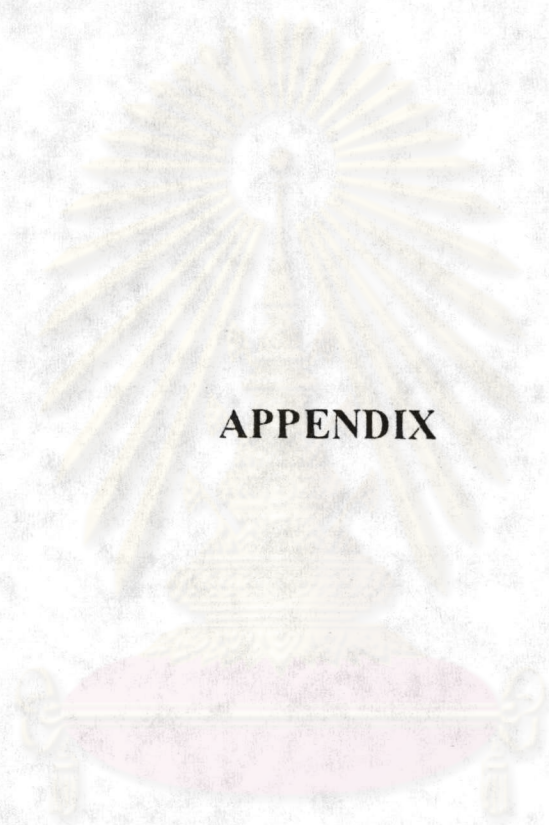


## REFERENCES

- Cosidine, D.M., ed. 1976. Van Nostrand's Scientific Encyclopedia. 5th ed. New York: Van Nostrand Reinhold.
- Gu, Z. 1990. A new liquid membrane technology – electrostatic pseudo liquid membrane. Journal of Membrane Science 52: 77-88.
- Gu, Z. 1992. Electrostatic Pseudo-Liquid-Membrane. In W.S. Winston Ho and K.K. Sirkar (eds.), Membrane Handbook, pp. 867-884. New York: Van Nostrand Reinhold.
- Gu, Z., Ho, W.S.W., and Li, N.N. 1992. Emulsion liquid membranes: Design considerations. In W.S. Winston Ho and K.K. Sirkar (eds.), Membrane Handbook, pp. 656-700. New York: Van Nostrand Reinhold.
- Ho, W.S.W, and Li, N.N. 1992. Emulsion liquid membranes: Definitions. In W.S. Winston Ho and K.K. Sirkar (eds.), Membrane Handbook, pp. 597-610. New York: Van Nostrand Reinhold.
- Hoechst Celanese Corporation. 1995. Operating Manual: Laboratory Liquid/Liquid Extraction System. n.p. (Typewritten)

- Loiacono, O., Drioli, E., and Molinari, R. 1986. Metal ions separation and concentration with supported liquid membranes. Journal of Membrane Science 28: 123-138.
- Majumda, S., and Sirkar, K.K. 1992. Hollow-fiber contained liquid membrane. In W.S. Winston Ho, and K.K. Sirkar (eds.), Membrane handbook, pp. 764-808. New York: Van Nostrand Reinhold.
- Ohtsuka, N. 1990. Cobalt recovery method. U.S. Patent 4,908,462. 13 March 1990.
- Prasad, R., and Sirkar, K.K. 1990. Hollow fiber solvent extraction: Performances and design. Journal of Membrane Science 50: 153-175.
- Schulz, G. 1988. Separation techniques with supported liquid membranes. Desalination 68: 191-202.
- Stephen, H., and Stephen, T., eds. 1979. Solubilities of Inorganic and Organic Compounds 2nd. ed. Vol.1. Oxford: Pergamon Press.
- Strauss, H.J., and Kaufman, M. n.d. Handbook for Chemical Technicians New York: McGraw-Hill Book Co.
- Tanigaki, M., Shiode, T., Ueda, M., and Eguchi, W. 1988. Facilitated transport of zinc chloride through hollow fiber supported liquid membrane. Part 1. Transport mechanism. Separation Science and Technology 23 (10&11): 1145-1159.

- Tanigaki, M., Ueda, M., and Eguchi, W. 1988. Facilitated transport of zinc chloride through hollow fiber supported liquid membrane. Part 2. Membrane stability. Separation Science and Technology 23 (10&11): 1161-1169.
- Tanigaki, M., Shiode, T., Okumi, S., and Eguchi, W. 1988. Facilitated transport of zinc chloride through hollow fiber supported liquid membrane. Part 3. Module operation. Separation Science and Technology 23 (10&11): 1171-1181.
- Tavlarides, L.L., Bae, J.H., and Lee, C.K. 1987. Solvent extraction, membranes, and ion exchange in hydrometallurgical dilute metal separation. Separation Science and Technology 22 (2&3): 581-617.
- Teramoto, M., Matsuyama, H., Takaya, H., and Asano, S. 1987. Development of spiral-type supported liquid membrane module for separation and concentration of metal ions. Separation Science and Technology 22 (11): 2175-2201.
- Weast, R.C., ed. 1968. The CRC Handbook of Chemistry and Physics 49th ed. Ohio: The Chemical Rubber Co.



**APPENDIX**

ศูนย์วิทยทรัพยากร  
จุฬาลงกรณ์มหาวิทยาลัย

## APPENDIX A

### THE CALIBRATION DATA OF FLOW METERS

Table A-1 The calibration data of the tubeside flow meter

Pump speed Controller	Flow meter	Pressure gauge (psi)		Volume (ml)	Time (sec)	Volumetric flowrate (ml/min)	
		inlet	outlet			Actual	Average
2	5.0	3.6	3.5	122.0	60.13	121.74	121.63
				122.0	60.24	121.51	
3	10.0	2.5	2.4	211.0	60.33	209.85	210.07
				211.0	60.20	210.30	
4	15.0	4.0	3.8	313.0	60.30	311.44	311.66
				312.5	60.12	311.88	
4	20.0	1.5	1.4	203.0	30.37	401.05	401.05
				204.0	30.52	401.05	
5	24.0	3.4	3.2	250.0	30.26	495.70	495.46
				250.0	30.29	495.21	
5	25.0	2.3	2.1	259.0	30.14	515.59	515.05
				260.0	30.32	514.51	
6	30.0	3.2	3.0	312.0	30.25	618.84	618.49
				310.0	30.09	618.15	
7	40.0	6.0	5.8	275.0	20.04	823.35	823.35
				275.0	20.04	823.35	
8	50.0	8.2	7.9	230.0	13.25	1041.51	1040.24
				235.5	13.60	1038.97	

Table A-2 The calibration data of the shellside flow meter

Pump speed controller	Flow meter	Pressure gauge (psi)		Volume (ml)	Time (sec)	Volumetric flowrate (ml/min)	
		inlet	outlet			Actual	Average
2	6.0	2.1	2.0	155.0	60.01	154.97	155.00
				155.0	59.99	155.03	
3	10.0	4.0	3.9	219.0	59.93	219.26	219.05
				219.5	60.18	218.84	
4	15.0	5.0	4.9	309.0	60.17	308.13	308.19
				310.0	60.34	308.25	
4	20.0	1.5	1.4	198.0	29.8	398.66	398.93
				202.0	30.36	399.21	
5	24.0	4.9	4.6	252.0	30.71	492.35	492.87
				249.0	30.28	493.39	
5	25.0	3.9	3.5	256.0	30.17	509.12	508.78
				256.0	30.21	508.44	
6	30.0	6.0	5.9	304.0	29.99	608.20	608.00
				304.0	30.01	607.80	
7	40.0	6.1	5.5	270.0	20.09	806.37	806.23
				269.5	20.06	806.08	
8	50.0	8.9	8.5	339.0	20.03	1015.48	1015.66
				342.0	20.2	1015.84	

ศูนย์วิทยทรัพยากร  
จุฬาลงกรณ์มหาวิทยาลัย

## APPENDIX B

### THE EXPERIMENTAL RAW DATA

Table B-1 The raw data of the batch experiments

Data Batch	Feed phase			Strip phase		
	time to reach equilibrium (min)	the final pH	the final concentration (ppm)	time to reach equilibrium (min)	the final pH	the final concentration (ppm)
1	30	2.35	9,487.5	30	1.53	246.6
2	30	2.46	11,639	30	1.64	138.1
3	30	2.05	10,416	30	1.43	1,143.0

Table B-2 The analyzed data of equilibrium constants in the batch experiments

Data Batch	The concentrations of all the species at equilibrium in extraction (mol/l)				$K_{ex}$ (-)	The concentrations of all the species at equilibrium in stripping (mol/l)				$K_{st}$ (-)
	$[Co^{2+}]$	$[RH]$	$[CoX_2]$	$[H^+]$		$[CoX_2]$	$[H^+]$	$[Co^{2+}]$	$[RH]$	
1	0.1610	0.6035	0.0022	0.0045	$7.6 \times 10^{-7}$	0.0002	0.0300	0.0042	0.6075	8611.3
2	0.1975	0.6045	0.0017	0.0035	$2.9 \times 10^{-7}$	0.0002	0.0240	0.0023	0.6074	7365.9
3	0.1768	0.5991	0.0045	0.0089	$5.6 \times 10^{-8}$	0.0007	0.0372	0.0194	0.6066	7369.2

Note: The concentrations of species in organic phase are calculated based on the concentrations of hydronium ion

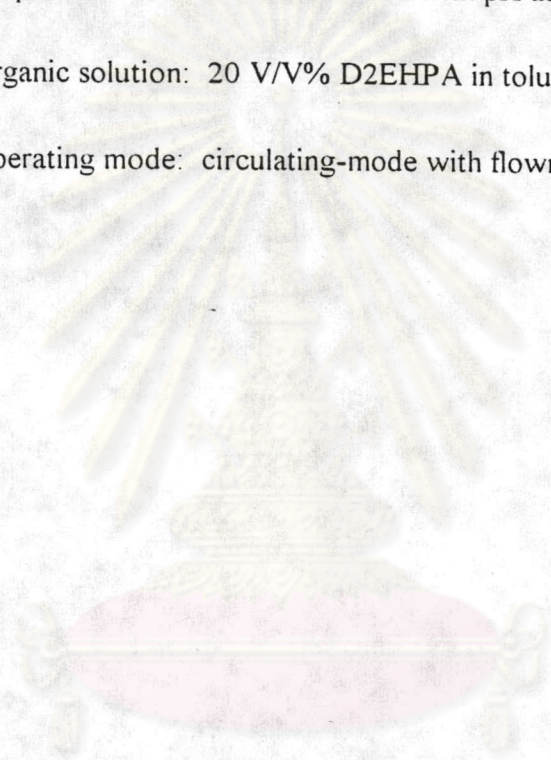
1. The experimental conditions for studying the effects of cobalt concentration in feed solution

Feed solution: 5,000, 8,000, and 10,000 ppm of cobaltous ion with pH about 4

Strip solution: oxalic acid solution with pH about 1.4

Organic solution: 20 V/V% D2EHPA in toluene

Operating mode: circulating-mode with flowrate of 500 ml/min



ศูนย์วิจัยทรัพยากร  
จุฬาลงกรณ์มหาวิทยาลัย



Table B-3 The experimental data for 5,000 ppm of cobaltous chloride

	Pump speed Controller	Flow meter	Pressure gauge (psi)	
			inlet	outlet
Feed	4	24.0	4.1	4.0
Strip	4	23.5	4.0	3.8

Time (min)	Sample	[Co <sup>2+</sup> ] (ppm)	pH	Sample	[Co <sup>2+</sup> ] (ppm)	pH
0	A-0	4.590	3.82	B-0	0	1.40
15	A-1	4.048	-	B-1	0.767	-
30	A-2	3.907	-	B-2	0.814	-
45	A-3	4.346	-	B-3	0.829	-
60	A-4	4.271	-	B-4	0.799	-
75	A-5	4.543	-	B-5	0.846	-
90	A-6	3.699	-	B-6	0.854	-
105	A-7	3.845	-	B-7	0.965	-
120	A-8	4.181	-	B-8	0.912	-
135	A-9	3.852	-	B-9	0.989	-
150	A-10	4.053	-	B-10	1.031	-
165	A-11	3.597	-	B-11	1.041	-
180	A-12	3.899	-	B-12	1.077	-
195	A-13	4.516	-	B-13	1.036	-
210	A-14	3.715	-	B-14	1.525	-
225	A-15	3.608	-	B-15	1.454	-
240	A-16	4.318	-	B-16	1.339	-
255	A-17	3.641	-	B-17	1.637	-
270	A-18	3.695	-	B-18	1.794	-
300	A-19	4.193	-	B-19	1.917	-
330	A-20	3.793	-	B-20	2.214	-
360	A-21	3.566	-	B-21	2.409	-
390	A-22	3.534	-	B-22	2.811	-

Table B-4 The experimental data for 8,000 ppm of cobaltous chloride

	Pump Speed Controller	Flow Meter	Pressure gauge (psi)	
			inlet	outlet
Feed	4	26.0	- 4.6	3.6
Strip	4	26.0	5.5	5.0

Time (min)	Sample	[Co <sup>2+</sup> ] (ppm)	pH	Sample	[Co <sup>2+</sup> ] (ppm)	pH
0	A-0	8,767	3.67	B-0	0	1.41
15	A-1	8,416	2.79	B-1	2.522	1.43
30	A-2	8,088	2.67	B-2	2.834	1.43
45	A-3	8,400	2.57	B-3	2.925	1.43
60	A-4	8,064	2.52	B-4	3.007	1.43
75	A-5	7,835	2.42	B-5	2.734	1.43
90	A-6	7,586	2.38	B-6	2.936	1.43
105	A-7	8,150	2.36	B-7	2.905	1.43
120	A-8	7,979	2.27	B-8	3.186	1.43
135	A-9	8,141	2.25	B-9	3.097	1.43
150	A-10	8,164	2.24	B-10	3.008	1.43
165	A-11	8,188	2.16	B-11	2.976	1.43
180	A-12	8,078	2.11	B-12	3.164	1.43
195	A-13	8,033	2.11	B-13	3.325	1.43
210	A-14	7,863	2.11	B-14	3.322	1.43
225	A-15	7,895	2.05	B-15	3.445	1.43
240	A-16	7,689	1.99	B-16	3.074	1.43
270	A-17	7,468	1.93	B-17	3.86	1.43
300	A-18	7,851	1.91	B-18	3.472	1.43
330	A-19	7,756	1.89	B-19	3.696	1.43
360	A-20	7,607	1.86	B-20	3.803	1.43

Table B-5 The experimental data for 10,000 ppm of cobaltous chloride

	Pump speed Controller	Flow meter	Pressure gauge (psi)	
			inlet	outlet
Feed	4	26.0	4.6	3.6
Strip	4	26.0	5.5	5.0

Time (min)	Sample	[Co <sup>2+</sup> ] (ppm)	pH	Sample	[Co <sup>2+</sup> ] (ppm)	pH
0	A-0	10,750	3.58	B-0	0	1.41
20	A-1	10,505	-	B-1	1.608	-
40	A-2	10,927	-	B-2	1.909	-
60	A-3	10,275	-	B-3	1.958	-
80	A-4	9,720	-	B-4	2.577	-
100	A-5	9,477	-	B-5	3.096	-
120	A-6	10,042	-	B-6	2.866	-
140	A-7	10,485	-	B-7	3.164	-
160	A-8	10,075	-	B-8	3.141	-
180	A-9	9,915	-	B-9	3.066	-
200	A-10	9,750	-	B-10	3.299	-
220	A-11	9,882	-	B-11	3.259	-
240	A-12	9,920	-	B-12	3.449	-
260	A-13	9,925	-	B-13	3.323	-
280	A-14	9,250	-	B-14	3.337	-
300	A-15	9,830	-	B-15	3.487	-
330	A-16	10,710	-	B-16	3.770	-
360	A-17	9,512	-	B-17	3.408	-
420	A-18	9,435	-	B-18	3.594	-

2. The experimental conditions for studying the effects of acidity in feed solution

Feed solution: 10,000 ppm of cobaltous ion with pH about 4 and 6

Strip solution: oxalic acid solution with pH about 1.4

Organic solution: 20 V/V% D2EHPA in toluene

Operating mode: circulating-mode with flowrate of 500 ml/min

The experimental data for feed solution containing 10,000 ppm of cobaltous ion with pH 4 is shown above in Table A-5. The experimental data for feed solution containing 10,000 ppm of cobaltous chloride with pH about 6 is shown in Table A-6.

ศูนย์วิทยทรัพยากร  
จุฬาลงกรณ์มหาวิทยาลัย

Table B-6 The experimental data for 10,000 ppm of cobaltous chloride at pH 6

	Pump speed Controller	Flow meter	Pressure gauge (psi)	
			inlet	outlet
Feed	4	24.0	4.1	3.5
Strip	4	24.0	5.0	4.5

Time (min)	Sample	[Co <sup>2+</sup> ] (ppm)	pH	Sample	[Co <sup>2+</sup> ] (ppm)	pH
0	A-0	10,709	6.53	B-0	0	1.39
20	A-1	10,123		B-1	2.193	
40	A-2	10,202		B-2	6.814	
60	A-3	9,420		B-3	8.752	
80	A-4	9,905		B-4	8.975	
100	A-5	9,496		B-5	8.239	
120	A-6	9,914		B-6	8.270	
140	A-7	9,771		B-7	8.414	
160	A-8	9,939		B-8	8.772	
180	A-9	10,212		B-9	8.304	
200	A-10	10,166		B-10	9.029	
220	A-11	9,886		B-11	8.717	
240	A-12	10,037		B-12	8.884	
260	A-13	8,036		B-13	9.081	
280	A-14	9,011		B-14	9.275	
300	A-15	8,325		B-15	10.71	
330	A-16	8,832		B-16	13.53	
360	A-17	8,059		B-17	14.09	
420	A-18	7,750	1.82	B-18	14.75	1.42

3. The experimental data for studying the effects of the types of strip solution

Feed solution: 5,000 and 10,000 ppm of cobaltous ion with pH 4

Strip solution: hydrochloric acid solution with pH about 1.4

Organic solution: 20 V/V% D2EHPA in toluene

Operating mode: circulating-mode with flowrate of 500 ml/min

Table B-7 The experimental data for 5,000 ppm of cobaltous chloride and using HCl as a strip solution

	Pump speed Controller	Flow meter	Pressure gauge (psi)	
			inlet	outlet
Feed	4	24.0	2.2	2.0
Strip	4	23.5	3.0	2.9

Time (min)	Sample	[Co <sup>2+</sup> ] (ppm)	pH	Sample	[Co <sup>2+</sup> ] (ppm)	pH
0	A-0	4,969	3.89	B-0	0	1.44
15	A-1	4,768	2.46	B-1	82.40	1.47
30	A-2	4,691	2.38	B-2	129.90	1.47
45	A-3	-	2.30	B-3	-	1.48
60	A-4	4,428	2.29	B-4	216.85	1.49
75	A-5	-	2.23	B-5	-	1.49
90	A-6	4,305	2.19	B-6	298.20	1.50
105	A-7	-	2.18	B-7	-	1.50
120	A-8	4,181	2.18	B-8	395.80	1.51
140	A-9	-	2.16	B-9	-	1.51
160	A-10	4,053	2.15	B-10	487.35	1.52
180	A-11	3,957	2.15	B-11	597.10	1.52
200	A-12	3,889	2.14	B-12	653.75	1.53
240	A-13	3,899	2.14	B-13	692.50	1.53

Table B-8 The experimental data for 10,000 ppm of cobaltous chloride and using HCl as a strip solution

	Pump speed Controller	Flow meter	Pressure gauge (psi)	
			inlet	outlet
Feed	4	24.0	2.5	2.3
Strip	4	24.0	3.1	3.0

Time (min)	Sample	[Co <sup>2+</sup> ] (ppm)	pH	Sample	[Co <sup>2+</sup> ] (ppm)	pH
0	A-0	11.192	3.55	B-0	0	1.42
15	A-1	10.986	2.51	B-1	95.65	1.44
30	A-2	10.654	2.34	B-2	162.40	1.45
45	A-3	-	2.28	B-3	-	1.46
60	A-4	10.432	2.24	B-4	264.28	1.47
75	A-5	-	2.21	B-5	-	1.48
90	A-6	10.218	2.18	B-6	346.75	1.49
105	A-7	-	2.15	B-7	-	1.49
120	A-8	10.075	2.12	B-8	429.84	1.50
140	A-9	-	2.10	B-9	-	1.50
160	A-10	10.023	2.08	B-10	596.90	1.50
180	A-11	9.978	2.07	B-11	653.95	1.51
210	A-12	9.926	2.06	B-12	697.85	1.51

4. The experimental conditions for studying the effects of acidity in feed solution

Feed solution: 10,000 ppm of cobaltous ion with pH about 4 and 6

Strip solution: hydrochloric acid solution with pH about 1.4

Organic solution: 20 V/V% D2EHPA in toluene

Operating mode: circulating-mode with flowrate of 500 ml/min

Table B-9 The experimental data for 10,000 ppm of cobaltous chloride and using HCl as a strip solution

	Pump speed Controller	Flow meter	Pressure gauge (psi)	
			inlet	outlet
Feed	4	24.0	4.1	3.5
Strip	4	24.0	5.0	4.5

Time (min)	Sample	[Co <sup>2+</sup> ] (ppm)	pH	Sample	[Co <sup>2+</sup> ] (ppm)	pH
0	A-0	11.952	6.98	B-0	0	1.40
15	A-1	11.760	2.62	B-1	187.3	1.45
30	A-2	11.374	2.41	B-2	376.6	1.46
45	A-3	-	2.32	B-3	-	1.47
60	A-4	10.918	2.28	B-4	692.4	1.48
90	A-5	10.528	2.13	B-5	996.8	1.49
105	A-6	-	2.11	B-6	-	1.50
120	A-7	9.851	2.11	B-7	1123.7	1.51
140	A-8	-	2.07	B-8	-	1.52
160	A-9	9.567	2.05	B-9	1228.4	1.52
180	A-10	9.483	2.03	B-10	1302.9	1.53
210	A-11	9.415	2.02	B-11	1367.3	1.53

ศูนย์วิทยทรัพยากร  
จุฬาลงกรณ์มหาวิทยาลัย



Table B-10 The experimental data for keeping the acidities of both feed and strip solutions

	Pump speed	Flow meter	Pressure (psi)	
			inlet	outlet
Feed	4	24.0	3.9	2.2

	Pump speed	Flow meter	Pressure (psi)	
			inlet	outlet
Strip	4	24.0	3.2	3.0

Feed	[Co <sup>2+</sup> ] (ppm)	time (min)	pH	NaOH added (ml)	
1A-0	5,493.0	0	6.64	-	0.01M NaOH
		10	2.80	10	
1A-1	5,366.0	15	2.55	-	
		20	2.49	-	
1A-2	5,601.0	30	2.42	10	
1A-3	4,991.0	45	2.33	10	
1A-4	4,968.0	60	2.27	10	
1A-5	5,015.0	75	2.23	20	
1A-6	4,684.0	90	2.23	20	
1A-7	4,623.0	105	2.21	20	
1A-8	5,465.0	120	2.23	20	2M NaOH
1A-9	4,741.0	135	2.25	20	
1A-10	5,190.0	150	2.36	10	
1A-11	4,811.0	165	2.66	-	
1A-12	4,645.0	180	2.51	10	
1A-13	4,679.0	195	3.09	-	
1A-14	4,237.0	210	2.86	-	
1A-15	4,688.0	225	2.71	-	
1A-16	5,643.0	240	2.61	-	
1A-17	3,930.0	255	2.56	10	
1A-18	4,237.0	270	2.85	-	
1A-19	4,388.0	285	2.70	-	
1A-20	4,571.0	300	2.58	-	
1A-21	3,716.0	330	2.47	-	
1A-22	3,537.0	360	2.38	-	
1A-23	3,573.0	345	2.31	-	

Strip	[Co <sup>2+</sup> ] (ppm)	time (min)	pH	0.01M HCl added (ml)
1B-0	0.716	0	1.53	-
1B-1	75.26	15	1.58	-
1B-2	136.0	30	1.55	10
1B-3	164.4	45	1.53	-
1B-4	186.5	60	1.53	-
1B-5	225.8	75	1.55	10
1B-6	270.5	90	1.57	10
1B-7	294.2	105	1.58	10
1B-8	291.8	120	1.58	10
1B-9	339.1	135	1.58	10
1B-10	440.9	150	1.50	-
1B-11	456.8	165	1.44	-
1B-12	492.2	180	1.40	-
1B-13	705.0	195	1.41	-
1B-14	741.0	210	1.42	-
1B-15	847.1	225	1.42	-
1B-16	893.8	240	1.42	-
1B-17	859.6	255	1.43	-
1B-18	1,197.0	270	1.45	10
1B-19	906.5	285	1.45	-
1B-20	985.2	300	1.45	-
1B-21	1,161.0	330	1.46	-
1B-22	1,225.0	360	1.48	-
1B-23	1,251.0	390	1.50	-

5. The experimental conditions for studying the effects of volumetric flowrate of both feed and strip solutions

Volumetric flowrates: 100, 100 with circulated strip solution, 500, and 1,000 ml/min

Feed solution: 5,000 ppm of cobaltous ion with pH about 6.5

Strip solution: hydrochloric acid solution with pH about 1

Organic solution: 20 V/V% D2EHPA in toluene

Table B-11 The experimental data for volumetric flowrate of 100 ml/min

Feed	Pump speed	Flow meter	Pressure (psi)	
			inlet	outlet
	2	6.0	1.5	1.6
	2	6.0	1.5	2.0
	2	6.0	11.5	6.3

Strip	Pump speed	Flow meter	Pressure (psi)	
			inlet	outlet
	2	7.0	2.6	2.4
	2	7.0	2.1	1.5
	2	7.0	1.6	1.2

Circulation number	Sample number	[Co <sup>2+</sup> ] (ppm)	pH	2M NaOH added (ml)	pH'
-	1F-0	5,009	-	4.5	6.78
1	1F-1	4,656	2.52	30.5	6.24
2	1F-2	4,481	2.80	25.0	6.57
3	1F-3	4,007	2.50		

Sample number	[Co <sup>2+</sup> ] (ppm)	pH
1S-0	0	0.95
1S-1	120.5	0.96
1S-2	259.9	0.98
1S-3	565.3	1.00

Table B-12 The experimental data for volumetric flowrate of 100 ml/min with the circulated strip solution

Feed	Pump speed	Flow meter	Pressure (psi)	
			inlet	outlet
	2	5.0	3.5	3.2
	2	5.0	30	30

Strip	Pump speed	Flow meter	Pressure (psi)	
			inlet	outlet
	2	6.0	4.2	4.0
	2	6.0	5.0	4.0

Circulation number	Sample number	[Co <sup>2+</sup> ] (ppm)	pH	2M NaOH added (ml)	pH'
-	1F-0	5.360	-	-	6.54
1	1F-1	5.119	2.21	15.0	6.54
2	1F-2	4.784	2.20		

Sample number	[Co <sup>2+</sup> ] (ppm)	pH
1S-0	0	0.99
1S-1	117.10	1.03
1S-2	397.70	1.07

Table B-13 The experimental data for volumetric flowrate of 500 ml/min

Feed	Pump speed	Flow meter	Pressure (psi)	
			inlet	outlet
	4	24.0	2.6	2.4
	4	24.0	6.0	5.1
	-	-	-	-
	4	24.0	15.0	7.8

Strip	Pump speed	Flow meter	Pressure (psi)	
			inlet	outlet
	4	24.0	2.0	1.6
	4	24.0	2.1	1.6
	-	-	-	-
	4	24.0	2.1	1.6

Circulation number	Sample number	[Co <sup>2+</sup> ] (ppm)	pH	2M NaOH added (ml)	pH'
-	1F-0	6.707	-	2.5	6.82
1	1F-1	6.208	2.33	20	6.38
2	1F-2	4.849	2.42	23	6.10
3	1F-3	4.747	2.43	29	5.49
4	1F-4	4.653	2.37	-	

Sample number	[Co <sup>2+</sup> ] (ppm)	pH
1S-0	0	0.85
1S-1	183.1	0.87
1S-2	406.0	0.89
1S-3	997.5	0.91
1S-4	1,754.0	0.99

Table B-14 The experimental data for volumetric flowrate of 1,000 ml/min

Feed	Pump speed	Flow meter	Pressure (psi)	
			inlet	outlet
	9	50.0	9.0	8.8

Strip	Pump speed	Flow meter	Pressure (psi)	
			inlet	outlet
	8	50.0	8.6	8.0

Circulation number	Sample number	[Co <sup>2+</sup> ] (ppm)	pH	2M NaOH added (ml)	pH'
1	1F-1	5.279	2.08		

Sample number	[Co <sup>2+</sup> ] (ppm)	pH
1S-1	173.7	0.81

6. The experimental conditions for studying the effects of extractant concentration in organic solutions

Organic solution: 10, 15, 20, and 25 V/V% of D2EHPA in toluene

Feed solution: 500 ppm of cobaltous ion with pH about 6.5

Strip solution: hydrochloric acid solution with pH about 1

Volumetric flowrates: 1,000 ml/min

ศูนย์วิจัยทรัพยากร  
จุฬาลงกรณ์มหาวิทยาลัย

Table B-15 The experimental data for extractant concentration of 10 V/V%

Feed	Pump speed	Flow meter	Pressure (psi)		Strip	Pump speed	Flow meter	Pressure (psi)	
			inlet	outlet				inlet	outlet
	8	50.0	8.2	8.0		8	50.0	9.3	8.5
	8	50.0	8.5	8.4		8	50.0	8.9	8.0
	8	50.0	9.2	8.5		8	50.0	9.3	8.5

Circulation number	Sample number	[Co <sup>2+</sup> ] (ppm)	pH	2M NaOH added (ml)	pH'	Sample number	[Co <sup>2+</sup> ] (ppm)	pH
-	1F-0	599.0		-	6.81	1S-0	0	0.75
1	1F-1	520.8	2.86	8.0	6.34	1S-1	54.12	0.76
2	1F-2	450.2	3.32	6.0	6.60	1S-2	96.34	0.77
3	1F-3	385.1	3.12	-		1S-3	157.0	0.78

Table B-16 The experimental data for extractant concentration of 15 V/V%

Feed	Pump speed	Flow meter	Pressure (psi)		Strip	Pump speed	Flow meter	Pressure (psi)	
			inlet	outlet				inlet	outlet
	8	50.0	8.0	7.8		8	50.0	9.0	8.3
	8	50.0	8.7	8.4		8	50.0	9.0	8.3
	8	50.0	9.2	8.8		8	50.0	8.8	8.0

Circulation number	Sample number	[Co <sup>2+</sup> ] (ppm)	pH	2M NaOH added (ml)	pH'	Sample number	[Co <sup>2+</sup> ] (ppm)	pH
-	1F-0	632.3	4.17	0.5	6.91	1S-0	0	0.73
1	1F-1	548.8	2.79	8.5	6.12	1S-1	70.10	0.74
2	1F-2	426.1	3.10	9.0	6.73	1S-2	158.4	0.75
3	1F-3	369.0	3.53			1S-3	219.7	0.76

Table B-17 The experimental data for extractant concentration of 20 V/V%

Feed	Pump speed	Flow meter	Pressure (psi)		Strip	Pump speed	Flow meter	Pressure (psi)	
			inlet	outlet				inlet	outlet
	9	50.0	8.0	7.9		9	50.0	8.4	7.5
	9	50.0	8.8	8.7		9	50.0	8.4	7.6
	8	50.0	10.5	9.0		9	50.0	8.6	7.9

Circulation number	Sample number	[Co <sup>2+</sup> ] (ppm)	pH	2M NaOH added (ml)	pH'	Sample number	[Co <sup>2+</sup> ] (ppm)	pH
-	1F-0	674.8	4.56	1.0	6.83	1S-0	0	0.78
1	1F-1	516.6	2.88	10.0	6.88	1S-1	51.62	0.79
2	1F-2	437.4	3.20	8.0	6.87	1S-2	154.7	0.80
3	1F-3	354.2	2.92			1S-3	268.1	0.81

Table B-18 The experimental data for extractant concentration of 25 V/V%

Feed	Pump speed	Flow meter	Pressure (psi)		Strip	Pump speed	Flow meter	Pressure (psi)	
			inlet	outlet				inlet	outlet
	9	50.0	9.0	8.9		8	50.0	8.2	7.5
	9	50.0	8.9	8.8		8	50.0	8.5	7.8
	8	50.0	9.4	9.2		8	50.0	8.1	7.3

Circulation number	Sample number	[Co <sup>2+</sup> ] (ppm)	pH	2M NaOH added (ml)	pH'	Sample number	[Co <sup>2+</sup> ] (ppm)	pH
-	1F-0	606.5	3.96	1.0	6.88	1S-0	0	0.78
1	1F-1	451.0	2.53	13.0	6.14	1S-1	86.00	0.79
2	1F-2	353.6	3.33	10.0	6.04	1S-2	196.2	0.81
3	1F-3	334.4	3.29			1S-3	281.4	0.83

7. The experimental conditions for studying the effects of organic solvent used in liquid membrane

Organic solution: 20, and 25 V/V% of D2EHPA in n-dodecane

Feed solution: 500 ppm of cobaltous ion with pH about 6.5

Strip solution: hydrochloric acid solution with pH about 1

Volumetric flowrates: 1,000 ml/min

Table B-19 The experimental data for extractant concentration of 20 V/V% in n-dodecane

Feed	Pump speed	Flow meter	Pressure (psi)		Strip	Pump speed	Flow meter	Pressure (psi)	
			inlet	outlet				inlet	outlet
	9	50.0	8.4	8.3		8	50.0	8.3	7.5
	9	50.0	8.8	8.7		8	50.0	8.2	7.5
	9	50.0	8.9	8.8		8	50.0	7.9	7.0

Circulation number	Sample number	[Co <sup>2+</sup> ] (ppm)	pH	2M NaOH added (ml)	pH'
-	1F-0	560.2	4.09	2.0	6.85
1	1F-1	482.8	2.57	8.0	6.90
2	1F-2	371.4	2.64	8.0	6.89
3	1F-3	258.8	2.69		

Sample number	[Co <sup>2+</sup> ] (ppm)	pH
1S-0	0	0.83
1S-1	71.40	0.84
1S-2	170.4	0.85
1S-3	297.6	0.86

Table B-20 The experimental data for extractant concentration of 25 V/V% in n-dodecane

Feed	Pump speed	Flow meter	Pressure (psi)	
			inlet	outlet
	9	50.0	8.0	7.8
	9	50.0	8.5	8.4
	8	50.0	8.6	8.5

Strip	Pump speed	Flow meter	Pressure (psi)	
			inlet	outlet
	9	50.0	8.3	7.6
	9	50.0	8.0	7.5
	9	50.0	8.3	7.5

Circulation number	Sample number	[Co <sup>2+</sup> ] (ppm)	pH	2M NaOH added (ml)	pH'
-	1F-0	620.6	4.13	2.0	6.82
1	1F-1	439.2	2.58	10.0	6.65
2	1F-2	344.4	2.58	9.0	6.50
3	1F-3	271.9	2.90		

Sample number	[Co <sup>2+</sup> ] (ppm)	pH
1S-0	0	0.79
1S-1	74.50	0.80
1S-2	215.2	0.81
1S-3	319.0	0.82

ศูนย์วิทยทรัพยากร  
จุฬาลงกรณ์มหาวิทยาลัย



## APPENDIX C

### THE DEFINITIONS FOR DATA CALCULATION

The definitions for data calculation used in this work could be shown as:

#### Extraction Factor

$$\text{extraction factor (EF)} = \frac{\text{the amount of cobaltous ion extracted}}{\text{the amount of cobaltous ion fed}}$$

#### Recovery Factor

$$\text{recovery factor (RF)} = \frac{\text{the amount of cobaltous ion stripped}}{\text{the amount of cobaltous ion fed}}$$

#### Difference in Ion Concentration

$$\text{Difference in } [M^{n+}] = \frac{[M^{n+}]_{f,0} + [M^{n+}]_{s,0} - [M^{n+}]_{f,t} - [M^{n+}]_{s,t}}{[M^{n+}]_{f,0} + [M^{n+}]_{s,0}}$$

APPENDIX D

THE STRUCTURE OF LIQUI-CEL MEMBRANE CONTACTOR



ศูนย์วิจัยทรัพยากร  
จุฬาลงกรณ์มหาวิทยาลัย

# Liqui-Cel<sup>®</sup>

## Extra-Flow Membrane Contactor



Figure D-1 Schematic representation of the structure of Liqui-Cel Membrane Contactor

ศูนย์วิทยทรัพยากร  
จุฬาลงกรณ์มหาวิทยาลัย



## VITA

Mr. Noppakorn Thamphiphit was born in January, 1970 in Bangkok. He graduated high school from Saint Gabriel's College in 1989. He received a Bachelor's Degree of Engineering in Chemical Engineering from Khon Kaen University in 1993. Subsequently, he completed the requirements for a Master's Degree in Chemical Engineering at the Department of Chemical Engineering, Faculty of Engineering, Chulalongkorn University in 1997.

ศูนย์วิทยทรัพยากร  
จุฬาลงกรณ์มหาวิทยาลัย