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Factorial (2^5) design for the extraction of V(IV) in the V(IV)–[SO_4^{2-}](H+, Na+) – Cyanex 302-kerosene system

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Abstract

The title system has been investigated from the modeling points of view. Equilibration time is 20 min and the significant extraction occurs above pH 2. Considering the constancy of the organic to aqueous phase ratio (1:1), the factors affecting the extent of extraction (value of log D or log ^{C}D) are [V(IV)], $pH_{(eq)}$, [Cyanex 302], [SO_4^{2-}] and temperature (T). The levels of these factors chosen in experimentation are high (+) and low (-). Regression or model equation for the extraction of vanadium (IV) by Cyanex 302 is determined from 2^5 full factorial design. On abbreviating log[V(IV)], $-\log(1+4641.14\text{x}10^{-pH} + (1.5\text{x}10^{6})\text{x}10^{-2pH})$, log[Cyanex 302], $-\log(1+2.24\ [SO_4^{2-}])$ and absolute temperatures as M, P, E, S and T, respectively, the model obtained is: $\log {}^{C}D = 10.452-0.16M+1.0047P+2.0011E+1.0003S-2425.3729/T$. From the regression model it is seen that there is no interaction effect between the factors under investigation. The model can describe the system well.

Keywords: Extraction; Vanadium(IV); Cyanex 302; Kerosene; Sulphate; Factorial design

Introduction

Vanadium is used for alloying steel and the manufacture of oxidative catalyst. The ores of vanadium are patronite (V_2S_3), vanadinite ($3Pb_3(VO_4)_2.PbCl_2$), carnotite ($K_2U_2V_2O_{11}.\ 3H_2O$) etc. which are rare on the earth's crust. Consequently, it is necessary to develop extraction processes for low grade ores and waste materials (tar sand, waste desulphurization catalyst etc.). Solvent extraction technique is convenient for such purpose. The technique can build up concentration by using low (O/A) ratio in extraction and high O/A ratio in stripping. In a reference book (Sekine and Hasegawa, 1977) the works on the solvent extraction of V(IV) by various extractants prior to 1976 have been included. Di-2-ethylhexyl phosphoric acid (D2EHPA) is an effective extractant for V(IV) and V(V) (Sato *et al.*, 1978; Brunette *et al.*, 1979; Islam and Biswas,1980a and 1980b; Hughes and Biswas, 1991; Juang and Lo,1993; Biswas and Mondal, 2003). EHEHPA (2-ethylhexyl phosphonic acid mono-2-ethylhexyl ester) (Saji and Reddy, 2002) can also extract V(IV) and V(V) efficiently. The organophosphinic acid derivatives and their sulphur analogues (Cyanex reagents) introduced by American Cynamide Company and Cytec Canada Inc. are recent developed promising extractants. Cyanex 302 and Cyanex 301 are the mono- and di-sulphide analogues of Cyanex 272 (di-2,4,4-trimethylpentyl phosphinic acid). The sulphur substitution decreases the pK_a values of the extracants permiting to work at lower pH (Rickelton, 1992). Cyanex reagents differ from other commercial organophosphorous reagents (*e.g.* D2EHPA, DDPA, TBP, EHPEHPA etc.) in that the former reagents contain P-C bonding, whereas the latter reagents contain P-O-C bonding. The presence of P-C bonding in Cyanex reagents renders them to be less susceptible to hydrolysis and less soluble in water (Saily and Tandon, 1998).

Recently, the extraction behaviors of V(IV) from sulphuric acid solution by Cyanex 272 (Zhang *et al.*, 1995, 1996) and of V(IV) and V(V) from hydrochloric acid solution by Cyanex 272 and Cyanex 301 (Saily and Tandon, 1998) have been reported. As there was no report on the extraction behavior of V(IV) from any acid solution using Cyanex 302, this system have been investigated in Authors' Laboratories and as well reported by others (Sole and Hiskey, 1992).

In the present work, the factorial design considering five factors ([V(IV)], $pH_{(eq)}$, [Cyanex 302], [SO_4^{2-}] and temperature (T)) at two levels (low '-' and high '+') has been done to model the extraction of V(IV) in the V(IV)-[SO_4^{2-}](H+, Na+) – Cyanex 302-kerosene systemand the effectiveness of the derived model has been justified.

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Materials and methods

Materials

Cyanex 302 containing 78-80% R_2PSOH, 10-12% R_3PO, 2-3% R_2PO_2H, 2% R_2PS_2H and 8% unknown compounds (Ali *et al.,*2011) was collected from Cytec Canada Inc. as a gift. In extractions, it has been used without further purification as R_3PO, R_2PO_2H and R_2PS_2H have extracting power. Kerosene is bought from the local market and distilled to collect the colorless aliphatic fraction distilling over 200-260°C. NH_4VO_3 (99%, Riedel-deHaen), $VOSO_4$ (99.9%, Alfa Aesar- Johnson-Mathey) and H_2O_2 (30%, Merck-Germany) have been used without further purification.

Analytical

Concentrations of V(IV) in aqueous solutions have been measured by the HNO_3, oxidative-H_2O_2 method (Ali *et al.,* 2011) at 450 nm using a UV-visible Spectrophotometer (UV-1650 PC, Shimadzu, Japan). For preparation of standard and test solutions, NH_4VO_3 and $VOSO_4$. $5H_2O$ have been used respectively. A Mettler Toledo pH meter (model 320) was used for pH measurement. The pH was adjusted by addition of either anhydrous Na_2CO_3 or dilute H_2SO_4 solution when required.

Procedure

Extraction procedures are given elsewhere (Paatero *et al.,* 1990). In this case, two phases at specified experimental parameters are agitated at O/A=1 (O = 20 mL) for a predetermined time of 20 min. The phase separation is found to be quick; and the aqueous phase after equilibration is analyzed for its equilibrium pH and V(IV)-content. Then the value of extraction ratio (D) is calculated as usual (Paatero *et al.*, 1990).

Results and discussion

A potential concern in the use of two-level factorial design is the assumption of linearity in the factor effect. In the previous report (Biswas and Karmakar, 2012), though approxi-

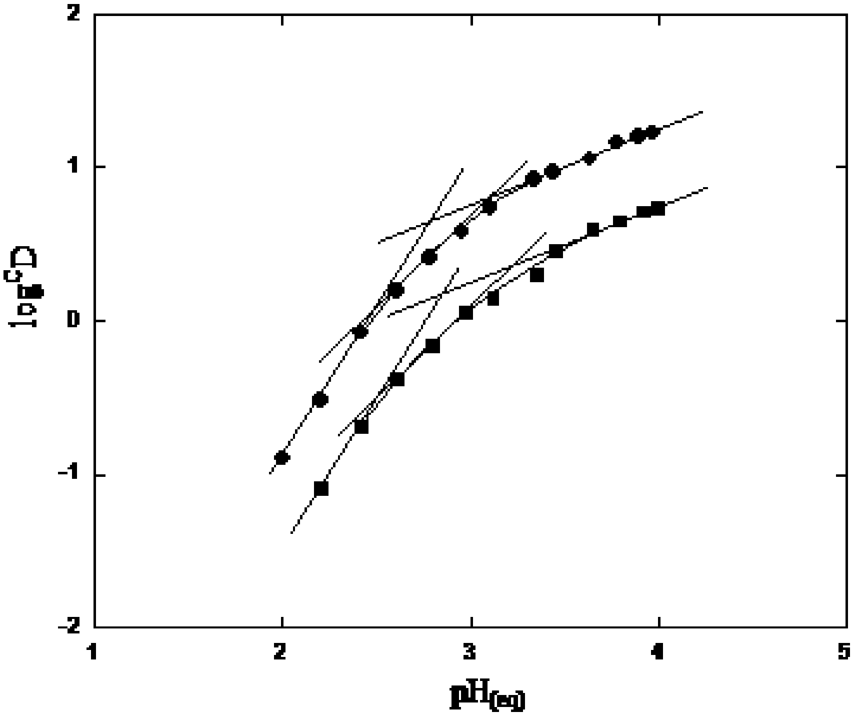

Fig. 1. Effect of equilibrium pH on the extraction of V(IV) Cyanex 302 in kerosene [14]. $[V(IV)]_{(ini)}$ = 200 mg/L, Temp. = 303 ± 0.5 K, Equilibration time = 20 min, O/A = 1 (O = 20 mL), $[SO_4^{2-}]$ = 0.02 mol/L.(n), [Cyanex 302] = 0.10 mol/L; S = 2 ($pH_{(eq)}$< 2.25), 1 ($pH_{(eq)}$ = 2.9) and 0.3 ($pH_{(eq)}$ = 4.0); I = -5.485 (when S = 2) and -3.04 (when S = 1); (3), [Cyanex 302] = 0.20 mol/L; S = 2 ($pH_{(eq)}$< 2.25), 1 ($pH_{(eq)}$ = 2.9) and 0.3 ($pH_{(eq)}$ = 4.0); I = -4.845 (when S = 2) and -2.34 (when S = 1)

mate linearity in the log ^{C}D versus log[V(IV)], log[Cyanex 302], -log(1+2.24 [SO_4^{2-}]) and 1/T plots have been established, the pH effect was not linear. The log ^{C}D vs. $pH_{(eq)}$ plots are reproduced in Fig.1. The non-linear curve fitting shows that log ^{C}D is proportional to -log(1+4641.14 10^{-pH} + (1.5 10^{6}) 10^{-2pH}). It is therefore expected that the log ^{C}D vs. -log(1+4641.14 10^{-pH} + (1.5 10^{6}) 10^{-2pH}) should be straight line of unity slope. Such a plot is shown in Fig. 2.

duplicate. In order to check the lack of fit due to curvature, additional trial (four in number) is made at the midpoint level of each factor. The difference between the average center point value and the overall average of the design points indicates the severity of curvature.

The average yield, $\overline{Y}$ and the variance for each trial; the pooled variance (S^2_{pooled}), standard $deviation_{pooled}$, [MIN] and [MINC] are calculated by using Eqs. (1) to (5) (Davies, 1979; Saha, *et al.*, 2010).

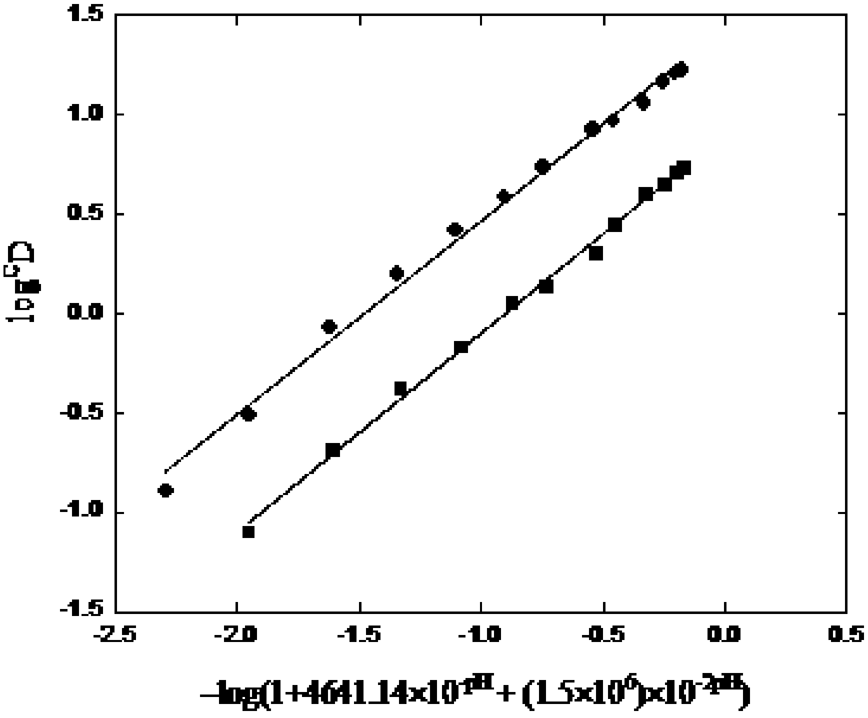

Fig. 2. Effect of equilibrium pH on the extraction of V(IV) Cyanex 302 in kerosene. $[V(IV)]_{(ini)}$ = 200 mg/L, Temp. = 303 ± 0.5 K, Equilibration time = 20 min, O/A = 1 (O = 20 mL), [SO_4^{2-}]= 0.02 mol/L.(n), [Cyanex 302] = 0.10 mol/L; S = 1.00; I = 0.90; (]), [Cyanex 302] = 0.20 mol/L; S = 0.97; I = 1.44.

The investigated system has been modeled by 2^k factorial design in considering logistic function (Hosmer and Lemeshow, 2000), where, k = 5(number of factors); each at 2 levels: high (+) and low (-) (Montgomery, 2001; Biswas and Karmakar, 2013). The statistical model for a 2^5 design includes 5!/0!(5-0)! = 1 mean effect, 5!/1!(5-1)! = 5 single factor effects, 5!/2!(5-2)! = 10 two-factor interactions, 5!/3!(5-3)! = 10 three factor interactions, 5!/4!(5-4)! =5 four-factor interactions and 5!/5!(5-5)! =1 five factor interaction.

In this case, there are 2^5 trials. Since the basic design involves 32 trials, there will be 64 trials when each is run in

Variance =

$$S^2 = \frac{(Y_1-\overline{Y})^2+(Y_2-\overline{Y})^2+\ldots\ldots\ \ldots\ldots\ldots\ldots+(Y_n-\overline{Y})^2}{n-1} \qquad (1)$$

The variances calculated for each trial are then used in the calculation of a weighted average i.e. pooled variance of the individual variances for each trial.

Pooled variance =

$$S^2_{pooled} = \frac{(n_1-1)(S_1^2)+(n_2-1)(S_2^2)-\ldots\ldots\ldots+(n_k-1)(S_k^2)}{(n_1-1)+(n_2-1)-\ldots\ldots\ldots\ldots\ldots+(n_k-1)}$$

Standard deviation$_{pooled}$ = $s\sqrt{\frac{1}{m.k}+\frac{1}{c}}$ (3)

[MIN] = $ts\sqrt{\frac{1}{m.k}+}$ (4)

[MINC] = $ts\sqrt{\frac{1}{m.k}+\frac{1}{c}}$ (5)

The t value of 2.03 is taken from the student's "t" table for 95% confidence level and 35 *df* resulting from thirty two (32) trials with two replicates and one trial with four replicates as *df* = 32(2-1)+1(4-1) = 35).

The experimental ranges of variables considered in this study are listed in Table I. The two level 5-factor design with factors in coded form is shown in the 3rd to 7th columns of the Table II. The results of these experiments are listed in the 34th and 35th columns with average in the 36th column in the Table II. The last column of Table II represents the variance of two measurements for each trial.

Table I. Process variables and response

Factor	Level			Logistic function	Level		
	(+)	(0)	(-)		(+)	(0)	(-)
(a) [V(IV)], mol/L	0.0195	0.0062	0.002	(a) log([V(IV)], mol/L)	-1.71	-2.21	-2.71
(b) pH	4.0	2.68	2.0	(b) -log(1+4641.14 10^{-pH} + (1.5 10^6) 10^{-2pH})	-0.17	-1.23	-2.29
(c) [H_2A_2], mol/L	0.50	0.07	0.01	(c) log ([H_2A_2], mol/L)	-0.301	-1.1505	-2.00
(d) [SO_4^{2-}], mol/L	0.01	0.50	1.50	(d) -log (1+2.24 [SO_4^{2-}])	-0.0096	-0.3245	-0.6395
(e) T, K	293	305	318	(e) 1/T, K^{-1}	0.003413	0.003279	0.003145

Response: Y (yield) = value of log ^CD

The computation analysis for this experiment is also shown in Table II. The design matrix is supplemented with a computation matrix, which is used to detect any interaction effect. This computation matrix is generated by simple algebraic multiplication of the coded factor levels. In trial 1, a is plus, b is plus, therefore ab is plus; in trial 2, a is minus, b is plus, therefore ab is minus. Based on Table II, the factor and interaction effects are determined as follows and presented in Table III. The sum +'s column (2nd column of Table III) is generated by totaling the response values on each row with a plus for each column of Table II: *e.g.* for factor a, 1.67-0.46-1.73-3.86+1.04-1.09-2.36-4.49+2.32+0.19-1.08-3.21+1.69-0.44-1.71-3.84= -17.36. In a similar manner the sum -'s column (3rd column of Table III) is generated. The sum of these two columns should be equal to the sum of all the average responses and can be used as a check on calculations. The difference column represents the difference between the responses in the 16 trials when the factor is at a high level and the responses in the 16 trials when the factor is at a low level. The effect is then calculated by dividing the difference by the number of plus signs in the column. With the single factor effects there are no other interaction effects for the investigated present system.

These results are expressed as a mathematical model using a first order polynomial. The values for the co-efficient are one half the factor effects listed in Table III since these are based upon coded levels +1 and -1 that differed by two units. Since there is only factor effects with no interaction effect, the polynomial is

Y = -1.005 + (-0.080) a + 1.065 b + 1.700 c + 0.315 d + (-0.325) e (6)

In Eq. (6), the factors are expressed in coded units. These are converted into real units by substituting:

i) for metal ion concentration (log[V(IV)], mol/L) = M let)

$$c=\frac{E-\frac{[illegible]}{2}}{\frac{[illegible]}{2}}=1.1771E+ \quad (7)$$

ii) for pH (-log(1+4641.14 10^{-pH} + (1.5 10^6) 10^{-2pH}) = P let)

$$c=\frac{E-\frac{[illegible]}{2}}{\frac{[illegible]}{2}}=1.1771E+1.3543 \quad (8)$$

iii) forextractant concentration (log ([Cyanex 302], mol/L) = E let)

$$c=\frac{E-\frac{[illegible]}{2}}{\frac{[illegible]}{2}}=1.1771E+1.3543 \quad (9)$$

Table II. Computation matrix for five factor two level experiment

	Design Matrix						Computation Matrix																											Yield (log ^{C}D)		Response ($\bar{Y}$)	
Trial	Mean	a	b	c	d	e	ab	ac	ad	ae	bc	bd	be	cd	ce	de	abc	abd	abe	bcd	ace	ade	bcd	bce	bde	cde	abcd	abce	abde	acde	bcde	abcde	Y_1	Y_2	Average log ^{C}D	Variance
1	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	1.64	1.70	1.67	0.0018
2	+	-	+	+	+	+	-	-	-	-	+	+	+	+	+	+	-	-	-	-	-	-	+	+	+	+	-	-	-	-	+	-	1.90	1.76	1.83	0.0098
3	+	+	-	+	+	+	-	+	+	+	-	-	-	+	+	+	-	-	-	+	+	+	-	-	-	+	-	-	-	+	-	-	-0.44	-0.48	-0.46	0.0008
4	+	-	-	+	+	+	+	-	-	-	-	-	-	+	+	+	+	+	+	-	-	-	-	-	-	+	+	+	+	-	-	+	-0.28	-0.32	-0.30	0.0008
5	+	+	+	-	+	+	+	-	+	+	-	+	+	-	-	+	-	+	+	-	-	+	-	-	+	-	-	-	+	-	-	-	-1.76	-1.70	-1.73	0.0018
6	+	-	+	-	+	+	-	+	-	-	-	+	+	-	-	+	+	-	-	+	+	-	-	-	+	-	+	+	-	+	-	+	-1.65	-1.49	-1.57	0.0128
7	+	+	-	-	+	+	-	-	+	+	+	-	-	-	-	+	+	-	-	-	-	+	+	+	-	-	+	+	-	-	+	+	-3.84	-3.88	-3.86	0.0008
8	+	-	-	-	+	+	+	+	-	-	+	-	-	-	-	+	-	+	+	+	+	-	+	+	-	-	-	-	+	+	+	-	-3.62	-3.78	-3.70	0.0128
9	+	+	+	+	-	+	+	+	-	+	+	-	+	-	+	-	+	-	+	-	+	-	-	+	-	-	-	+	-	-	-	-	1.02	1.06	1.04	0.0008
10	+	-	+	+	-	+	-	-	+	-	+	-	+	-	+	-	-	+	-	+	-	+	-	+	-	-	+	-	+	+	-	+	1.25	1.15	1.20	0.0050
11	+	+	-	+	-	+	-	+	-	+	-	+	-	-	+	-	-	+	-	-	+	-	+	-	+	-	+	-	+	-	+	+	-1.10	-1.08	-1.09	0.0002
12	+	-	-	+	-	+	+	-	+	-	-	+	-	-	+	-	+	-	+	+	-	+	+	-	+	-	-	+	-	+	+	-	-0.90	-0.96	-0.93	0.0018
13	+	+	+	-	-	+	+	-	-	+	-	-	+	+	-	-	-	-	+	+	-	-	+	-	-	+	+	-	-	+	+	+	-2.29	-2.43	-2.36	0.0098
14	+	-	+	-	-	+	-	+	+	-	-	-	+	+	-	-	+	+	-	-	+	+	+	-	-	+	-	+	+	-	+	-	-2.15	-2.25	-2.20	0.0050
15	+	+	-	-	-	+	-	-	-	+	+	+	-	+	-	-	+	+	-	+	-	-	-	+	+	+	-	+	+	+	-	-	-4.41	-4.57	-4.49	0.0128
16	+	-	-	-	-	+	+	+	+	-	+	+	-	+	-	-	-	-	+	-	+	+	-	+	+	+	+	-	-	-	-	+	-4.29	-4.36	-4.33	0.0025
17	+	+	+	+	+	-	+	+	+	-	+	+	-	+	-	-	+	+	-	+	-	-	+	-	-	-	+	-	-	-	-	-	2.28	2.38	2.32	0.0050
18	+	-	+	+	+	-	-	-	-	+	+	+	-	+	-	-	-	-	+	-	+	+	+	-	-	-	-	+	+	+	-	+	2.44	2.52	2.48	0.0032
19	+	+	-	+	+	-	-	+	+	-	-	-	+	+	-	-	-	-	+	+	-	-	-	+	+	-	-	+	+	-	+	+	0.15	0.23	0.19	0.0032
20	+	-	-	+	+	-	+	-	-	+	-	-	+	+	-	-	+	+	-	-	+	+	-	+	+	-	+	-	-	+	+	-	0.33	0.37	0.35	0.0008
21	+	+	+	-	+	-	+	-	+	-	-	+	-	-	+	-	-	+	-	-	+	-	-	+	-	+	-	+	-	+	+	+	-1.02	-1.14	-1.08	0.0072
22	+	-	+	-	+	-	-	+	-	+	-	+	-	-	+	-	+	-	+	+	-	+	-	+	-	+	+	-	+	-	+	-	-0.94	-0.90	-0.92	0.0008
23	+	+	-	-	+	-	-	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	+	+	-	+	+	-	-	-3.16	-3.26	-3.21	0.0050
24	+	-	-	-	+	-	+	+	-	+	+	-	+	-	+	-	-	+	-	+	-	+	+	-	+	+	-	+	-	-	-	+	-3.02	-3.08	-3.05	0.0018
25	+	+	+	+	-	-	+	+	-	-	+	-	-	-	-	+	+	-	-	-	-	+	-	-	+	+	-	-	+	+	+	+	1.66	1.72	1.69	0.0018
26	+	-	+	+	-	-	-	-	+	+	+	-	-	-	-	+	-	+	+	+	+	-	-	-	+	+	+	+	-	-	+	-	1.81	1.89	1.85	0.0032
27	+	+	-	+	-	-	-	+	-	-	-	+	+	-	-	+	-	+	+	-	-	+	+	+	-	+	+	+	-	+	-	-	-0.42	-0.46	-0.44	0.0008
28	+	-	-	+	-	-	+	-	+	+	-	+	+	-	-	+	+	-	-	+	+	-	+	+	-	+	-	-	+	-	-	+	-0.26	-0.30	-0.28	0.0008
29	+	+	+	-	-	-	+	-	-	-	-	-	-	+	+	+	-	-	-	+	+	+	+	+	+	-	+	+	+	-	-	-	-1.69	-1.73	-1.71	0.0008
30	+	-	+	-	-	-	-	+	+	+	-	-	-	+	+	+	+	+	+	-	-	-	+	+	+	-	-	-	-	+	-	+	-1.50	-1.60	-1.55	0.0050
31	+	+	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	-	+	+	-3.78	-3.90	-3.84	0.0072
32	+	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	-	-	-	+	+	+	+	+	-	-3.61	-3.75	-3.68	0.0098
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.85	-0.84	-0.86	0.0003
																																	-0.87	-0.88		

S^2_{pooled}= 0.0039, Standard deviation$_{pooled}$ = 0.0625, [MIN] = 0.03, [MINC] = 0.08 and curvature = -0.15

Table III. Evaluation of factor and interaction effects (based on Table II)

Factor	Sum +'s	Sum -'s	Difference	Effect
Mean	-32.16	0.00	-32.16	-1.01
a	-17.36	-14.80	-2.56	-0.16
b	0.96	-33.12	34.08	2.13
c	11.12	-43.28	54.40	3.40
d	-11.68	-21.76	10.08	0.63
e	-21.92	-11.52	-10.40	-0.65

Table IV. Experimental average yield and calculated yield

Trial	$Y_{(exp.)}$	$Y_{(cal.)}$	Deviation
1.	1.67	1.665	0.0049
2.	1.83	1.825	0.0048
3.	-0.46	-0.465	0.0048
4.	-0.30	-0.305	0.0048
5.	-1.73	-1.735	0.0047
6.	-1.57	-1.575	0.0047
7.	-3.86	-3.865	0.0047
8.	-3.70	-3.705	0.0047
9.	1.04	1.035	0.0049
10.	1.20	1.195	0.0049
11.	-1.09	-1.095	0.0049
12.	-0.93	-0.935	0.0049
13.	-2.36	-2.365	0.0048
14.	-2.20	-2.205	0.0048
15.	-4.49	-4.495	0.0048
16.	-4.33	-4.335	0.0048
17.	2.32	2.316	0.0041
18.	2.48	2.476	0.0041
19.	0.19	0.186	0.0041
20.	0.35	0.346	0.0041
21.	-1.08	-1.084	0.0040
22.	-0.92	-0.924	0.0040
23.	-3.21	-3.214	0.0039
24.	-3.05	-3.054	0.0039
25.	1.69	1.686	0.0042
26.	1.85	1.846	0.0042
27.	-0.44	-0.444	0.0041
28.	-0.28	-0.284	0.0041
29.	-1.71	-1.714	0.0040
30.	-1.55	-1.554	0.0040
31.	-3.84	-3.844	0.0040
32.	-3.68	-3.684	0.0040
33. Middle point	-0.86	-1.009	0.1490

iv) for sulphate ion concentration (-log (1+2.24 $[SO_4^{2-}]$)= S let)

$$c = \frac{[illegible]}{[illegible]} = 1.1771E + 1.3543 \qquad (10)$$

v) for temperature (T being absolute temperature)

$$d = \frac{\frac{1}{T} - \frac{0.003413 + 0.003145}{2}}{\frac{0.003413 - 0.003145}{2}} = \frac{7462.686}{T} - 24.47 \qquad (11)$$

in Eq. (6) to obtain the following final equation:

$$Y = 10.452 - 0.16\ M + 1.0047\ P + 2.0011\ E + 1.0003\ S - 2425.3729/T \qquad (12)$$

For trial 1 (M = -1.71, P = -0.17, E = -0.301, S = -0.0096 and T = 293), the yield calculated from the derived model represented by Eq. (12) is: $Y_{(cal.)}$ = 1.665 and the experimental average yield is $Y_{(exp.)}$ = 1.67 producing deviation = 0.0049.

All the values of the experimental average yield and the calculated yield using the derived equation (12) are shown in Table IV. It is seen in all cases that the deviation of modeled yield from the experimental yield is in between 0.15. At any set of experimental parameters the model can efficiently predict experimental log ^{C}D value which is shown in Table V. The optimization of the factors to obtain maximum possible %E of V(IV) are shown in Table VI. At three optimized conditions of ~99%E, values of %E have been verified by the shake-out experiments at the optimized conditions. These values are found to be comparable.

Table V . Data for comparison of model value with shake-out experimental value

[V(IV)], mg/L	$pH_{(eq)}$	[Cyanex 302], mol/L	$[SO_4^{2-}]$, mol/L	Temp., K	log ^{C}D (experimental)	log ^{C}D (calculated)	Deviation
300	3.38	0.10	0.02	303	0.22	0.278	-0.058
700	3.27	0.10	0.02	303	0.16	0.128	0.032
200	2.60	0.20	0.02	303	0.20	0.067	0.133
200	2.80	0.10	0.02	303	-0.17	-0.275	0.105
200	3.35	0.10	0.02	303	0.30	0.282	0.018
200	3.20	0.05	0.02	303	-0.49	-0.445	-0.045
200	3.11	0.15	0.02	303	0.40	0.429	-0.029
200	3.12	0.10	0.05	303	0.10	0.052	0.048
200	3.22	0.10	0.50	303	-0.19	-0.134	-0.056
200	3.08	0.20	0.02	298	0.57	0.508	0.062
200	3.19	0.20	0.02	313	0.94	1.005	-0.065

Table VI . Optimization of factors

[V(IV)]x 10^3, mg/L	^{a}M	$pH_{(eq)}$	^{a}P	$[H_2A_2]$, mol/L	^{a}E	$[SO_4^{2-}]$, mol/L	^{a}S	Temp.	log ^{C}D (cal)	%E	%E (exptl)
5.88	-2.230	4.5	-0.06	0.2	-0.699	0.02	-0.019	303	1.326	95.496	
13.73	-1.862	4.5	-0.06	0.5	-0.301	0.02	-0.019	303	2.064	99.144	98.9[b]
19.61	-1.708	4.5	-0.06	0.8	-0.097	0.02	-0.019	303	2.447	99.644	
5.88	-2.230	3.5	-0.42	0.5	-0.301	0.02	-0.019	303	1.761	98.296	98.01[b]
13.73	-1.862	3.5	-0.42	0.7	-0.155	0.02	-0.019	303	1.995	98.997	
19.61	-1.708	3.5	-0.42	1.0	0.000	0.02	-0.019	303	2.280	99.478	
5.88	-2.230	3.0	-0.85	0.9	-0.046	0.02	-0.019	303	1.840	98.574	
13.73	-1.862	3.0	-0.85	1.2	0.079	0.02	-0.019	303	2.031	99.077	
19.61	-1.708	3.0	-0.85	1.5	0.176	0.02	-0.019	303	2.200	99.373	99.21[b]

[a] M = log([V(IV)], mol/L); P = log(1+4641.14 10^{-pH} + (1.5 10^6) 10^{-2pH}); E = log ($[H_2A_2]$, mol/L); S = log (1+2.24 $[SO_4^{2-}]$); T = Absolute temperature. [b] Average of 3 readings

Conclusion

The extraction process has been successfully modeled by the five factor two level experimental design. On symbolizing log[V(IV)], -log(1+4641.14 10^{-pH} + (1.5 10^6) 10^{-2pH}), log [Cyanex 302], -log (1+2.24$[SO_4^{2-}]$) and absolute temperature as M, P, E, S and T, respectively; the model obtained is: log ^{C}D= 10.452-0.16 M+1.0047 P+2.0011 E+1.0003 S-2425.3729/T. From this model it has been seen that the extraction of V(IV) by Cyanex 302 is dependent on the factors.

Notations and abbreviations

D	Extraction or distribution ratio
^{C}D	D at a constant equilibrium pH and extractant concentration
Y	Response value
$\overline{Y}$	Average or mean of response value
n	Number of observations
t	Appropriate value from "t-table"
s	Pooled standard deviation
m	Number of plus signs in column
k	Number of replicates in each trial
c	Number of center point
df	Degree of freedom
[MIN]	Minimum significant factor effect
[MINC]	Minimum significant curvature effect
Suffix (o)	Organic phase
(ini)	Initial
(eq)	Equilibrium

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