



Solvent extraction and stripping of zinc from synthetic chloride solution in presence of manganese and cadmium as impurities

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Abstract

In this research work, solvent extraction and stripping of zinc ions from a Zn-Mn-Cd-bearing solution was investigated using D2EHPA as the extractant in a chloride medium. The efficiency of the extraction and stripping stages was evaluated separately, and different parameters such as the pH, extractant concentration, reaction temperature, and contact time were studied. Based on the results obtained, 97% of zinc, 14% of manganese, and 3% of cadmium were extracted at pH = 2.5, 10% (v/v) of D2EHPA, and 40 °C from the solution containing 5 g L⁻¹ of each metal ion. The stripping isotherms of zinc, manganese, and cadmium at different pH values showed that manganese and zinc were stripped at two different pH values. Thus more than 70% of manganese and more than 90% of zinc were stripped at pH = 2.5 and pH = 0.5, respectively. Kinetic studies indicated that the extraction and stripping of zinc in the first 0.5-1 minute was high. The McCabe-Thiele diagrams showed that two stages of extraction and two stages of stripping in the continuous counter-current flow condition were adequate to separate zinc from Mn and Cd. The dominant Zn species extracted by D2EHPA was ZnCl⁺, and the values for the thermodynamic parameters ΔH° , ΔS° , and ΔG° were 25.65 kJ mol⁻¹, 79.20 J K⁻¹ mol⁻¹, and 0.86 kJ mol⁻¹, respectively, which showed that the reaction was endothermic at equilibrium.

1. Introduction

In addition to the production of zinc from its concentrate, zinc retrieval of secondary sources of zinc such as waste and slag of brass smelting furnace, dust and ash of industrial processes, and non-metallic and automobile scraps are also possible. In these cases, lead and zinc-containing wastes are also one of the most suitable sources for lead and zinc production [1, 2]. More than 90% of the existing lead in these wastes can be dissolved in a chloride solution [3, 4]. As a result, the chloride dissolution method (mainly brine leaching) is widely used [5]. The PLS solution from the dissolution of lead and zinc wastes has many impurities. Among the impurities in the zinc-containing PLS solution, manganese and cadmium are the dominant species [6, 7]. In the process of zinc extraction from its concentrate by

the hydrometallurgical route, potassium permanganate is used to treat zinc solutions [8, 9]. Therefore, there are typically significant amounts of manganese in lead and zinc wastes (e.g. about 10% manganese in filter cake obtained from a warm refining) [9]. The cake filter produced by the cold refining is also one of the wastes in the zinc metal industry, which contains roughly a large content of zinc and cadmium (approx. 10-15%) [10]. The solvent extraction with properties such as the ability to extract metal from a high-impurity solution and also non-contamination of the environment is one of the most effective separating methods to extract zinc from different solutions [11]. Extraction of zinc from a chloride solution using various extraction agents such as the first and second

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group amine extractants, cationic extractants such as D2EHPA and Cyanex 272, and neutral extractants such as TBP and DPPP have been studied by various researchers [12-21]. According to the previous studies, D2EHPA is the best solvent extractant ever used for the recovery and extraction of zinc from different solutions. Features such as high extraction rates and low price have caused this extractant to be one of the most commonly used extraction agent in zinc solvent extraction, especially in the sulfate media. D2EHPA acts well at pH values between 1 and 3 for zinc extraction from solution. D2EHPA in the sulfate environment does not have a good function for zinc separation compared to manganese [22-26]. For separation of zinc from cadmium as an impurity, the results also indicated that the addition of a modifier improves the separation of zinc relative to cadmium [10, 27-30]. In contrast to the sulfate media, few studies have been conducted on the solvent extraction of zinc in the chlorine solution using this extractant. The previous research works done by authors have shown that D2EHPA has a good function in zinc separation compared to manganese and especially cadmium, and can be considered as an appropriate extraction agents in a chloride solution in the presence of the manganese and cadmium ions [31].

In this research work, solvent extraction of zinc from a chloride solution using D2EHPA was investigated in the presence of manganese and cadmium as impurities. A variety of influential parameters such as the extractant and ion concentrations, solution pH, reaction temperature, O:A ratio, and time were studied. Also this research work aimed to focus more on the stripping step of zinc; this has not been reported in the recent investigations. In the meantime, the behaviors of all the three elements were studied under different stripping conditions. The zinc stripping from the organic phase was studied, and the effective parameters such as the pH (acidity), temperature, and mixing time were optimized. Finally, the McCabe–Thiele diagrams for the extraction and stripping stages were plotted to determine the number of process stages required in the continuous counter-current flow condition. According to the McCabe–Thiele diagrams for the extraction and stripping stages, the general flowsheet of zinc solvent extraction from a chloride solution in the presence of manganese and cadmium ions was prepared. In order to study the extraction, stripping and separation of zinc, manganese, and cadmium ions

precisely, different separation indices of extraction percentage (E), distribution coefficient (D), and separation factor (β) were also calculated.

2. Materials and methods

2.1. Chemicals

In order to prepare a synthetic chloride solution containing the zinc, manganese, and cadmium ions, zinc chloride (ZnCl_2), manganese chloride ($\text{MnCl}_2 \cdot 4\text{H}_2\text{O}$), and cadmium chloride (CdCl_2) were supplied from Merck Co. (Germany). Industrial-grade D2EHPA with a 97% purity, used as the organic phase, was prepared from Bayer Co. (Germany). Dilution of D2EHPA was performed using kerosene, prepared from the Tehran Oil Refinery. Hydrochloric acid with a purity of 37% and ammonia with a purity of 25%, used to adjust the pH of the solutions in the extraction stage, and sulfuric acid with a purity of 98%, used for stripping the organic phase, were prepared from Merck Co. (Germany). To measure the acidity of the aqueous solution, the titration method was performed using NaOH and methylene blue, which were supplied from Merck Co. (Germany). All the chemicals were used without any purification.

2.2. Experimental procedures

Study of the zinc solvent extraction in the presence of the cadmium and manganese ions was carried out using a synthetic chloride solution with a concentration of 5 g L^{-1} from each ion (with a total concentration of 15 g L^{-1}). This synthetic solution was prepared by dissolving zinc, manganese, and cadmium chlorides in distilled water. The organic phase D2EHPA was diluted by kerosene at different volume percentages of 30% (30% D2EHPA and 70% kerosene), 20%, 10%, and 5%. The ratio of the organic to the aqueous phases (O:A) was considered as 1:1 for optimizing all the effective variables in the experiments.

The solvent extraction and stripping experiments were carried out in a laboratory fiberglass dish, which included baffles to mix the two-phase solution more. The two-phase solution mixing was carried out using a mechanical stirrer (IKA RW20 digital). In all experiments, the pH was measured by a pH-meter (lab 827 Metrohm pH-meter), and its adjustment in the extraction and stripping stages was performed using ammonia and sulfuric acid. The times of 10 minutes in the extraction tests and 15 minutes in the stripping tests were considered to complete the

reactions. In order to adjust and keep fixed the temperature, a bin Marie bath (WNB14 Memmert bath bin Marie) was used. After the complete separation of the aqueous and organic phases from each other, the aqueous solution was analyzed by an atomic absorption spectrometer (Varian AA240) to determine the ion concentrations, and the amount of ions in the organic phase was calculated using the mass balance. Determination of the solution acidity was carried out by titration with NaOH.

The extraction percentage (E) of the three ions (Zn, Mn, and Cd) from the aqueous phase was calculated using the following equation (Eq. 1):

$$\%E = \frac{[C]_{in.aq} - [C]_{fi.aq}}{[C]_{in.aq}} \times 100 \quad (1)$$

where $[C]_{in.aq}$ and $[C]_{fi.aq}$ are the initial and the final concentrations of the metal ion in the aqueous phase, respectively.

The stripping percentage of the three ions was calculated using the following equation (Eq. 2), which is almost the opposite of Equation 1:

$$\%S = \frac{[C]_{aq}}{[C]_{org}} \times 100 \quad (2)$$

where $[C]_{aq}$ is the concentration of the metal ion in the aqueous phase and $[C]_{org}$ is the concentration of the metal ion in the organic phase. This value was calculated by mass balance in the extraction stage.

The distribution coefficient (D) of the metal ion, which measures the value of the metal ion transport tendency from the aqueous to the organic phase, was calculated using the following equation (Eq. 3):

$$D = \frac{[C]_{org}}{[C]_{aq}} \quad (3)$$

where $[C]_{org}$ is the concentration of the metal ion in the organic phase and $[C]_{aq}$ is the concentration of the metal ion in the aqueous phase.

Also the separation factor (β) for Zn from the Mn and Cd ions was calculated using the following equation (Eq. 4):

$$\beta_{Zn/M} = \frac{D_{Zn}}{D_M}, \quad \beta_{M/Zn} = \frac{D_M}{D_{Zn}} \quad (4)$$

where D_{Zn} is the distribution coefficient of zinc and D_M is the distribution coefficient for the manganese or cadmium ions [32, 33].

3. Results and discussion

3.1. Extraction stage

3.1.1. Effects of pH and D2EHPA concentration

The effects of pH change and D2EHPA concentration on the extraction of the Zn, Mn, and Cd ions from the aqueous solution are presented in Figure 1. According to this figure, ion extraction increases with increasing pH. Due to the D2EHPA extraction mechanism, the reduction of H^+ concentration provides more metal ion extraction. Also with increase in the concentration of D2EHPA, zinc is extracted better in an acidic pH solution. For example, at an extractant concentration of 5% (v/v) and pH = 4, more than 98% of Zn is extracted. However, this amount of extraction occurs at pH=2 by 30% (v/v) D2EHPA. Studies carried out on D2EHPA for the extraction of zinc metal in sulfated and chlorinated environments show that this extractant is capable of extracting more than 90% zinc ion in an acidic pH [16, 21]. Also by increasing the concentration of D2EHPA, the extraction rates of the other ions (Mn and Cd) also increase. For example, at a pH value in the range of 1-6 and for an extractant concentration of 5% (v/v), the extraction of the manganese and cadmium ions is less than 20%; however, at an extraction concentration of 30% (v/v) at pH = 4, more than 90% of these ions are extracted from aqueous solutions. By selecting D2EHPA 10% (v/v) and pH = 2.5 as the solution acidity, 97% of Zn, 14% of Mn, and 3% of Cd were transferred to the organic phase in the extraction stage.

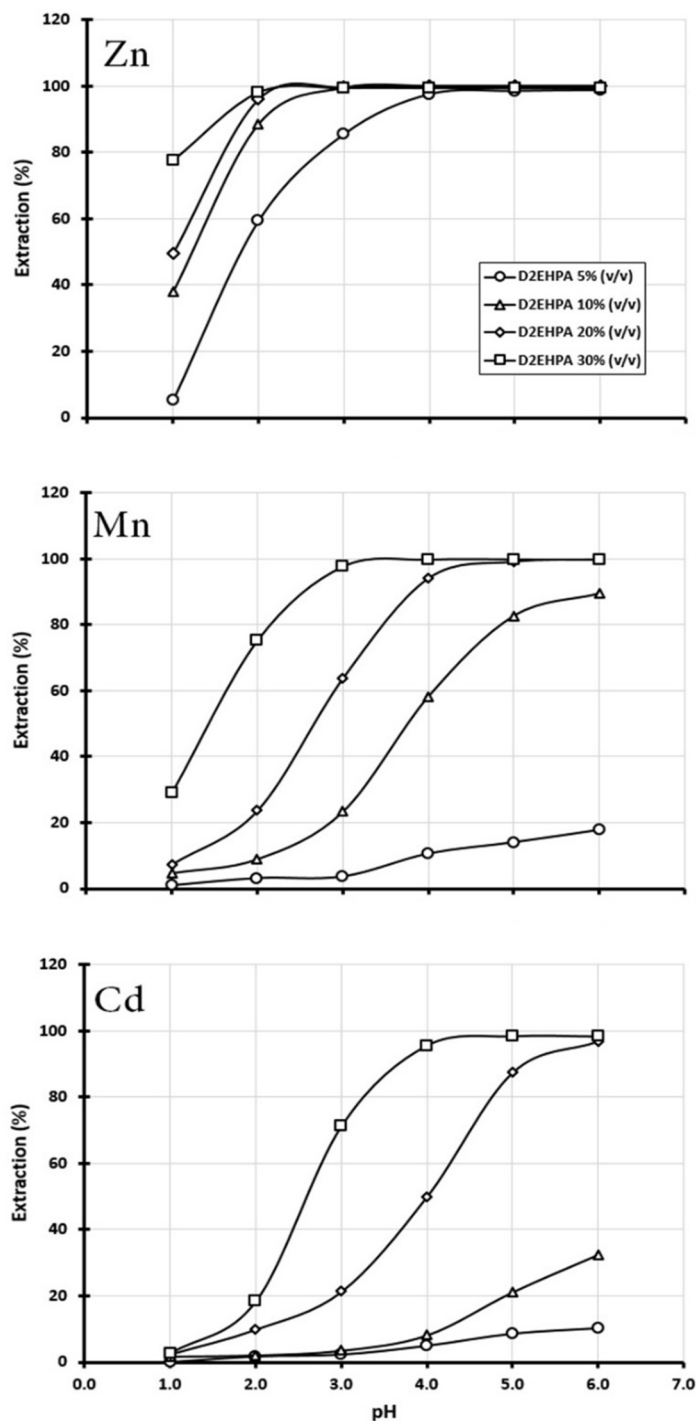


Figure 1. Effects of pH and D2EHPA concentration on zinc, manganese, and cadmium extraction at 40 °C and pH range of 1-6.

3.1.2. Effect of contact time

The study of the extraction kinetics of the Zn, Mn, and Cd ions from a chloride solution with a concentration of 5 g L⁻¹ for each ion (totally 15 g L⁻¹) was carried out using 10% D2EHPA (v/v) at a temperature of 40 ± 2 °C and pH = 2.5-3. The reaction time was considered to be in the range of 0.5-15 minutes. The variations in the extraction percentages of the three ions as a function of time

is shown in Figure 2. It could be seen that the extraction kinetics of all the three ions were high in the time interval of the first 0.5-1 minute. About 96.43% of Zn was extracted in the first 0.5 minute of reaction, while after 15 minutes, it was slightly changed and reached 97.79%. Also 11.06% of Mn was extracted in the first 0.5 minute, and it increased to 14.42% after 15 minutes. Interestingly, major changes in the

extraction percentage over time was for the Cd ions. About 10% increase in the extraction percentage was observed for this element after 15 minutes. It meant that Cd ions were extracted by about 8.4% in the first 0.5 minutes, reaching

18.09% in 15 minutes. According to the kinetics study at the time period of 5-10 minutes, the extraction was performed almost completely for all the three ions for a short period of time.

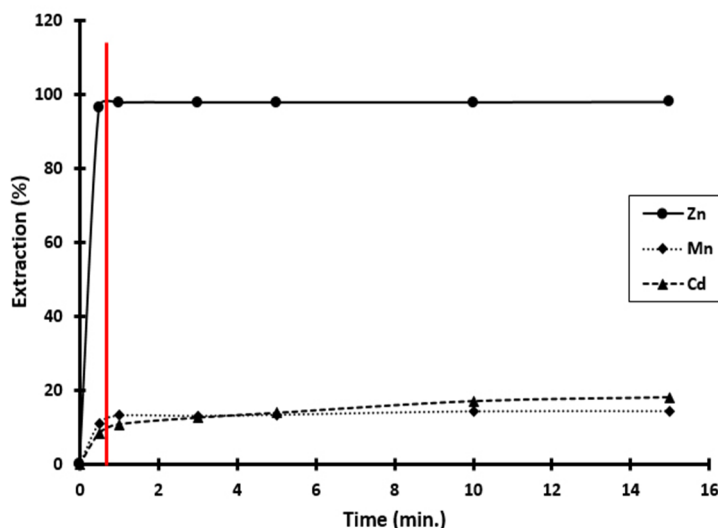


Figure 2. The extraction kinetics of Zn, Mn, and Cd in chloride solution using D2EHPA 10% (v/v) at 40 °C and pH = 2.5-3; the red line is the time with a high extraction rate.

3.1.3. Effect of temperature (thermodynamic study)

The thermodynamic and the mechanism of extraction of the zinc ion from chloride solution containing 5 g L⁻¹ of each zinc, manganese, and cadmium ions using D2EHPA 10% (v/v) have been completely studied in our previous research work [31]. Based on this study, among the temperatures of 30, 40, and 50 °C, the temperature of 40 °C was considered as the optimal one for the extraction stage. The results of the studies on the zinc extraction mechanism using the Medusa software and the slope analysis method showed that the following relation dominated the zinc extraction process; the Zn-bearing species extracted in this condition was ZnCl⁺.



Based on Eq. 5, the values for ΔH° , ΔS° , and ΔG° for zinc extraction at 40 °C and [D2EHPA] = 10 (v/v) were 25.65 kJ mol⁻¹, 79.20 J K⁻¹ mol⁻¹, and 0.86 kJ mol⁻¹, respectively. The amount of enthalpy change obtained from the experiments was a positive value, which indicated that zinc extraction with D2EHPA was an endothermic process. Studies on the sulfate medium also indicated that zinc extraction was an endothermic process [21]. Therefore, an increase in the reaction temperature resulted in an improved Zn ion

extraction. The positive amount of entropy change meant that the degree of system irregularity increased. According to the thermodynamic results, the extraction rate was high at the first 0.5 minute of the process, and reached equilibrium after a short period of time. Therefore, ΔG° was also a value close to zero, confirming this.

3.1.4. Effect of A:O ratio (distribution isotherm)

In order to find the number of stages to complete the zinc extraction in the presence of manganese and cadmium ions, the McCabe–Thiele plot was used. In these tests, pH was constant. The aqueous solution used for this purpose was the same as the previous one with a concentration of 5 g L⁻¹ for each ion. The distribution isotherm tests were performed in optimal conditions (D2EHPA 10% (v/v), and pH = 2.5-3) at A:O ratios between 10:1 and 1:10. According to the plot obtained, in the ratio of A:O = 1:1 as the operating line, two extraction steps were required under the counter-current flow condition in which zinc was extracted almost entirely from the aqueous solution (Figure 3). Pereira *et al.* indicated that 3 extraction stages were required to extract more than 98% zinc in the conditions of pH = 2.5, [D2EHPA] = 20% (w/w), A/O = 1, and [Zn]_{aq} = 13.5 g/L [34].

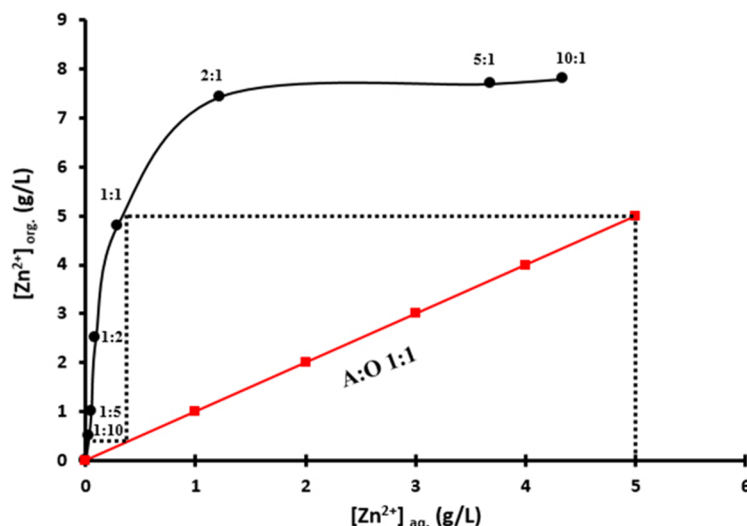


Figure 3. The McCabe–Thiele plot for the extraction of zinc from chloride solution with a concentration of 5 g L⁻¹ of each three Zn, Mn, and Cd ions at 40 °C.

3.2. Stripping stage

3.2.1. Effect of pH

In order to study the effect of pH on the Zn stripping efficiency, the loaded organic phase prepared under the optimal conditions for the extraction stage was mixed with distilled water at the ambient temperature (25 °C) at a ratio of O:A = 1:1. The solution pH was reduced using pure sulfuric acid, and the samples were withdrawn at different pre-determined pH values. The variation in the stripping percentage of the zinc, manganese, and cadmium ions from the loaded organic phase versus pH changes in the range of 0-3.5 is presented in Figure 4. It can be concluded that by decreasing the solution pH, the Zn stripping increases. The highest value for Zn stripping (93.63%) occurs at pH = 0. Also a small

amount of Cd ions enters the aqueous phase during the stripping process (< 20%). Its highest concentration in the aqueous phase is about 30 ppm. The stripping percentage of the Mn ions was also increased from pH = 2.5 to zero, and then slightly changed in the range of 65-75%. The results obtained showed that 92.52% of zinc was stripped at pH = 0.5, which was nearly 1% less than that at pH = 0. In contrast, Mn stripping at pH = 0.5 was about 7% less than that at pH = 0. Since the amount of acid used to decrease pH from 0.5 to 0 was too high, it could be stated that pH = 0.5 was the optimal pH value for the recovery of zinc from the organic phase. The acidity of the aqueous phase was equal to 75 g L⁻¹, which was determined by NaOH titration [35].

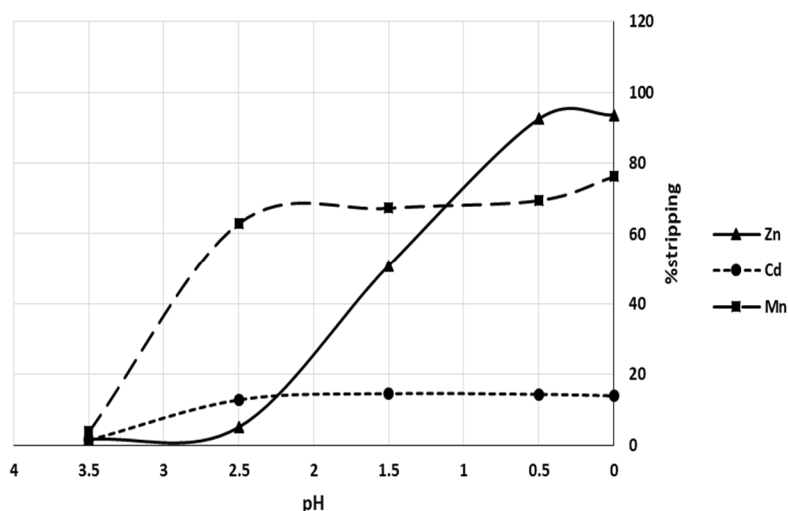


Figure 4. The plot of stripping percentage of Zn, Mn, and Cd ions from loaded organic phase at 25 °C versus pH changes in the range of 0-3.5.

By investigating the stripping isotherms and separation factor of the three understudied ions (Table 1), it is observed that Zn and Mn enter the aqueous solution at two different pH values. More than 60% of Mn and nearly 5% of Zn are stripped at pH = 2.5, while Zn is stripped completely at pH = 0.5. According to Table 1, the separation factor for the separation of manganese from zinc at pH =

2.5 is at the highest value of 12.47 and the separation factor for the separation of zinc from manganese is at the lowest value of 0.08. The results obtained indicate a good separation of zinc from manganese at pH = 2.5. Therefore, these two ions can be separated by considering a washing (scrubbing) stage at pH = 2.5.

Table 1. The stripping percentage, distribution coefficient, and separation factors for Zn, Mn, and Cd ions in binary systems at different pH values.

pH	Stripping (%)			Distribution coefficient			Separation factor ($\beta = D_{Zn}/D_M$)		
	Zn	Cd	Mn	Zn	Cd	Mn	β_{Zn-Cd}	β_{Zn-Mn}	β_{Mn-Zn}
3.5	1.58	1.41	3.80	0.016	0.014	0.038	1.12	0.42	2.40
2.5	5.05	12.76	62.98	0.050	0.128	0.629	0.39	0.08	12.47
1.5	50.91	14.48	67.31	0.509	0.145	0.673	3.52	0.76	1.32
0.5	92.52	14.28	69.48	0.925	0.143	0.694	6.48	1.33	0.75
0	93.64	13.88	76.20	0.936	0.138	0.762	6.74	1.23	0.81

3.2.2. Effect of temperature

In order to study the effect of temperature on the isotherm of retrieving the three ions Zn, Mn, and Cd, two experiments were carried out at 25 °C and 40 °C. The plot of changes of the stripping percentage versus different pH values is shown in Figure 5. Based on the results presented in this figure, increasing the temperature has little effect on the stripping of the Zn and Cd ions. However, for the Mn ions, it can be observed that the stripping isotherm for this ion is shifted slightly upward at a higher temperature. For example, at pH = 0.5 and a temperature of 25 °C, 68.48% of

Mn was stripped, while at the same pH and at the temperature of 40 °C, 74.80% of this ion was stripped accordingly. Since increasing the temperature leads to an increase in the Mn stripping percentage, the percentage of Zn stripping is constant in both temperatures. At 25 °C, less manganese enters the aqueous phase. Consequently, the temperature of 25 °C was considered as the optimal temperature for the zinc stripping process. By choosing a temperature of 25 °C, the manganese concentration was lower in the aqueous solution after the stripping stage.

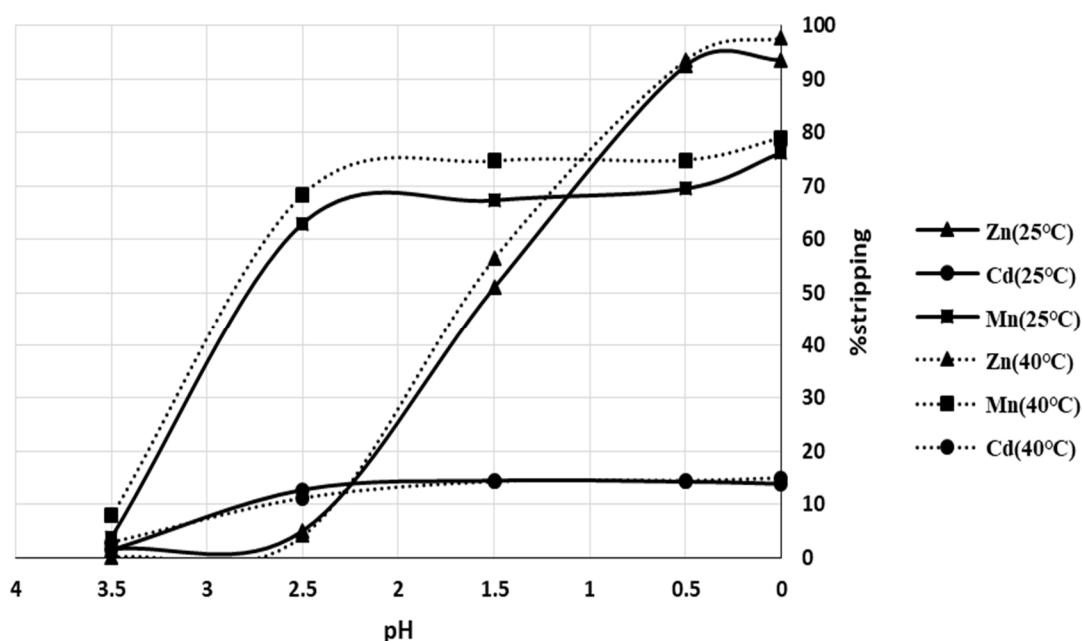


Figure 5. The plot of stripping percentage of Zn, Mn, and Cd ions from loaded organic phase versus different pH values at temperatures of 25 °C and 40 °C.

3.2.3. Contact time

The zinc stripping from the organic phase containing zinc, manganese, and cadmium was carried out at 25 ± 2 , pH = 0.5, and a reaction time in the range of 0.5-30 minutes. Figure 6 shows the variation in the stripping of Zn ions as a function of time. It can be seen that the stripping rate of

zinc ions is high. At a time of 0.5-1 minute, a significant amount of Zn ions enters the aqueous phase. At 0.5 and 1 minutes, the Zn stripping reaches 88.18% and 92.20%, respectively. However, it changes slightly to 92.42% over 30 minutes.

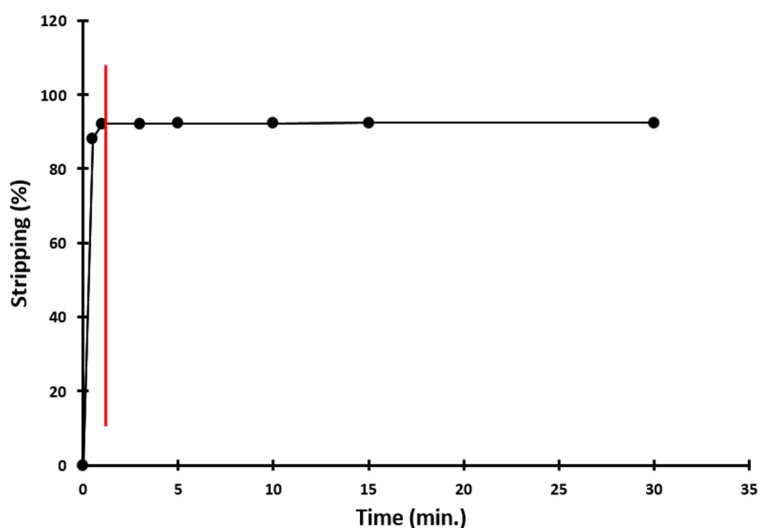


Figure 6. The stripping rate of Zn ions in chloride solution using D2EHPA 10% (v/v) at 25 °C and pH = 0.5; the red line is the time with a high stripping rate.

3.2.4. Effect of A:O ratio (distribution isotherm)

The stripping isotherm for zinc ions was prepared to determine the number of stages required for stripping at the selected phase ratio. To plot the stripping isotherm (Figure 7), seven tests were carried out under the optimal stripping conditions (pH = 0.5, a contact time 10 minutes, and a

temperature of 25 °C) at different proportions of the organic and aqueous phases in the range of A:O = 10:1 to 1:10. By considering the operating line (A:O = 5:1) in continuous condition in two counter-current steps, more than 99% of zinc ions was stripped successfully. Pereira *et al.* have indicated that in three stripping steps in A:O = 4:1, more than 98% of zinc is striped [34].

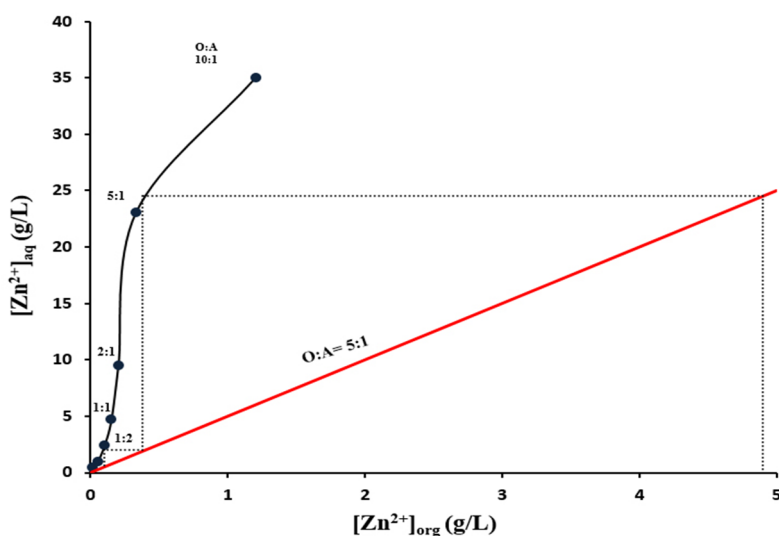


Figure 7. The McCabe–Thiele plot for the stripping of zinc ions under the optimal conditions (pH = 0.5, 10 minutes contact time, and temperature of 25 °C).

The results of extraction and stripping experiments indicated that the solvent extraction method was an effective route to separate zinc from the two impurities of manganese and cadmium. According to Table 2, about 86% of manganese and 97% of cadmium remain in the aqueous phase at the optimal conditions for the extraction stage. Also by examining the stripping isotherms of these three ions (Figures 4 and 5), Zn and Mn ions are transferred to the aqueous solution at two different pH values. Since the major amounts of Mn and Zn ions are stripped at different pH values (pH = 2.5 for Mn and pH = 0.5 for Zn), these two ions can be separated from each other by two stripping steps at pH values of 2.5 and 0.5. It is obvious that by taking a washing stage at pH = 2.5, about 60% of the residual manganese in the organic phase is removed. The same result has been observed in similar studies in the sulfate medium [36]. Finally, with a stripping stage at pH = 0.5, the amounts of manganese and

cadmium ions entering the aqueous phase were 180 ppm and 20 ppm, respectively. By comparing the amount of manganese and cadmium ions in the initial and final solutions, it could be postulated that manganese and cadmium ions were eliminated by 96.7% and 99.6% in optimal laboratory conditions, respectively.

Based on the results obtained, the proposed flowsheet for zinc extraction from the Zn-Mn-Cd-bearing chloride solution containing 5g L⁻¹ of each of the three ions by the extractant D2EHPA 10% and its stripping with sulfuric acid in concentration of 75 g L⁻¹ is demonstrated in Figure 8. As indicated, each stage of extraction and stripping consists of two steps in order to complete the separation and recovery. According to the results obtained from the stripping stage, it can be suggested that if a washing stage is performed at pH = 2.5, it can remove about 60% of the transferred manganese to the organic phase.

Table 2. The results of the extraction, washing, and stripping stages in optimal conditions.

	pH	O:A	[Zn] (g L ⁻¹)		[Mn] (g L ⁻¹)		[Cd] (g L ⁻¹)	
			aq	org	aq	org	aq	org
Feed	----	----	5		5		5	
Extraction stage	2.5-3	1:1	0.15	4.85	4.3	0.7	4.85	0.15
Washing stage	2.5	1:1	0.24	4.61	0.441	0.26	0.02	0.13
Removal percentage				4.9%		63%		13.3%
Stripping stage	0.5	1:1	4.40	0.21	0.18	0.07	0.02	0.11
Total removal percentage			----		96.7%		99.6%	

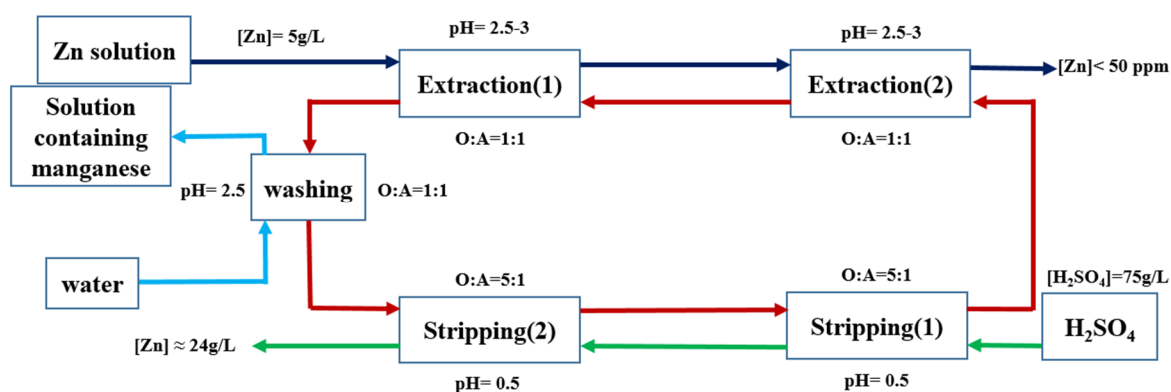


Figure 8. The proposed flowsheet for the extraction, washing (scrubbing), and stripping of zinc ions from chloride solution in the presence of manganese and cadmium as the impurities.

4. Conclusions

The main findings of this research work are summarized as follow:

- Based on the results obtained, in optimal conditions (pH = 2.5, [D2EHPA] = 10% (v/v), and at 40 °C), the extraction of zinc, manganese, and cadmium ions was about 97%, 14%, and 3%, respectively.

- The dominant Zn species extracted by D2EHPA was ZnCl⁺. Also the ΔH° , ΔS° , and ΔG° values for zinc were 25.65 kJ mol⁻¹, 79.20 J K⁻¹ mol⁻¹, and 0.86 kJ mol⁻¹, respectively, which showed that the process was endothermic at equilibrium.

- In the stripping stage, with a decrease in pH, the stripping of Zn increased and at pH = 0.5,

92.52% of Zn, about 70% of manganese, and 15% of cadmium were stripped into the aqueous phase. The solution acidity was estimated to be about 75 g L⁻¹.

- Since the major amounts of Mn and Zn ions were stripped at different pH values (pH = 2.5 for Mn and pH = 0.5 for Zn), these two ions could be separated from each other by two stripping steps at the pH values of 2.5 and 0.5.

- The stripping rate of zinc ions was high so that a significant amount of Zn was stripped at the first 0.5-1 minute of the process.

- According to the McCabe–Thiele plots for the extraction and stripping stages, two steps for each extraction and stripping stages seem to be adequate to separate successfully the zinc ions from the manganese and cadmium ions as the impurities.

Acknowledgments

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استخراج حلالی و بازپس‌گیری روی از محلول کلریدی سنتزی در حضور منگنز و کادمیوم به عنوان ناخالصی

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چکیده:

در پژوهش حاضر استخراج حلالی و بازپس‌گیری یون روی از محلول حاوی روی، منگنز و کادمیوم توسط استخراج کننده D2EHPA در محلول کلریدی مورد بررسی قرار گرفت. عملیات استخراج و بازپس‌گیری به صورت جداگانه بررسی شد و پارامترهای مؤثر بر فرآیند از قبیل اثر pH، غلظت استخراج کننده، دمای محیط واکنش و زمان اختلاط مورد مطالعه قرار گرفت. با توجه به نتایج به دست آمده روی در شرایط pH=2.5، D2EHPA 10% (v/v) و دمای 40°C از محلول حاوی 5 g/L از هر یک از یون‌های روی، منگنز و کادمیوم به مقدار ۹۷٪ استخراج شده و ۱۴٪ یون منگنز و ۳٪ یون کادمیوم استخراج می‌شود. ایزوترم بازپس‌گیری روی، منگنز و کادمیوم در pH های مختلف نشان داد که منگنز و روی در دو pH مختلف بازپس‌گرفته می‌شوند. به طوری که بیش از ۷۰٪ منگنز در pH=2.5 و بیش از ۹۰٪ روی در pH=0.5 بازپس‌گرفته می‌شوند. مطالعات سینتیکی صورت گرفته نشان می‌دهد که در بازه زمانی ۵-۱ دقیقه هر دو فرآیند استخراج و بازپس‌گیری برای روی انجام می‌شود. منحنی مک‌کیب‌تیل نشان‌دهنده دو مرحله استخراج و دو مرحله بازپس‌گیری در شرایط پیوسته غیرهمسو برای جدایش روی از منگنز و کادمیوم نیاز است. گونه فلزی استخراج شده Zn توسط D2EHPA، ZnCl⁺ می‌باشد و مقادیر پارامترهای ترمودینامیکی ΔH^0 ، ΔS^0 و ΔG^0 به ترتیب برابر $25/65 \text{ KJ.mol}^{-1}$ ، $79/20 \text{ J.K}^{-1}.\text{mol}^{-1}$ ، $0/86 \text{ KJ.mol}^{-1}$ است که بیانگر گرماده بودن واکنش در شرایط تعادلی است.

کلمات کلیدی: استخراج حلالی و بازپس‌گیری، دپا، محلول کلریدی، یون‌های روی- منگنز- کادمیم، نمودار مک‌کیب‌تیل.