Extractive removal of chromium (VI) from industrial waste solution

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ABSTRACT

Extractive removal of Cr (VI) was carried out from chloride solutions using cyanex 923 mixed with kerosene. The efficiency of this extractant was studied under various experimental conditions, such as concentration of different mineral acids in the aqueous phase, concentration of cyanex 923 and Cr (VI) present in the initial aqueous feed, temperature and time of extraction, organic to aqueous (O/A) phase ratio. Percentage Cr (VI) extraction decreases with the increase in temperature at varying concentration of cyanex 923. The interference of the impurities usually associated with Cr (VI) such as Cr (III), Cu, Ni, Fe (II), Zn, Chloride and sulphate, etc., were examined under the optimized conditions and only Zn was found to interfere. Under the optimum experimental conditions 98.6–99.9% of Cr (VI) was extracted in 3–5 min at O/A of 2 with the initial feed concentration of 1 g/L of Cr (VI). The extracted Cr (VI) was quantitatively stripped with 1 M NaOH and the organic phase obtained after the stripping of Cr (VI) was washed with dilute HCl solution to neutralize any NaOH trapped/adhered to the solvent and then with distilled water. This regenerated solvent was reused in succeeding extraction of chromium (VI). Finally a few experiments were performed with the synthetic effluent from an electroplating industry.

1. Introduction

Removal of metal ions from dilute or concentrated solutions has received a great deal of attention for recovery of valuable metals or decontamination of effluents. Among all heavy metals, copper, chromium and zinc ingestion beyond permissible quantities causes various chronic disorders in human beings [1]. The extensive use of chromium in leather tanning, metallurgy, electroplating and other industries has resulted in the release of chromium to the sub surface at numerous sites thereby releasing undesirable amounts of chromium (VI) according to the water standards. Chromium is found in various oxidation stages ranging from -2 to $+6$ [2] and $+3$ and $+6$ states are most prevalent in the environment. The toxic hexavalent chromium anions such as chromate ($CrO_4{}^{2-}$), bichromate ($HCrO_4{}^-$) and dichromate ($Cr_2O_7{}^{2-}$) are not strongly sorbed in many soils under alkaline to slightly acidic conditions [3]. Thus, they can be very mobile in subsurface environment and exert toxic effects on biological systems. Potable waters containing more than 0.05 mg/L chromium are considered to be toxic for living beings [4,5]. Hence their effective removal from the waste waters before disposal is very important. Various methods such as ion-exchange, solvent extraction, liquid membrane and adsorption have been studied for the removal of hexavalent chromium and liquid–liquid extraction amongst those is the most

effective conventional method which is extensively used in separation science. A number of extractants [6] have been used for the extraction/removal of Cr (VI) such as diethylether, isobutyl ketone, ethyl acetate, hexane, tri-*n*-butylphosphate, ethylglycol monoethyl ether and chloroform. Several ion-association forming systems such as triphenylsulphonium, ammonium cation, triphenylphosphonium, tetraphenylstibonium and triphenylselenium have also been used to extract chromium in the anionic form. Methylviolet and diantipyrylmethane are also reported to extract Cr (VI) quantitatively [6]. Lo and Shiue investigated the recovery of Cr (VI) from the acidic solution using a mixture of Aliquat 336 and xylene in kerosene [7]. Lanagan and Ibana [8] and Rao and Prasad [9] investigated the extraction of Cr (VI) with cyanex 272 at pH less than 2, with the involvement of neutral chromic acid (H_2CrO_4) species in the extraction. 99.9% of this extracted Cr (VI) was stripped using a solution of 0.1 M NaOH and 1.0 M NaCl. Galan et al. [10] studied the extraction of Cr (VI) using aliquat 336 (RCl) in kerosene. They observed that the extraction proceeds with the formation of $RHCrO_4$ as a result of the reversible ion-exchange reaction of $HCrO_4{}^-$ with aliquat 336 hydroxide (ROH) and aliquat 336 chloride (RCl). Deputala studied the extraction of Cr (VI) by tri-*n*-octyl amine from various mineral acid solutions and found that Cr (VI) is extracted as CrO_3Cl^- from HCl medium and as $Cr_2O_7{}^{2-}$ species from other mineral acids [11,12]. He also observed that the extraction percentage decreases with the increasing acid concentration for all the mineral acids system except HCl. This decrease in Cr (VI) extraction may be due to the change in composition of the extracted species. Thus, only a limited number of potential extractant such as,

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tributyl phosphate, alamine 336, aliquat 336, alkyl phosphoric acid and LIX 84 are of importance due to the stable complex formation and coordination ability [13–15]. Several workers [16,17] studied the Cr extraction with tri-*n*-octylphosphine oxide (TOPO). Tuck and Walters studied the Cr (VI) extraction using tri-butylphosphate (TBP) from various mineral acids at both trace and macro concentrations and suggested that the species extracted from hydrochloric and hydrobromic acid is $HCrO_3X$ (X = Cl or Br) while from other acids it is $HCr_2O_7^-$ [18].

In the present study, cyanex 923 has been suggested as a potential extractant for Cr (VI). A number of other metals extracted by this solvent includes gold [19,20], 3d transition metals [21], zirconium and hafnium [22], iron (III) [23], cadmium [24]. A few data are available on the extraction of chromium (VI) along with iron extraction by cyanex 923, in the work done by Saji et al. [23], but no systematic work has been reported till date. The present investigation deals with the removal of chromium (VI) from HCl medium using a very dilute solution of cyanex 923 as an effective and efficient solvent for the extraction of Cr (VI). Stripping of the loaded chromium was done with NaOH solution.

2. Experimental

2.1. Reagent

Cyanex 923 (CYTEC, Canada) was used as a solvent in the present investigation without further purification. It is a mixture of various trialkylphosphine oxides. It is reported to contain about 93% of trialkylphosphine oxides, including dioctylmonohexylphosphine oxide (40–44%), dihexylmono-octylphosphine oxide (28–32%), trihexylphosphine oxide and trioctylphosphine oxide [25]. The main extracting entity of cyanex 923 is the trialkyl phosphine oxide and its general extracting properties are similar to those of tri-*n*-octyl phosphine oxide (TOPO) [26]. The presence of trihexylphosphine oxide as one of the constituent lowers the freezing point and the viscosity of cyanex 923. This makes the extractant soluble in all the commonly used hydrocarbon diluents even at a low ambient temperature. Its average molecular weight is equal to 348. Extraction efficiency of cyanex 923 was compared with that of other extractants such as tributyl phosphate (TBP) and methyl isobutyl ketone (MIBK), which are reported to be very strong and effective extractants for the extraction of Cr (VI). Distilled kerosene oil was used as a diluent. Effect of other diluents such as xylene, chloroform, benzene, hexane, etc., were also studied.

Stock solution of 2000 ppm chromium (VI) was prepared by dissolving 5.6538 g of $K_2Cr_2O_7$ (Merck) in distilled water and its pH value was adjusted by adding required amount of NaOH or HCl. All other chemicals used in the present study were of AR grade. The extracting solvent was prepared by dissolving appropriate volume of cyanex 923 in distilled (160–200 °C fraction) kerosene oil (diluent) unless otherwise stated, to obtain organic solutions of different concentrations. The pH value of aqueous phase was measured with a pH meter (Systronics μpH system 362). The concentration of chromium (VI) in aqueous phase was determined with an Atomic Absorption Spectrophotometer (Thermo electronics S2) at a wavelength of 359.3 nm.

2.2. Methods

All experiments were carried out at ambient temperature. Aqueous solution containing a known amount of Cr (VI) was mixed with 2.5% of cyanex 923 diluted with kerosene oil at an organic/aqueous (O/A) ratio of 1:1 in a separatory funnel. A preliminary experimental result showed that the extraction equilibrium takes place at about 2 min. Thus, the phases were mixed gently for 5 min (to ensure complete equilibrium) and allowed to separate. The aqueous layer was analyzed for remaining Cr (VI) by AAS. The metal loaded solvent was stripped with alkaline solution of 1 M NaOH to recover the extracted Cr (VI) by mixing for 5 min. All the experiment runs were carried out in duplicate and the analysis was carried out in triplicate for each run. Confidence limit of 95% was taken for reliable results. The concentration of Cr (VI) in the organic phase was calculated from the difference in the Cr (VI) concentrations of aqueous phase before and after extraction.

3. Results and discussion

3.1. Comparison of the extraction efficiency of cyanex 923 with other potential Cr (VI) extractants

A comparative extraction efficiency of cyanex 923, with other extractants for the extraction of Cr (VI) was studied. Other extractants investigated were TBP, and MIBK. Thus, 1–5% solutions of each solvent was prepared by mixing extractant: kerosene in the ratio of 1–5:99–95. 10 mL of this organic solvent was then contacted with 10 mL of the aqueous feed containing Cr (VI) for 5 min at 30 °C. Results exhibited in Fig. 1 shows that there is an increase in Cr (VI) extraction from 44.95% to 98.86% with the increase in cyanex 923 concentration from 0.5% to 5%, whereas in the same solvent concentration range TBP shows the percent extraction from 4.5% to 9.5% and MIBK shows no extraction at all. Hence cyanex 923 has the maximum chromium extractability as compared to TBP and MIBK and Cr (VI) extraction efficiency follows the apparent order as: cyanex 923 > TBP > MIBK, which can be interpreted in terms of the electron-donor properties of the active species of the solvent because of which the extraction is higher in the case of the phosphine oxide and lower in the case of the phosphoric ester (TBP) and ketones. However, 100% TBP or MIBK can be used for Cr (VI) extraction effectively, but dilute solutions of these two solvents are not effective for Cr (VI) extraction like that of cyanex 923.

3.2. Effect of pH of the aqueous feed on the extraction of Cr (VI) by cyanex 923

pH of the aqueous solution has a marked effect on the extraction and formation of ion pair between Cr (VI) and the solvent. Different ionic forms in which chromate ions may exist in the aqueous phase are $HCrO_4^-$, CrO_4^{2-}, $Cr_2O_7^{2-}$, $HCr_2O_7^-$. Thus, in a highly
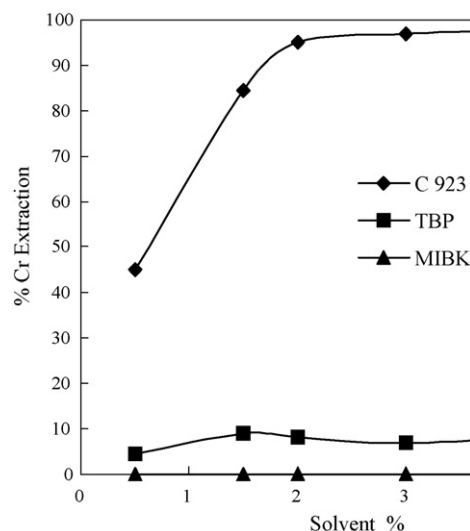

Fig. 1. A comparative extraction of Cr (VI) at different concentration of various extractants (cyanex 923, TBP and MIBK).

acidic medium (pH < 1) Cr (VI) ion exists mostly as H_2CrO_4 with $pK_1 = 6.51$ and $pK_2 = 5.65$. At pH between 2 and 6 there is an equilibrium between $Cr_2O_7^{2-}$ and $HCrO_4^-$ ionic species and under alkaline conditions (pH > 8) it exists predominantly as chromate anion [27]. The equilibrium between chromate and dichromate ions in water can be shown as the following equation:

$$Cr_2O_7^{2-} + H_2O \rightarrow 2CrO_4^{2-} + 2H^+ \qquad (1)$$
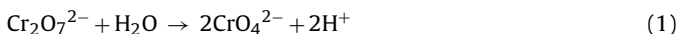
Even the concentration of chromium along with pH is responsible for the presence of a particular species in the aqueous phase. Thus, in acidic pH condition (pH < 6) if the Cr (VI) concentration is less than 0.02 M, bichromate ion ($HCrO_4^-$) is the predominant species and when Cr (VI) concentration is greater than 0.02 M then dichromate ion ($Cr_2O_7^{2-}$) is the predominant species.

Hence influence of pH on the extraction of Cr (VI) by cyanex 923 was studied in the whole pH range from 0.5 to 10 (Fig. 2). The pH in the acidic range was maintained by using HCl solution and in the basic range by NaOH solution. Cyanex 923 shows the maximum extraction efficiency (93%) for the uptake of Cr (VI) at pH of 0.5. With increase in pH to 1, 1.5, and 2 the extraction efficiency decreases to 82, 50 and 20%, respectively. Further increase in pH up to 10 decreases the extraction of Cr (VI) up to 2.5%. Fig. 2 also shows a decrease in distribution coefficient (*D*) values from 12.6 to 0.02 with the increase in pH from 0.5 to 10, indicating the maximum extractability of the solvent at a very low pH. Similar observations were made by Takahasi et al. [28], where they found that the lower extraction percentage is related to the decrease in fractions of $HCrO_4^-$ and $Cr_2O_7^{2-}$ with the increasing pH based on the calculations of the concentrations of chromium species from the reaction equations, equilibrium constants and activity coefficient from the Davis equation [28]. Thus, pH of the sample solution is critical for Cr (VI) extraction and acidic pH of 0.5 was found to be essential for maximum chromium extraction.

3.3. Effect of different mineral acids on Cr (VI) extraction

After the optimization of pH for the maximum extraction of Cr (VI), effect of other mineral acids such as H_2SO_4 and HNO_3 was seen on the percent extraction of Cr (VI) in the pH range 0–2.5
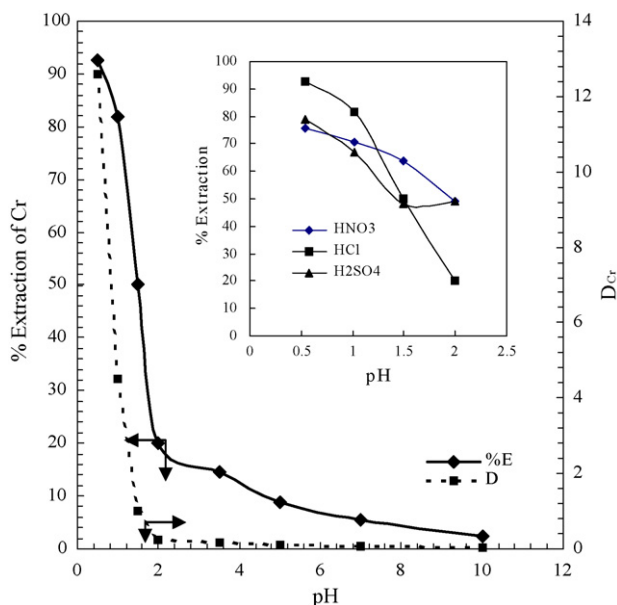
Fig. 2. Effect of pH from 1 to 10 on the extraction of Cr (VI) by cyanex 923. Inside figure: Effect of different mineral acids in the pH range 0–3 on the extraction of Cr (VI) by cyanex 923.
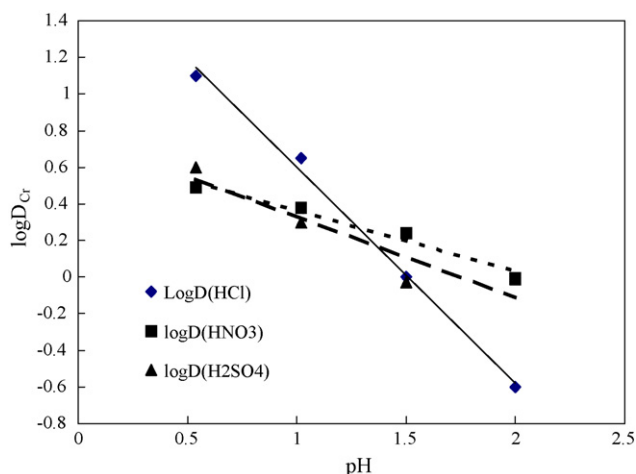
Fig. 3. Effect of pH on log D_{Cr} in different mineral acids.

(Fig. 2 (inner figure)). It was found that at a pH of 0.54 maximum extraction takes place in case of all the acids and amongst the three acids studied, percentage extraction of Cr (VI) was maximum in HCl medium. To explain this preference and more extraction of Cr (VI) by this solvent in chloride medium, reference may be made to the work done by Zouhri et al. [29] where they have recovered Cr (VI) from HCl medium using a crown ether as extractant carrier on a liquid membrane. They have discussed that chromate ions reacts in an aqueous chloride medium (high acidic conditions) by forming the trioxochlorochromate (VI) ion according to the equation

$$HCrO_4^- + Cl^- + H^+ \leftrightarrow CrO_3Cl^- + H_2O \qquad (2)$$
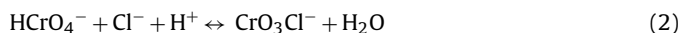
This CrO_3Cl^- is extracted by the extractant carrier, i.e. dicyclohexano-18-crown-6 used by them. Effect of hydrogen ion concentration with all the three acids on the distribution ratio of chromium (VI) was investigated by keeping the concentration of chromium (VI) at 500 ppm at an organic to aqueous (O/A) phase ratio of 1:1 as shown in Fig. 3. This figure shows that with the increase in pH of the aqueous feed from 0.5 to 2.5 there is a decrease in the percent extraction of chromium. The slope and regression coefficient values (R2) obtained from the straight line in Fig. 3 for all the three acids are given below

$$HCl: \quad y = -1.1831x + 1.7845, \quad R2 = 0.9954 \qquad (3)$$

$$HNO_3: \quad y = -0.3344x + 0.698, \quad R2 = 0.9658 \qquad (4)$$

$$H_2SO_4: \quad y = -0.444x + 0.7761, \quad R2 = 0.8719 \qquad (5)$$

Thus, the regression coefficient value indicates the best fit for Cr extraction in HCl medium and the slope indicates the participation of chloride ions in the Cr (VI) extraction with Cr: HCl in a ratio of 1:1, whereas the slopes for HNO_3 and H_2SO_4 were found to be 0.33 and 0.44, respectively. In light of the results obtained it can be suggested that there is a formation of chloro complex of chromate and Cr (VI) is extracted as $HCrO_3Cl$ from HCl medium into cyanex 923. Similar results were obtained by Manzoori and Shemirani [30]. The extraction of trioxochlorochromate (VI) ion was also identified as the extracted species in the extraction of chromium (VI) from hydrochloric acid medium by tri-*n*-butyl phosphate [31], but it was not recognized in chromium (VI) extraction from chloride medium by triisooctylamine [32].

3.4. Effect of diluent

A number of diluents namely xylene, hexane, benzene, kerosene (160–200 °C), and chloroform, were employed to observe any
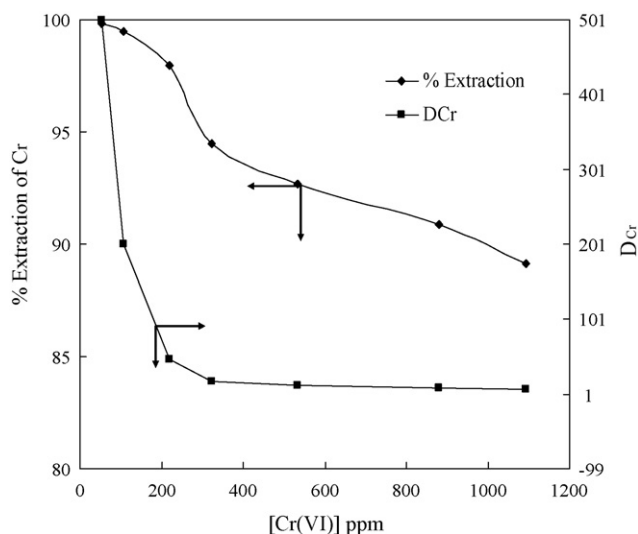
Fig. 4. Effect of initial Cr (VI) concentration in the aqueous feed on the extraction of Cr (VI) by 2.5% cyanex 923.

Fig. 5. Effect of cyanex 923 concentration on the percent extraction of Cr(VI). (a) Plot of [cyanex 923] vs % Extraction of Cr(VI) and (b) log[cyanex 923] vs log D_{Cr}.

change in the extraction of Cr (VI) with varying nature of the organic diluents. Results show that an insignificant variation in the extraction percentage of Cr (VI) was observed in the diluents having similar dielectric constants (2.0–2.28), such as *n*-hexane (96.74%), kerosene (96.76%), benzene (93.6%) and xylene (95.4%). As apparent from the data the extraction of Cr (VI) slightly decreases in the diluents, having higher dielectric constants (4.9), namely chloroform (57.22). The results also suggest that kerosene can be used for commercial purposes without affecting the percent Cr (VI) extraction. In all other studies kerosene was used as diluent.

3.5. Effect of initial Cr (VI) concentration in aqueous solution

Effect of Cr (VI) present initially in the aqueous feed was studied in order to assess the concentration range of Cr (VI) which can be treated by this extractant effectively. Thus, 10 mL of the aqueous feed containing varying concentration of chromium (VI) ranging from 54 to 1100 ppm were mixed with 10 mL of 2.5% cyanex 923 for the extraction of Cr (VI). Results shows that 99.8% of Cr was extracted (Fig. 4) from a solution containing 54 ppm of Cr. With the increase in Cr concentration in the aqueous feed the percent extraction of chromium by this solvent decreases and is 89% with 1100 ppm of Cr in the aqueous phase. The distribution ratio (*D*) value varies from 500.4 to 8.2 for Cr (VI) varying from 54 to 1100 ppm. Hence this solvent can effectively remove the hexavalent Cr from aqueous solutions containing Cr (VI) ranging from 54 to 1100 ppm. Even solutions containing 2000 ppm of Cr (VI) can be treated by this solvent and in 4 stages the Cr concentration can be brought down to the safe disposal level.

3.6. Effect of cyanex 923 concentration and temperature

The experiments were accomplished at different concentrations of cyanex 923 ranging from 0.5% to 5% diluted with distilled kerosene oil. Solvent of different concentration and Cr (VI) solution containing 250 ppm of Cr (VI) were mixed in the ratio of 1:1 at pH of 0.5 at 30 °C for 5 min. The extraction was found to increase from 44.9% to 96.5% for concentration varying from 0.5% to 2.5% and there after the percent extraction was marginal, i.e. 98.9% with the increase in solvent concentration up to 5% (Fig. 5). Straight line obtained for the variation of distribution coefficient (log D_{Cr})
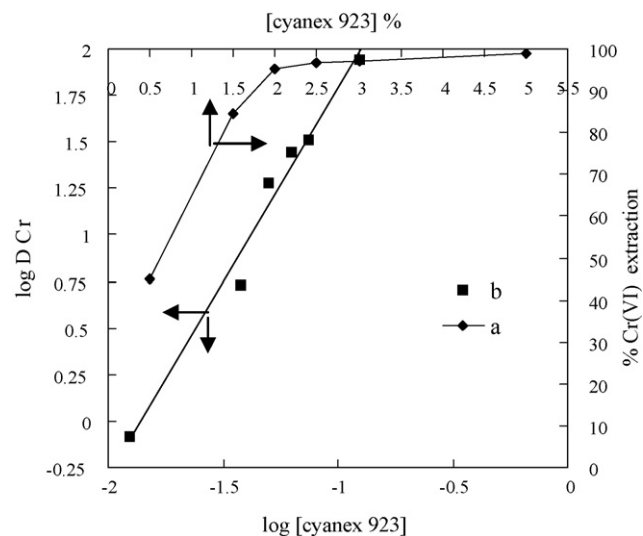
with varying concentration of the extractant in the solvent mixture (log cyanex 923) is also depicted in Fig. 5. A slope of 2.08 and regression coefficient value of 0.98 indicates the requirement of 2 moles of cyanex 923 for one mole of Cr (VI). As can be seen in Fig. 3, the variation of distribution coefficient (log D_{Cr}) with varying pH gives a straight line with slope of 1.18 indicating the involvement of one mole of HCl with one mole of Cr (VI) anionic species. Based on these results, it can be suggested that Cr (VI) is extracted from hydrochloric acid media by cyanex 923 as $HCrO_3Cl$ and the probable extraction mechanism of Cr (VI) from acidic chloride and HCl media by cyanex 923 may be shown as follows:

$$HCrO_{4(aq)}^- + 2H_{(aq)}^+ + Cl^-(aq) + n \cdot cyanex923(org)$$

$$\rightarrow HCrO_3Cl \cdot n \cdot cyanex923 + H_2O \qquad (6)$$
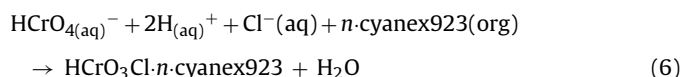
Where *n* is the number of molecules of cyanex 923 required for the extraction of one molecule of Cr (VI) and as per Fig. 5 it is 2.

Effect of temperature was also studied for Cr (VI) extraction at different solvent concentration. Fig. 6 shows that with the increase in temperature there is a decrease in the percent extraction of Cr (VI) irrespective of the cyanex 923 concentration.
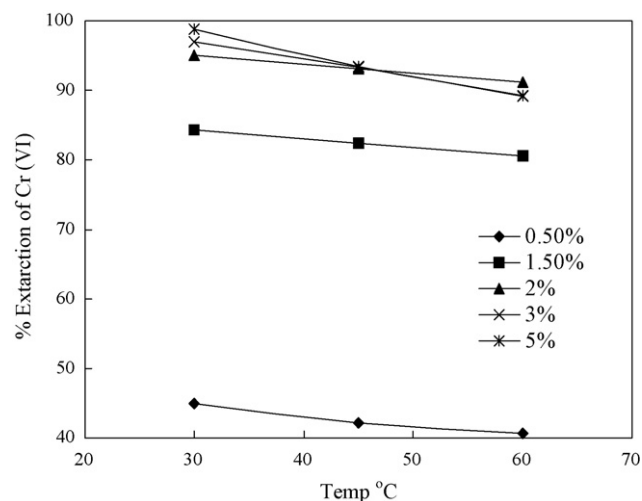

Fig. 6. Effect of temperature on the percent Cr (VI) extraction at different concentration of cyanex 923.
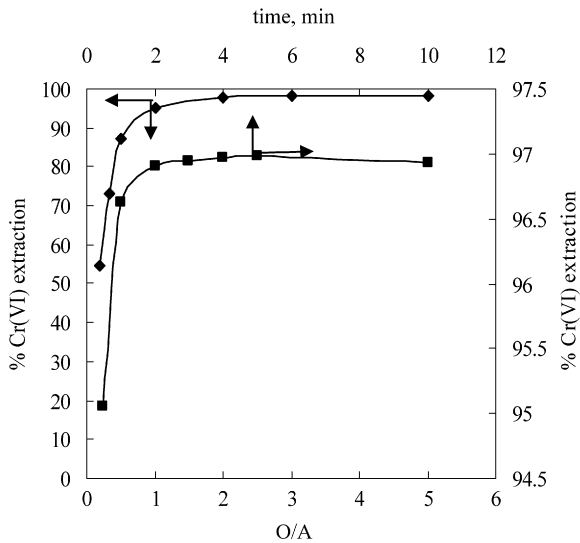
Fig. 7. Effect of O/A and time on the extraction of Cr (VI) by 2.5% cyanex 923.

3.7. Hydrolytic stability and regeneration capacity of cyanex 923

The stability and regeneration capacity of cyanex 923 were determined to assess its potential as a commercial reagent. The stability of 2.5% cyanex 923 in distilled kerosene oil was checked by keeping it in contact with 10% of mineral acid such as HCl/H$_2$SO$_4$/HNO$_3$ for 20 days with intermittent shaking. A known aliquot of the extractant solution was removed periodically after 5 days, neutralized by washing with water, and employed for the extraction of Cr (VI) at a solution pH of 0.5. An insignificant change (0.5–2%) in the percent extraction of chromium has been observed even after a contact of 20 days. Thus, this extractant is very stable in high acid conditions making it very suitable for the treatment of Cr (VI) containing waste solutions from electroplating industries.

3.8. Effect of equilibrium time

Rate of extraction or time for equilibrium to reach, was studied by mixing the Cr (VI) solution with 2.5% cyanex 923 at O/A of 1/1 for a predetermined time ranging from 30 s to 10 min (Fig. 7). The extraction of Cr (VI) was rapid and quantitative even for a shaking time of 2 min. However, to ensure maximum extraction, 5 min equilibration time was maintained for extraction studies.

3.9. Effect of organic to aqueous (O/A) phase ratio

Aqueous feed containing hexavalent chromium was contacted with the organic feed in different phase ratio to study the extraction behaviour of Cr (VI). Fig. 7 shows that with the increase in O/A ratio from 1:5 to 5:1 the amount of chromium extracted increases from 55% to 98% in a single contact with 2.5% cyanex 923. The McCabe–Thiele plot (Fig. 8) for the experiment carried out at different O/A ratio showed the requirement of three stages for maximum extraction of chromium from an aqueous feed containing 600 ppm Cr (VI) at O/A ratio of 2.7/1 under the optimized conditions. Since Cr (VI) extraction was found to be very sensitive to pH, the desired pH was maintained in every step. Thus, 2.8 ppm of Cr (VI) was finally left unextracted in the raffinate.

3.10. Stripping of the extracted Cr (VI) from the loaded cyanex 923

Various stripping agents have been used by various workers for the stripping of loaded Cr such as NaOH, NaCl, NaNO$_3$, Na$_2$SO$_4$,
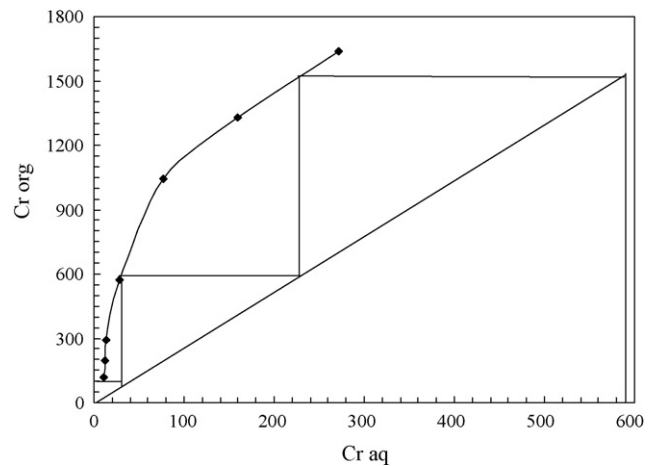

Fig. 8. McCabe–Thiele plot for the extraction of Cr (VI) by cyanex 923.

etc., from various solvents. In the present study, strippants like sodium chloride, sodium hydroxide, sodium sulphite, and ammonium chloride, ammonium hydroxide, hydrochloric acid, nitric acid, hot distilled water and reductive stripping using ascorbic acid in acidic medium were tested for Cr (VI) stripping from cyanex 923. As expected, sodium hydroxide has the ability to strip about 97% Cr (VI) from cyanex 923 whereas sodium chloride and ammonium chloride could strip only 25% and 70% of Cr (VI), respectively. Mixture of 0.1 M NaCl and 1 M NaOH was also used for stripping and showed the same result as observed with 1 M NaOH alone. Hence NaOH was selected for stripping studies. Fig. 9 shows the effect of aqueous to organic (A/O) ratio on Cr (VI) stripping in different stages. Thus, with the increase in A/O from 0.2 to 2, there is an increase in Cr stripping. At A/O of 2, 82.25% of the loaded Cr (VI) could be recovered back in 1st stage. McCabe–Thiele plot for the stripping of Cr (VI) from the loaded solvent as shown in Fig. 9 shows that at A/O of 2.3 the loaded Cr (VI) can be stripped out completely in three stages. The stripped solvent was then washed with dilute acid solution and water to remove the residual NaOH and reused for Cr (VI) extraction under the optimized conditions.
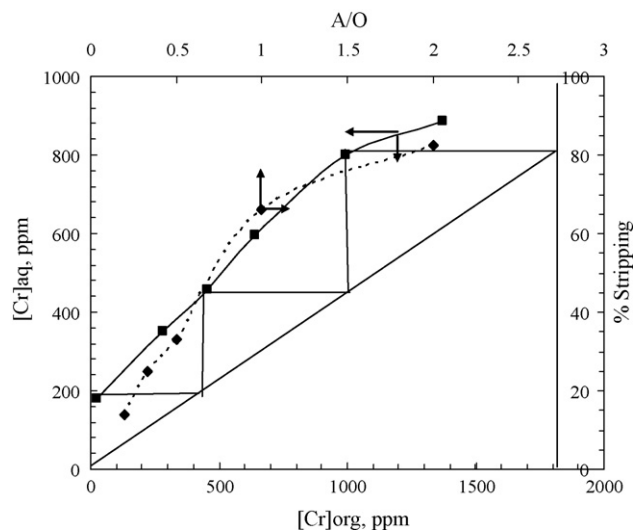

Fig. 9. Effect of A/O and McCabe–Thiele plot for the stripping of loaded Cr (VI) from cyanex 923 by 1 M NaOH.
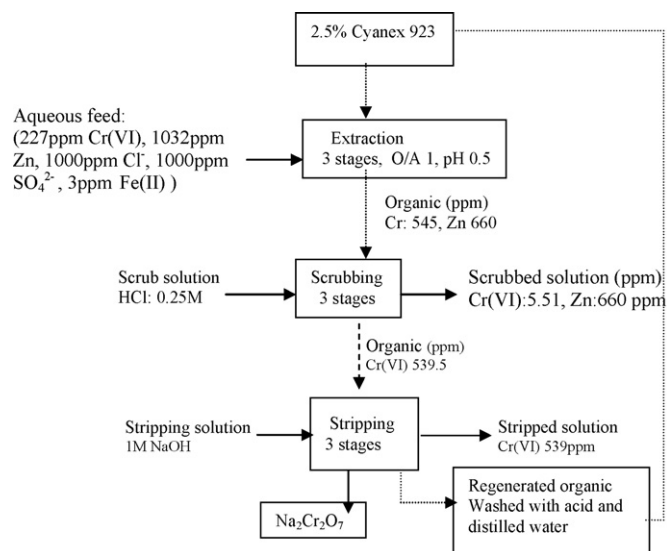
Fig. 10. Flow diagram for the treatment of the effluent (synthetic) from an electroplating industry.

3.11. Extraction of Cr (VI) from electroplating effluent (synthetic solution)

After the optimization of the parameters for the extraction and stripping of Cr (VI) from acidic solutions the process was substantiated by applying it to the electroplating effluents generated from electroplating industries. Effect of several other metal ions such as Cr (III), Fe (II), Cu (II), Ni (II), Zn (II), Ca (II), Mg (II), generally accompanying Cr (VI) in the effluents of electroplating industries has been studied. It was found that Zn (II) is co extracted with Cr (VI) and other ions were found to be non-interfering. This co-extracted Zn was scrubbed with 0.25 M HCl solutions. A detailed study on Zn scrubbing was done when the extraction was performed with the effluent of electroplating industry. Since the actual solution was not available a synthetic solution similar in composition to the electroplating effluent of one such local electroplating industry was used with the chemical composition as Cr (VI): 227 ppm, Cl$^-$: 1000 ppm, SO$_4{}^{2-}$: 1000 ppm, Fe (II): 3 ppm, Zn: 1032 ppm. Results show that in 3 stages about 60.9% of Zn is extracted along with Cr (VI). Chloride, sulphate and Fe (II) did not interfere during the extraction of Cr (VI). Hence before stripping, loaded Zn was scrubbed with 0.25 M HCl in three stages thereby scrubbing out 100% Zn and about 2–3 ppm of loaded Cr (VI). After scrubbing of Zn, stripping of Cr was done with 1 M NaOH solution at A/O of 2.3:1, and 100% Cr was stripped in 3 stages. A flow diagram for the whole process is given in Fig. 10.

4. Conclusions

The method described herein brings forth the potential of cyanex 923 as an extractant for the extraction and recovery of Cr (VI) from industrial effluents and waste water. Based on the experimental results it is concluded that cyanex 923 is a very effective, efficient and a stable reagent under highly acidic conditions which can be used to recover Cr (VI) from industrial effluents. Cr (VI) can be quantitatively extracted from a solution at a very low pH of around 0.5. Kinetics was found to be very fast taking only 2 min for extraction, however experiments were performed at a shaking time of 5 min. Extraction of Cr (VI) was more in chloride medium as compared to sulphate and nitrate medium. A solvent concentration of 2.5% was found sufficient for the extraction studies. This solvent can be used for Cr (VI) concentration varying from 54 to 1100 ppm. Experiments showed the requirement of 2 moles of cyanex 923 for one

mole of Cr (VI). The McCabe–Thiele plot showed the requirement of three stages for maximum extraction of chromium from an aqueous feed containing 600 ppm Cr (VI) at O/A ratio of 2.7/1. Of the various stripping agents tried NaOH was found to be the most effective one. McCabe–Thiele plot for the stripping showed that at an aqueous to organic (A/O) ratio of 2, a complete stripping of loaded Cr (VI) was achieved in three stages. Effect of various interfering elements such as Cr (III), Fe (II), Cu (II), Ni (II), Zn (II), Ca (II), Mg (II) were studied and Zn was found to be co-extracted with Cr (VI), however the loaded Zn could be completely scrubbed out with 0.25 M HCl along with traces of Cr (VI). After the scrubbing of Zn, stripping of loaded Cr (VI) was done with NaOH. A few experiments were also performed with the simulated effluent solution from electroplating industry and Cr (VI) could be removed successfully from it.

Acknowledgement

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