEHPA and CYANEX in samples obtained from the mentioned Zn rich mine effluent in order to get a Zn sulphate rich liquor to be used later in an electrowinning plant..

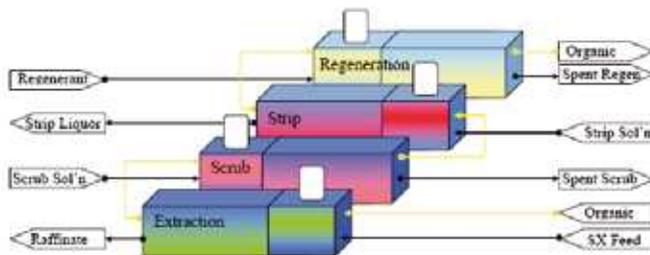


Figure 1. Typical solvent extraction process steps.

Nowadays, a wide number of extractants are available for use in solvent extraction for the recovery of metals. Some of them are suitable for a specific metal; others must be used at certain conditions to avoid extraction of impurities. The most widely used extractants for Zn recovery are those corresponding to the organophosphorous acids group, i.e. DEHPA and CYANEX, commonly used in SX. In this study, a new commercial extractant never tested before, IONQUEST 290, is compared with the results of DEHPA and CYANEX in samples obtained from the mentioned Zn rich mine effluent in order to get a Zn sulphate rich liquor to be used later in an electrowinning plant.

Di-(2-ethylhexyl)phosphoric acid (DEHPA) has been successfully used as an extractant for many metal ions, including zinc (Ritcey, 1971; Kunzmann, 1992; Sastre, 1984) due to its great extraction capacity and low cost. It has been used to extract zinc more efficiently than other bivalent metal ions (Grimm, 1974) such as copper, nickel, cobalt and cadmium. The order of extraction of eight metal ions from a sulphate solution using DEHPA has been reported as a function of pH (Ritcey and Ashbrook, 1984) to be $Fe^{3+} > Zn^{2+} > Cu^{2+} > Co^{2+} > Ni^{2+} > Mn^{2+} > Mg^{2+} > Ca^{2+}$ where zinc is extracted much earlier than manganese. In a more recent study of the separation of divalent metal ions from a synthetic laterite leach solution (Cheng, 2000), the extraction of metal ions was in the order $Zn^{2+} > Ca^{2+} > Mn^{2+} > Cu^{2+} > Co^{2+} > Ni^{2+} > Mg^{2+}$. By varying the acidic conditions and the temperature as main parameters, the target metal can be separate from the bulk solution or even different metals can be extracted separately by varying in various steps the conditions to get pure solutions of the target metals.

CYANEX 272, which is a commercial dialkylphosphinic acid produced by Cytec, has been used as well as its thiosubstituted derivatives (CYANEX 302 and CYANEX 301) in the extraction of several metal ions. Various studies report the adequacy of Cyanex 272 to extract, for instance, Fe, Zn, Cr, Cu and Ni from sulphuric and/or sulphate solutions (Rickelton, 1990; Lanagan, 2003; Rickelton, 1984; Reddy, 2001).

In the present study, to achieve greater recoveries of improved selectivity, another commercial extractant, IONQUEST 290, was selected, having the same active ingredient of CYANEX 272, Bis(2,4,4-TriMethylPentyl) Phosphinic Acid. However, IONQUEST 290, provides an average a 5-10% higher activity than in Cyanex 272. Two kerosene types with different flash point were employed as a solvent for this extractant, Ketrul D80 and Ketrul D100, with a flash point of 72 °C and 100°C or superior (ISO 2719), respectively. It must be pointed out that the higher the flash point, the lesser the flammability of the kerosene, and, therefore the higher the security of the solvent extraction process, specially when it is applied at outside warm climate conditions.

Thus, the aim of this work is to investigate the solvent extraction/stripping processes for the recovery of zinc from a mine effluent using either DEHPA, CYANEX 272 or IONQUEST 290 as extractants to identify the best extractant regarding the efficiency as well as the process selectivity. In addition, we want to determine the best type of kerosene to be used as a solvent for the mentioned extraction/stripping process.

II – Methods

Sample description. The initial solution from the mine tailing was previously treated in order to remove the Fe content since no extractants capable to extract Zn selectively from a solution containing Fe are commercially available. Thus, a previous step involving the Fe precipitation by a biooxidation process using *Thiobacillus ferrooxidans* (Mazuelos, 2000; Carranza, 1993) was mandatory. This process was implemented in the pilot plant on a specific reactor developed by Prof. F. Carranza, from the Seville University. After iron removal, a representative sample of Aznalcollar Corta effluent was received from EGMASA at our laboratories. The solution was colourless and with a pH value of 3.7. The Zn concentration and other metal impurities were determined by ICP-OES analysis, having a content of 210 ppm of Al, 580 ppm of Ca, 45 ppm of Cu, 1.2 ppm of Fe, 195 ppm of Mn and 881 ppm of Zn amongst other elements.

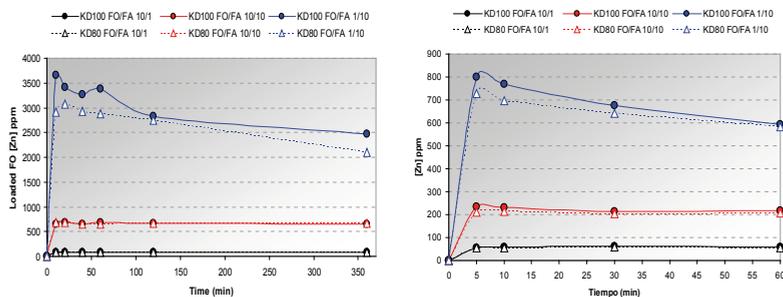
Reagents. DEHPA (Batch ref. 0063829) was purchased from Rhodia INC, Cranbury, NJ, USA. Kerosene solvent with Flash Point 80 and 100 (Bath ref. 20062016 and 20061560, respectively) was purchased from TOTAL FLUIDES, Oudalle, France. IONQUEST 290 (Batch Ref. G05A1) was supplied by Rhodia Ltd, Oldbury, United Kingdom. The stripping of the organic enriched phase was performed using 2.0 M sulphuric acid solution. Sulphuric acid was purchased from J.T. Baker, Phillipsburg, NJ, USA. The two phases contact experiments were carried out in 50 mL stoppered glass tubes agitated by a rotating rack. The experiments to obtain the isotherms of

the solvent extraction procedure were carried out varying the Vorg/Vaq ratio from 0.1 to 10 using stoppered glass tubes on a rotary rack. No centrifugation of the dual phase system was needed because of the clear phase separation obtained. Selectivity of Zn extraction is determined by metal impurities in the recovered liquor by means of ICP-OES analysis using a ThermoElemental ICP-OES (model Intrepid II XLS, Franklyn, MA, USA) on the obtained 2.0 M sulfuric acid stripping, considering the metals concentration in the initial effluent. All of them were used as it is without any further purification.

Procedure. Batch experiments were carried out by equilibrating equal volumes of CYANEX 272 or IONQUEST 290 at 5% v/v and DEHPA at 40% in each type of kerosene with the liquor containing the metals in stoppered glass tubes and were agitated using an end-over-end shaker. The different DEHPA concentration is due to reasons of efficiency (extraction yield vs extractant cost). For the kinetic experiments, the time of agitation was varied ranging from 5 to 30 minutes. For the experiments varying the equilibrium pH, the time of agitation was 30 minutes. After the extraction and phase separation, the stripping of the organic solution loaded with the metals was carried out during 30 minutes with an equal volume of H₂SO₄ 2.0 M. The concentration of the metals in the re-extracted phase and in the aqueous phase after separation were analysed using a Thermo ICP-OES Intrepid II. The experiments to obtain the isotherms of the solvent extraction procedure were carried out varying the Vorg/Vaq ratio from 0.1 to 10 using stoppered glass tubes on a rotary rack. No centrifugation of the dual phase system was needed because of the clear phase separation obtained. Selectivity of Zn extraction is determined by metal impurities in the recovered liquor by means of ICP-OES analysis using a ThermoElemental ICP-OES (model Intrepid II XLS, Franklyn, MA, USA) on the obtained 2.0 M sulfuric acid stripping, considering the metals concentration in the initial effluent. % Remaining OP was found by difference of the % Remaining AP of the metal and the % Recovery found in the strip solutio

III – Results and discussion

Kinetics experiments. Extraction kinetics data are given below for Zn and metal impurities such as Ca, Al, Cu, Fe and Mn for the extractants DEHPA and CYANEX 272, the latter having a behaviour similar to that of IONQUEST 290.

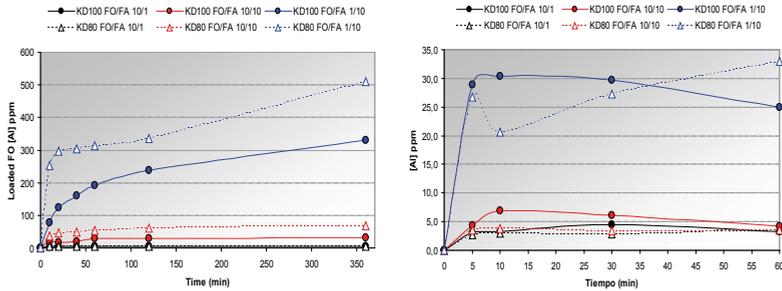


Figures 2 and 3. Comparison of Zn (organic phase) extraction kinetics when using kerosene flash point 80 and 100 at different organic/aqueous (FO/FA) ratio with DEHPA 40% (left) and CYANEX 272 5% (right).

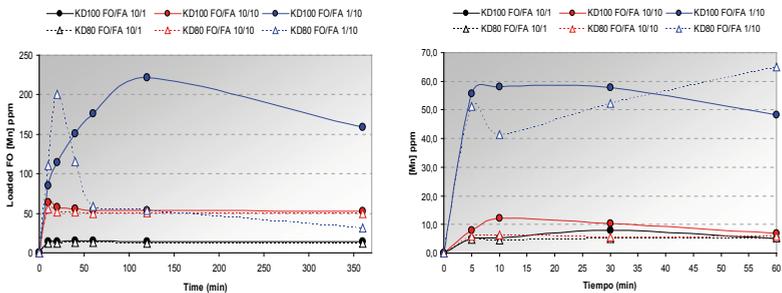
It is observed for both extractants, DEHPA and CYANEX, that less than 10 min are enough to reach the equilibrium for Zn extraction. No significant differences for Zn extraction were observed for the two flash point kerosene.

The higher recoveries obtained for kerosene with a flash point of 80 can be attributed to the higher solubility of the corresponding Al-DEHPA complex in this media. More than 10 minutes are necessary to reach the extraction equilibrium for both extractants. Comparing these data with

those obtained for Zn, it is observed a higher extraction and a faster kinetics for Zn, independently of the employed kerosene. The highest differences in terms of extracted amounts are observed for a Vorg/Vaq 1/10 phase ratio. Almost an order of magnitude is observed between the extracted amounts of Zn and Al, and those differences are exacerbated in kerosene with flash point 100.

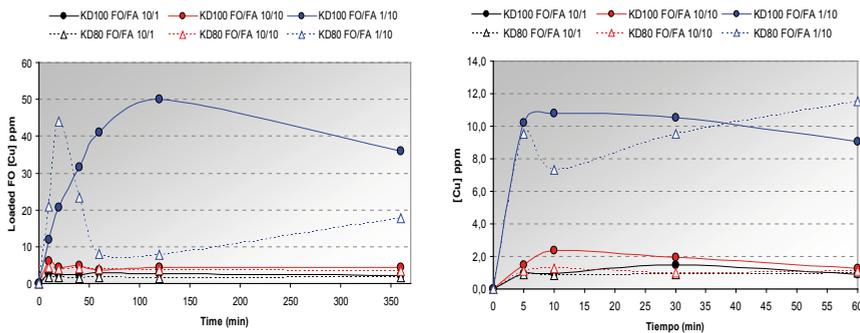


Figures 4 and 5. Comparison of Al (organic phase) extraction kinetics when using kerosene flash point 80 and 100 at different organic/aqueous (FO/FA) ratio with DEHPA 40% (left) and CYANEX 272 5% (right).



Figures 6 and 7. Comparison of Mn (FO) extraction kinetics when using kerosene flash point 80 and 100 at different organic/aqueous (FO/FA) ratio DEHPA 40% (left) and CYANEX 272 5% (right).

The comparison of Mn extraction kinetic with that of Zn shows a similar behaviour in terms of time needed to reach the equilibrium independently of the considered kerosene. Higher differences between the enrichment of the organic phase are observed for kerosene flash point 80 when comparing Zn and Mn rather than when using kerosene flash point 100.



Figures 8 and 9. Comparison of Cu (FO) extraction kinetics when using kerosene flash point 80 and 100 at different organic/aqueous (FO/FA) ratio DEHPA 40% (left) and CYANEX 272 5% (right).

As an impurity, the enrichment of Cu in the stripping indicates that the highest amounts are observed for the 1/10 ratio, especially for the kerosene flash point 100. The extraction equilibrium was reached at 120 minutes. No differences between both kerosenes were observed, except for the Vorg/Vaq 1/10 phase ratio where kerosene with a flash point of 80 released higher amounts of Fe.

For Ca, the main difference is observed again for the 1/10 ratio phase, the organic phase being more enriched for kerosene FP 100 once the equilibrium is reached. When dealing with Ca, the comparison against Zn, indicates that almost no differences are observed from the kinetic point of view. However, it is interesting to highlight the higher difference on the organic phase enrichment ratio between Zn and Ca when considering kerosene flash point 80, on the 1/10 phase ratio.

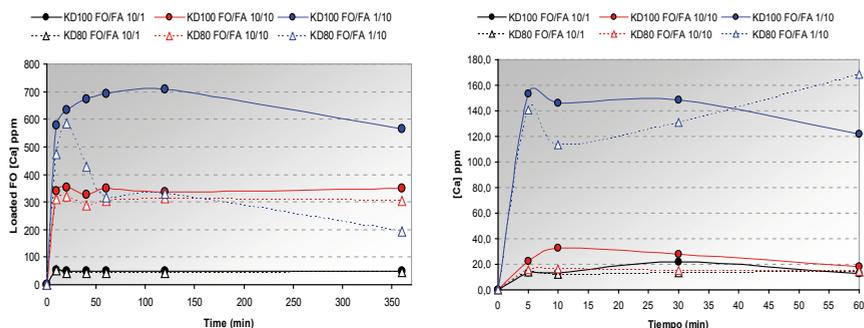


Figure 10 and 11. Comparison of Ca (FO) extraction kinetics when using kerosene flash point 80 and 100 at different organic/aqueous (FO/FA) ratio DEHPA 40% (left) and CYANEX 272 5% (right). FO=Organic Phase.

As a conclusion, kinetics of Zn extraction for both extractants employed, DEHPA and CYANEX 272, report no big differences. In terms of the other metals present, DEHPA followed the next trend: Zn > Ca > Al > Mn > Cu, being all the extractions of the interfering metals slower than for CYANEX that presents similar kinetics for all the metals in the solution. Thus, when using DEHPA short equilibrium times must be considered although for CYANEX 272 no differences will be found. Considering both solvents, Ketrul D80 and Ketrul D100, no big differences were found.

Selectivity. From the point of view of the selectivity, experiments varying the aqueous phase volume against a constant volume of the organic phase containing DEHPA and vice versa were realised. Recoveries achieved and percentage of the elements remaining in the aqueous phase after extraction process (FA) and percentage of metal remaining in the organic phase after stripping process (OP or FO) are shown in Table 1. Percentage of recoveries, element remaining in the aqueous phase (AP) and element remaining in the organic phase (OP) achieved using DEHPA for kerosenes Ketrul D80 and Ketrul D100 when varying the aqueous phase volume. Table 2.

Table 1. Percentage of recoveries, element remaining in the aqueous phase (AP) and element remaining in the organic phase (OP) achieved using DEHPA for kerosenes Ketrul D80 and Ketrul D100 when varying the aqueous phase volume.

FAP	FOP	Ketrul D80			FAP	FOP	Ketrul D100		
		% Recovery	% Remaining AP	% Remaining OP			% Recovery	% Remaining AP	% Remaining OP
Zn									
10	10	72,75	17,41	9,84	10	10	74,77	17,80	7,43
7	10	77,81	13,95	8,24	7	10	75,53	14,10	10,37
5	10	77,99	11,05	10,97	5	10	78,61	11,47	9,91
3	10	81,48	7,97	10,56	3	10	83,98	8,38	7,64
1	10	86,69	4,96	8,35	1	10	92,46	5,05	2,49
Ca									
10	10	54,34	30,35	15,31	10	10	59,01	25,14	15,84
8	10	60,43	27,34	12,23	8	10	63,46	21,74	14,80
5	10	65,43	19,56	15,01	5	10	67,07	15,42	17,51
3	10	68,14	15,21	16,65	3	10	69,35	11,26	19,40
1	10	76,66	11,11	12,23	1	10	79,72	7,47	12,81
Al									
10	10	18,89	3,55	77,56	10	10	12,92	9,19	77,88
8	10	20,95	3,41	75,64	8	10	18,17	4,45	77,38
5	10	27,80	0,65	71,55	5	10	21,91	1,76	76,33
3	10	22,39	0,00	77,61	3	10	17,60	0,80	81,60
1	10	25,06	0,00	74,94	1	10	25,78	0,00	74,22
Mn									
10	10	23,97	71,61	4,42	10	10	29,34	72,95	0,00
8	10	28,16	66,63	5,21	8	10	34,10	68,76	0,00
5	10	35,61	56,32	8,08	5	10	43,05	58,16	0,00
2	10	48,47	40,45	11,08	2	10	59,13	39,97	0,89
1	10	56,45	34,76	8,79	1	10	67,24	33,45	0,00
Cu									
10	10	5,77	98,45	0,00	10	10	9,70	97,53	0,00
8	10	6,90	95,13	0,00	8	10	11,60	97,13	0,00
5	10	9,85	89,89	0,26	5	10	18,11	91,57	0,00
3	10	13,33	87,45	0,00	3	10	22,45	86,55	0,00
1	10	21,81	79,45	0,00	1	10	34,79	77,49	0,00

Table 2. Percentage of recoveries, element remaining in the aqueous phase and element remaining in the organic phase achieved using DEHPA for kerosenes Ketrul D80 and Ketrul D100 when varying the organic phase volume.

AP	OP	Ketrul D80			AP	OP	Ketrul D100		
		%Recovery	% Remaining AP	% Remaining OP			%Recovery	% Remaining AP	%Remaining OP
Zn									
10	8	73,83	21,44	4,72	10	8	74,40	17,70	7,90
10	5	64,31	27,61	8,08	10	5	62,14	25,85	12,01
10	1	31,40	66,10	2,50	10	1	36,83	59,22	3,95
Ca									
10	8	56,91	29,08	14,01	10	8	58,25	28,66	13,09
10	5	49,57	41,08	9,35	10	5	49,49	37,97	12,54
10	1	9,37	85,31	5,32	10	1	11,60	84,69	3,71
Al									
10	8	21,76	2,29	75,95	10	8	15,74	0,44	83,82
10	5	17,70	1,36	80,94	10	5	13,30	15,44	71,26
10	1	6,56	65,66	27,79	10	1	5,26	75,16	19,58
Mn									
10	8	21,49	77,92	0,59	10	8	25,08	75,84	-0,92
10	5	14,16	83,50	2,34	10	5	18,59	84,71	-3,30
10	1	2,44	104,45	-6,89	10	1	4,70	103,08	-7,78
Cu									
10	8	5,33	-4,63	99,30	10	8	6,90	98,26	-5,16
10	5	4,19	-3,45	99,26	10	5	7,87	100,47	-8,34
10	1	1,57	-6,02	104,45	10	1	3,21	102,98	-6,19

As observed, metal extraction follows the sequence Zn>Ca>Mn>Al>Cu. Under these conditions Cu is practically non extracted from the solution. Elements with high %Remaining OP, are extracted by the extractant but were poorly released to the stripping solution (H₂SO₄ solution). This will cause fouling of the extracting phase because the saturation of the extractant, hindering its possible reuse. This behaviour is specially shown by Al. In general, using Ketrul D100 slight higher recoveries are achieved than using Ketrul D80. The variation of the OP/AP values resulted on the expected variation of the metal extraction. The poor selectivity of Zn extraction against Ca resulted on a gypsum precipitate in the stripping solution. To solve this drawback, CYANEX 272 and IONQUEST 290, two extractants with the same active ingredient that can selectively extract Zn from a solution containing Ca and other metals, were tested.

A comparison between 5% CYANEX 272 and 5% IONQUEST 290 is shown in Figure 12. The results obtained indicate a higher performance of IONQUEST 290 regarding Zn extraction efficiency, while Cu, Mn and Al show a similar behaviour with no practical differences and an extraction recovery always below 15%, meanwhile Ca illustrates a slightly different extraction recovery, being higher for IONQUEST 290 rather than for CYANEX 272. Neither IONQUEST 290, nor CYANEX 272 at the end of the stripping show Al, Cu, Mn or Ca enrichment, thus there is no need for scrubbing the solvent. Considering the different employed kerosene, no differences are observed for Zn independently of the employed extractant while the rest of interferences show higher extraction efficiency for kerosene F.P. 100, more pronounced in CYANEX 272 than in IONQUEST 290. Thus, Ionquest seems to be a more effective extractant for Zn, also indicating lower concentration of interfering elements in the stripped solution.

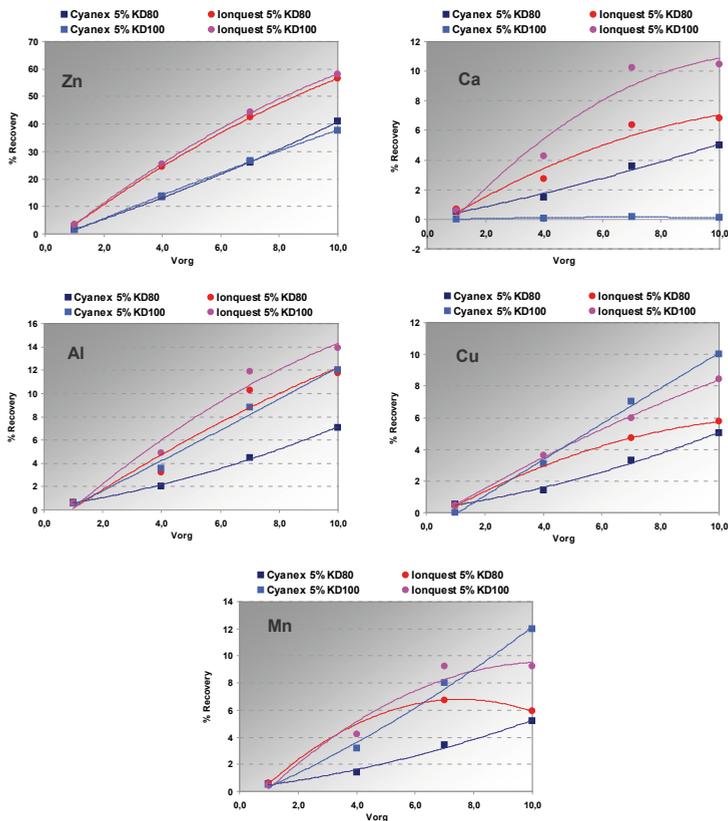


Figure 12. IONQUEST 290 5 % vs CYANEX 272 5% extraction efficiency using Kerosene F.P. 80 and 100.

Metal extraction increases when IONQUEST concentration increases. On the other hand, the observed extraction using 40% DEHPA is similar than that obtained by 20% IONQUEST and is not proportionally higher than the obtained by 5% IONQUEST (see Figure 13). No differences are observed between both employed kerosene. The most important difference when comparing IONQUEST 290 against DEHPA, is related to the Al and Ca extractability, mainly because IONQUEST 290 can greatly and selectively extract Zn without Al and Ca stripping enrichment, as Figure 13 clearly show. Despite, the low values in Ca extraction, this should be taken into account in the pilot plant when the process will be done several times with the same reactants. Taking into account this results, due to his higher recoveries achieved, IONQUEST 290 is found the most suitable extractant for the process.

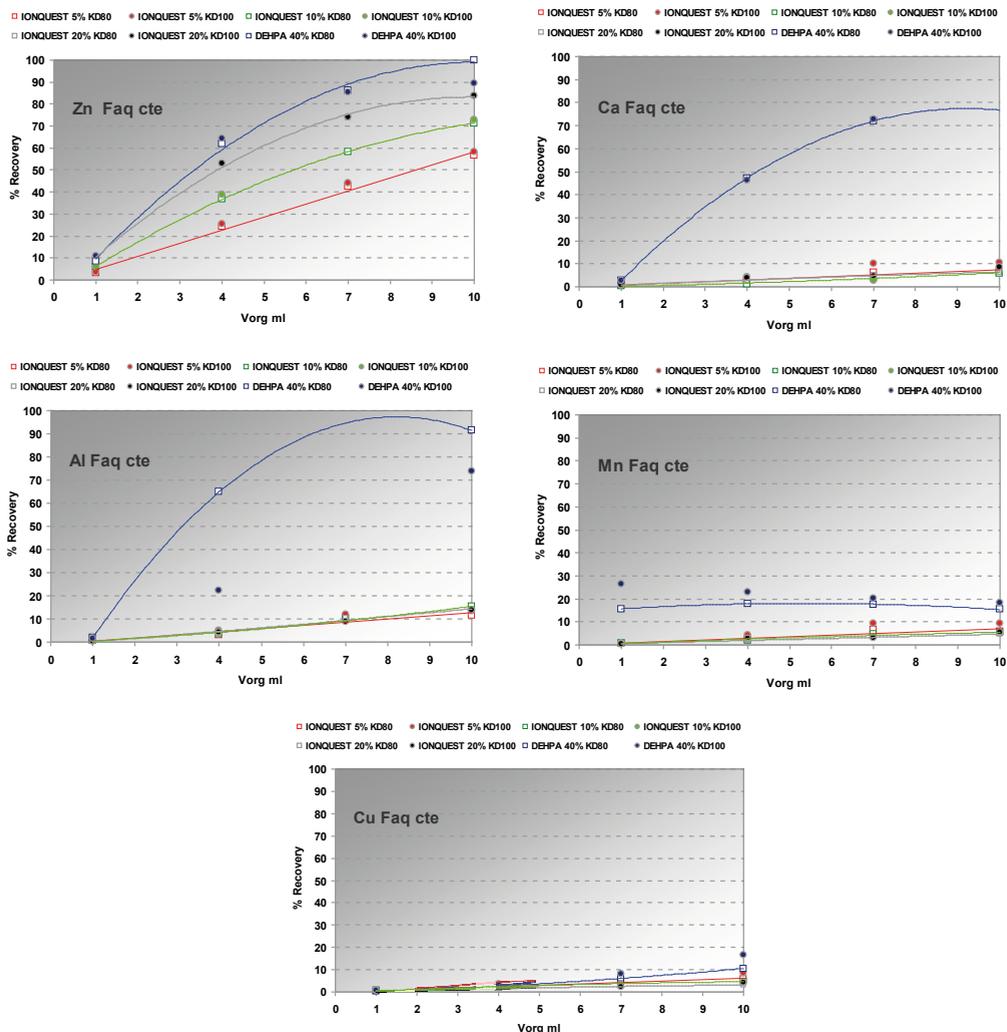


Figure 13. Recoveries obtained using IONQUEST 5% (red), IONQUEST 10% (green), IONQUEST 20% (black) and DEHPA 40% (blue) using Ketrol D80 (continuous lines) or Ketrol D100 (dashed lines).

Results from Figure 13 indicates a significantly higher recovery of Ca for DEHPA 40% than for Cyanex 5% or Ionquest 5%. Also, Cyanex 5% provides up to four times higher recovery of Ca than Ionquest 5%. These results indicate that the most selective extractant to minimize calcium extraction is Ionquest at a concentration of 5%. In addition, due to their higher price, five-seven times more than DEHPA, CYANEX 272 or IONQUEST 290 concentration should be as low as possible. Furthermore, is important to determine the amount of metals remaining in the organic phase to predict the design of the overall recovery process, i.e., additional scrubbing, washing steps. This parameter was determined by applying the metals mass balance to the extraction and recovery process. The average percentage of metals remaining in the extractant phase is given in the Table 3.

Table 3. Percentage of metals remaining in the organic phase after the extraction process.

Extractant	Ca	Cu	Mn	Al	Zn
DEHPA	30 ± 4 %	0 ± 3 %	3 ± 5 %	73 ± 4 %	7 ± 3 %
CYANEX	0 ± 4 %	0 ± 2 %	0 ± 4 %	0 ± 2 %	1,4 ± 0,6 %
IONQUEST	0 ± 6 %	0 ± 6 %	0 ± 5 %	0 ± 3 %	0 ± 2 %

From the results given in Table 3 Table 3. Percentage of metals remaining in the organic phase after the extraction process. It can be said that both IONQUEST and CYANEX are the extractants that have less capability of fouling because none of the metals analysed remained in the organic phase after the extraction process. In the case of DEHPA, high concentrations of Ca and Al were found.

VI – Conclusions

The most relevant conclusions of the study can be summarized as follows:

- DEHPA reagent was unable to extract Zn selectively from the solution at the target pH and temperature conditions. Moreover, high amounts of Ca were extracted creating a gypsum precipitate in the strip solution avoiding their possible use for electrowinning. Furthermore, Al was extracted from the leachate but not stripped out causing fouling of the extractant and avoiding their reuse.
- Using 5% extractant solutions, IONQUEST 290 presents the highest Zn extraction yield of the studied extractants. Comparable concentrations of Ca, Al, Cu and Mn in the stripping solution were obtained against those for CYANEX 272.
- As both solvents, Ketrul D80 and Ketrul D100 showed similar behaviour, Ketrul D100 is the solvent recommended due to its lower volatility and flammability.

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