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Sequential Separation of Cobalt, Copper, and Nickel from Alkaline Glycinate Solutions Using Solvent Extraction

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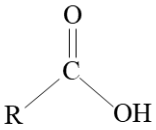
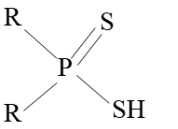
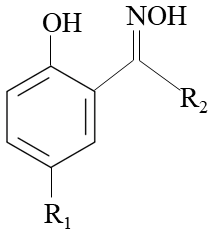
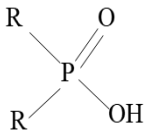
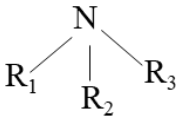
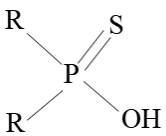
Table S1: Common reported solvent extractants in the literature for the extraction of base metals.

Extractant type and structure	Commercial examples	Extraction medium	Comment(s)/salient findings
 Carboxylic acid	Versatic 10	Sulphate[a]	• Co-extraction of Ni and Co • Phase modifier is required (e.g. tributyl phosphate) • Care should be taken as the extractant starts to hydrolyse in alkaline media
 Dithiophosphhinic acid	Cyanex 301	Chloride[b]	• Co-extraction of Co and Ni over Al(III), Ca(II), Mg(II) and Mn(II) at pH = 1.0. • While 80% Co was stripped using 3 M H_2SO_4, nil Ni was stripped using even higher conc. of H_2SO_4 up to 10 M. • 80% Ni was stripped using 10 M HCl. • Cyanex 301 is exposed to degradation if Cu presents in solution.
 Phenolic oxime	Oxime extractants including LIX 84-IC	Ammonia[c]	• Co-extraction of Ni and Co • After Co(II) is transferred to the organic phase, it undergoes oxidation to Co(III), which presents difficulties in the stripping process, leading to the degradation of the organic phase.
		Sulphate[d]	• Sequential separation of Cu, Ni and Zn • Cu was selectively extracted at equilibrium pH = 4, Ni at pH = 7.5 and Zn at pH = 9.0. • H_2SO_4 (2-3 M) stripped the metals.
 Phosphinic acid	Cyanex 272	Sulphate[e]	• Fe(III) was selectively extracted ahead of Co at pH = 3. • Co was extracted at pH = 8, while Ni was not. • The extractant starts to hydrolyse at higher pH > 8.
 Tertiary amine	Alamine 308[f]	Chloride[f]	• Co and Cu form anionic species (MCl_4^{2-}), while those for Ni are neutral ($NiCl_2$). • The anionic species can be then selectively extracted using either a tertiary or quaternary amine.
 Thiophosphinic acid	Cyanex 302	Sulphate[f]	• Selectively of the extractant follows the order Cu> Fe(III) > Zn > Co >Mn > Ni >>> Mg ~Ca • Cyanex 302 was withdrawn from the market due to instability issues.

a: (Alvial-Hein et al., 2021); b: (Wang & Lee, 2017); c: (Mubarok & Yunita, 2015); d: (Reddy & Priya, 2004); e: (Gandhi et al., 1993); f:(Sole & Cole, 2001).

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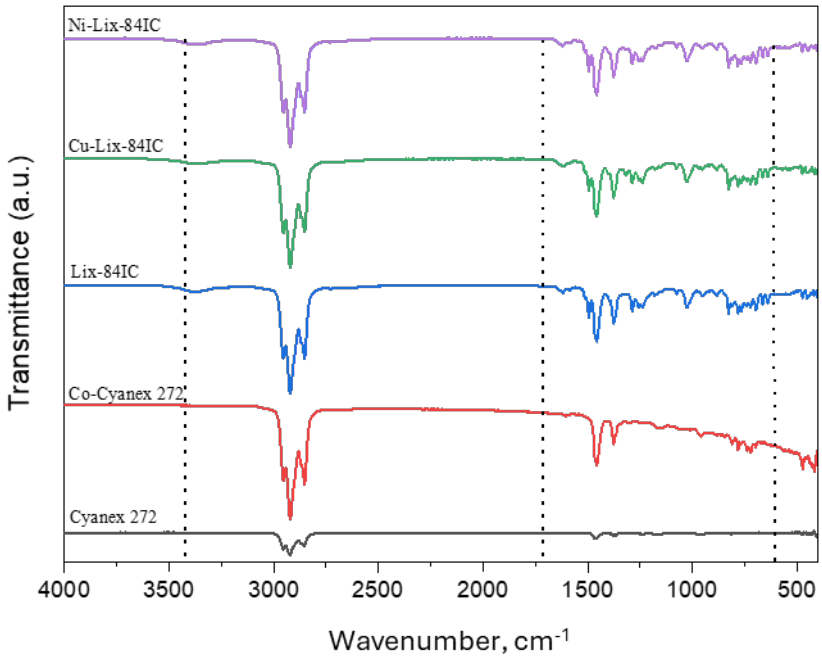

Fig. S1: FTIR spectra of extractants before and after extraction.

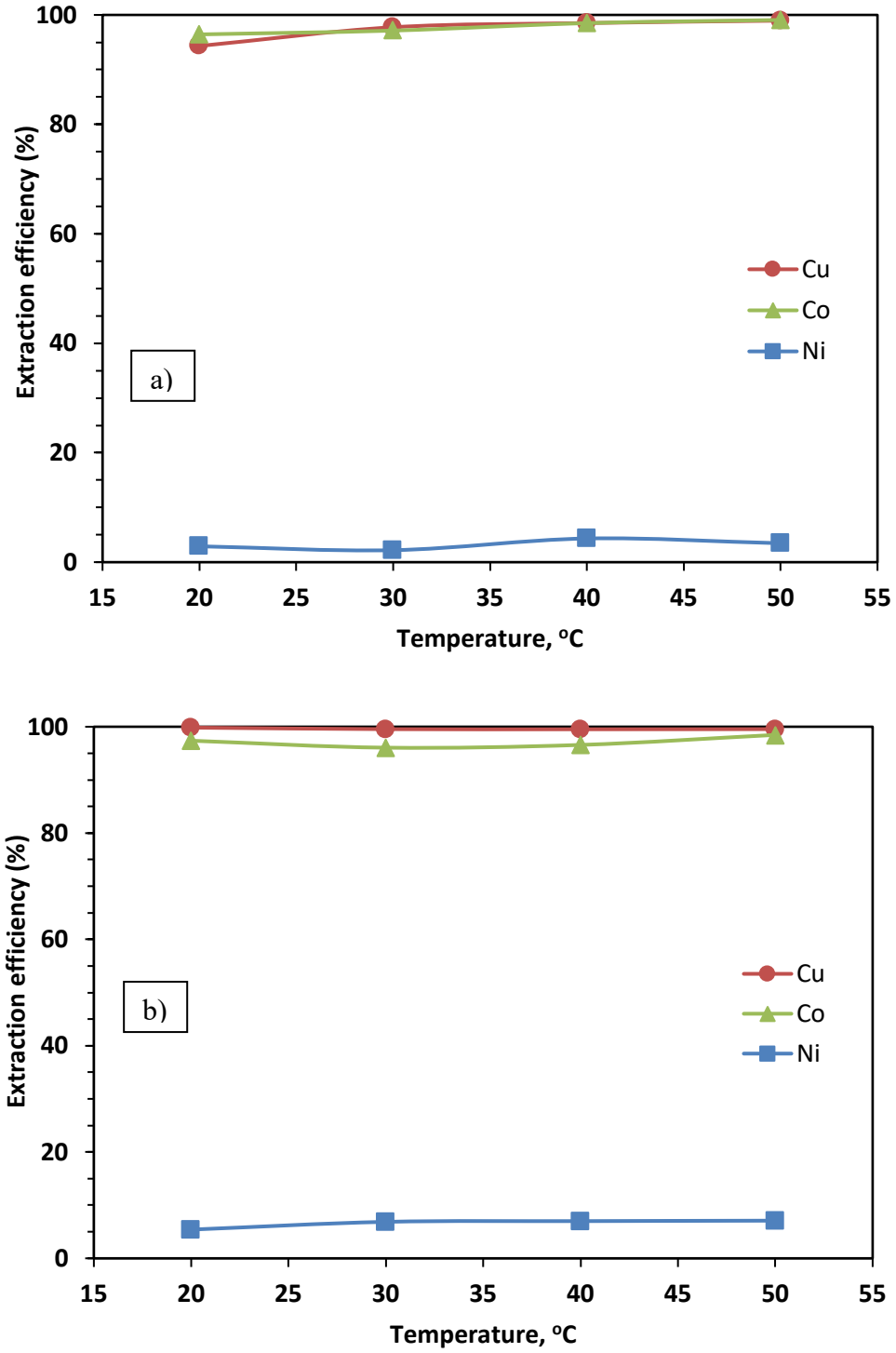

Fig. S2: Effect of temperature on the extraction efficiencies of Co, Cu and Ni from glycinate solution at a) pH = 9 and b) pH = 10. Conditions: LIX-84IC/kerosene = 30% v/v, O:A = 1.0, time = 20 min.

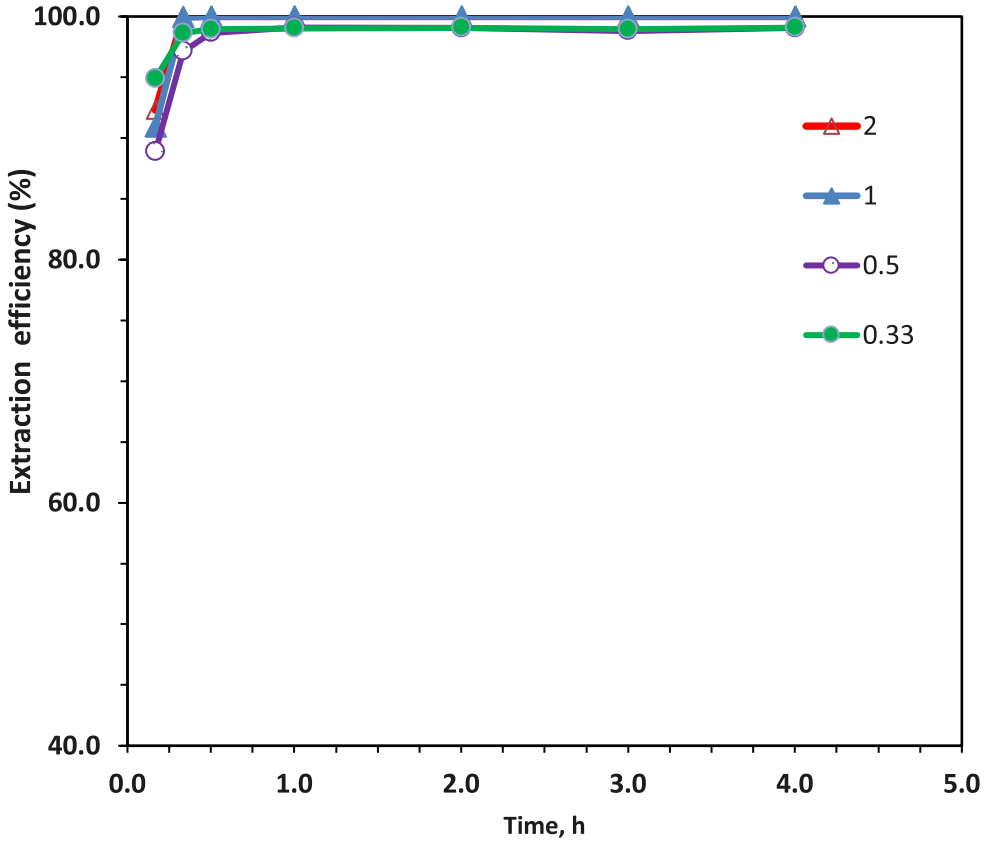

Fig. S3: Effect of O:A phase ratio and contact time on the extraction efficiencies of Cu from glycinate solution. Conditions: temperature = 20 °C; LIX-84IC/kerosene = 30% v/v; pH = 9.

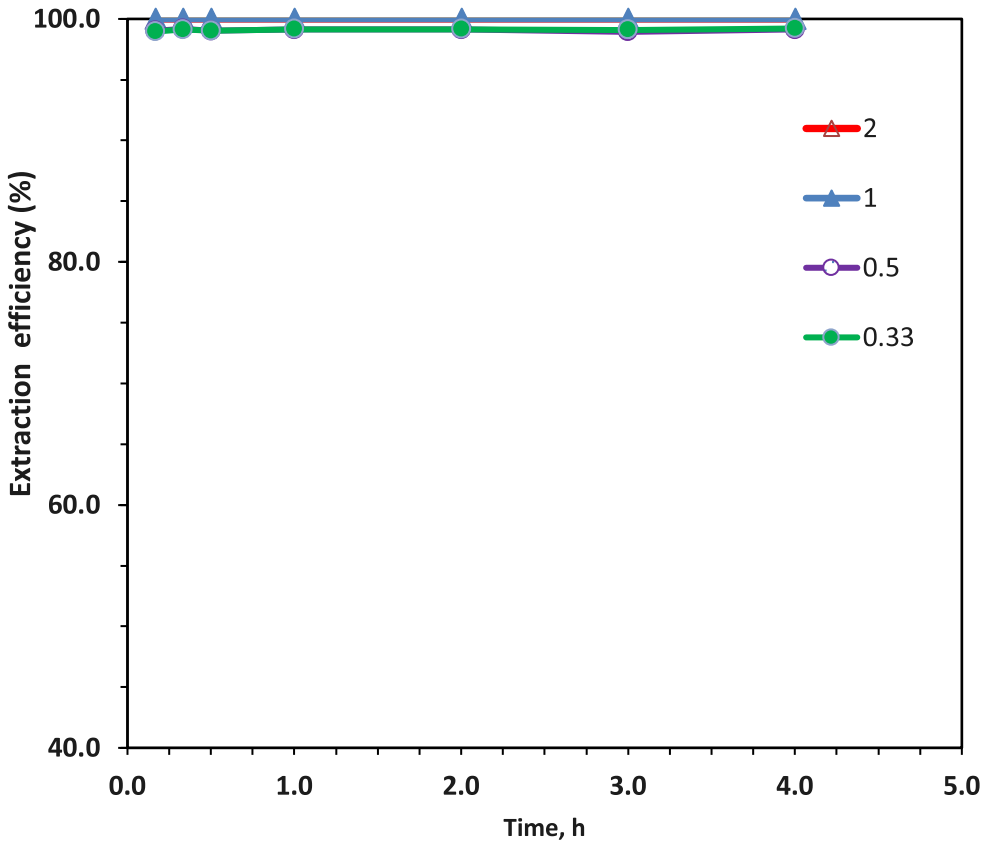

Fig. S4: Effect of O:A phase ratio and contact time on the extraction efficiencies of Cu from glycinate solution. Conditions: temperature = 20 °C; LIX-84IC/kerosene = 30% v/v; pH = 10.

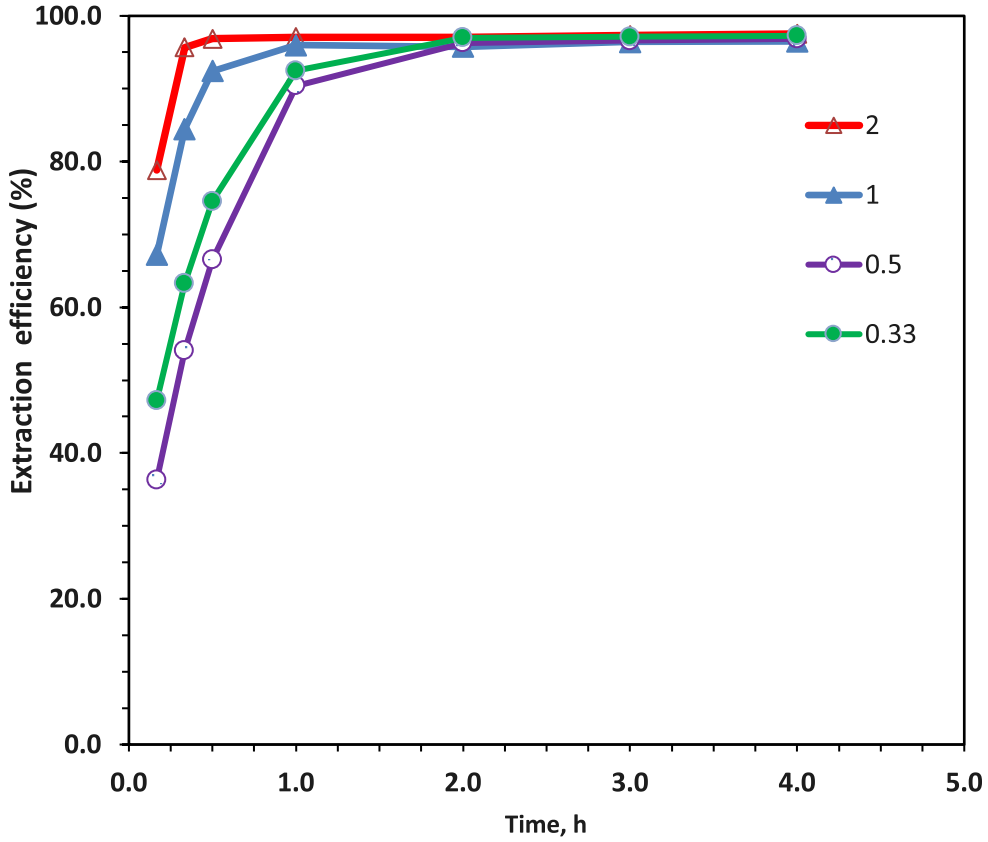

Fig. S5: Effect of O:A phase ratio and contact time on the extraction efficiencies of Co from glycinate solution. Conditions: temperature = 20 °C; LIX-84IC/kerosene = 30% v/v; pH = 8.

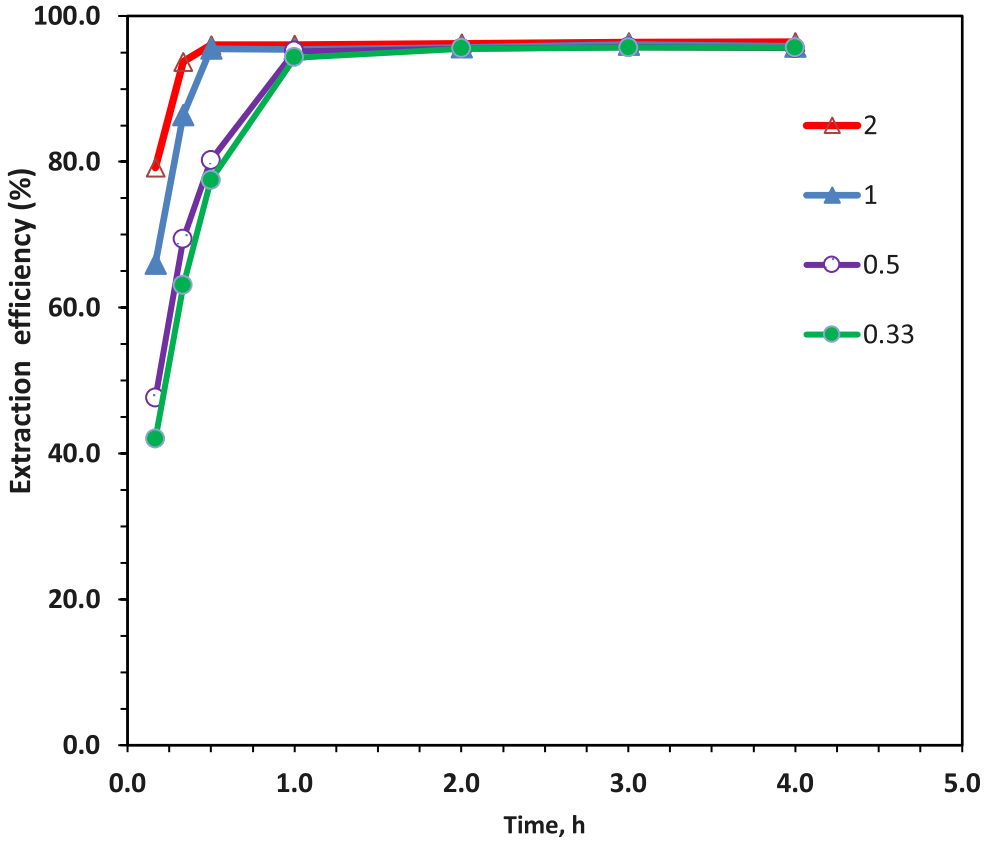

Fig. S6: Effect of O:A phase ratio and contact time on the extraction efficiencies of Co from glycinate solution. Conditions: temperature = 20 °C; LIX-84IC/kerosene = 30% v/v; pH = 9.

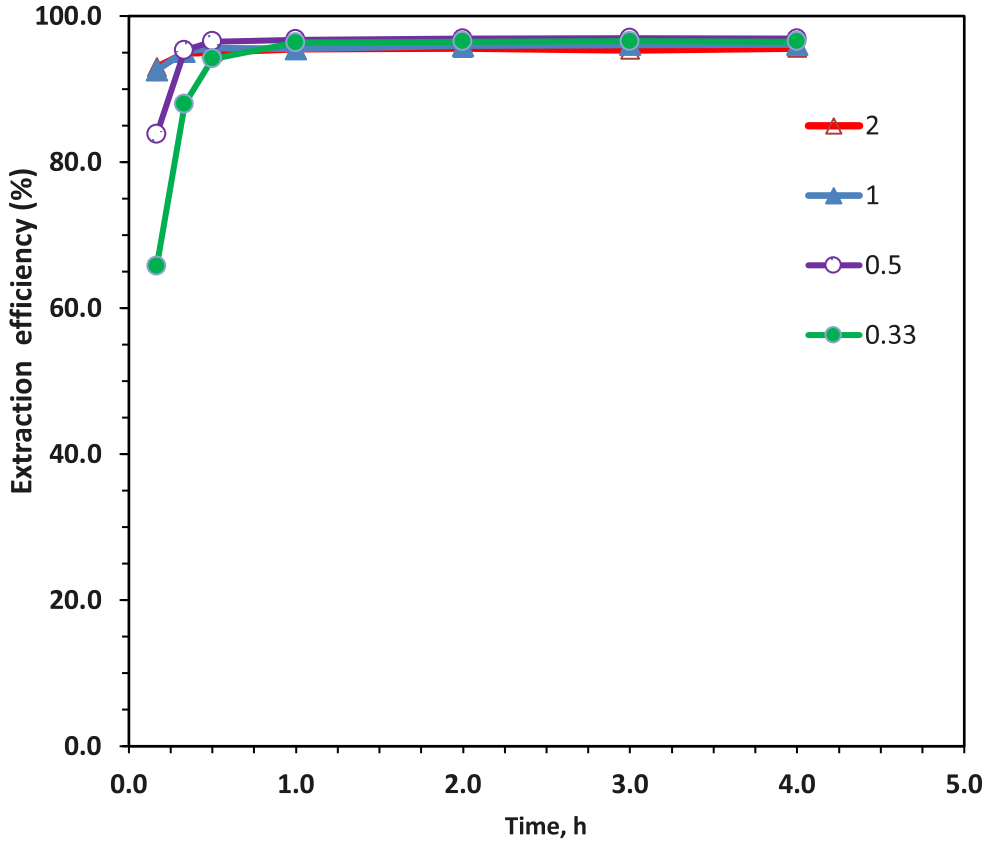

Fig. S7: Effect of O:A phase ratio and contact time on the extraction efficiencies of Co from glycinate solution. Conditions: temperature = 20 °C; LIX-84IC/kerosene = 30% v/v; pH = 10.

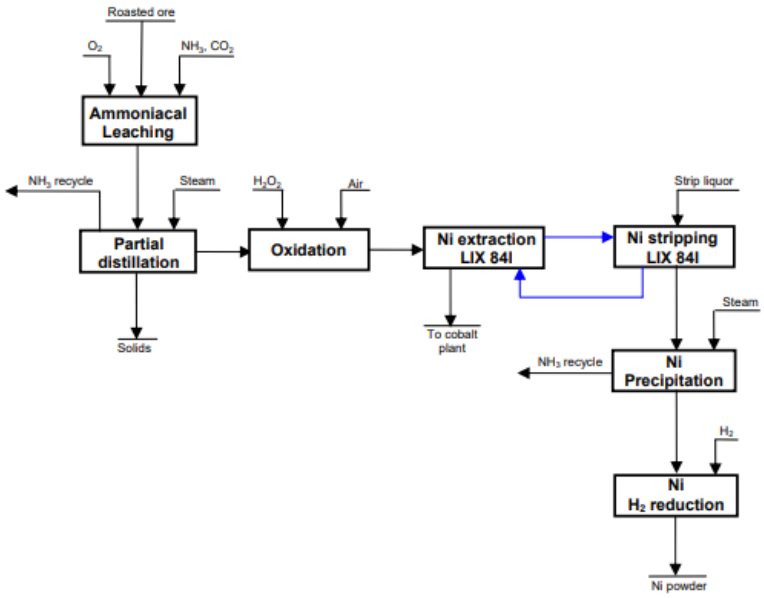

Fig.S8: Queensland SX process flowsheet highlighting oxidation step of Co(II) to Co(II) prior to applying Lix-84IC for the extraction of Ni(II). Adopted from (Cheng & Urbani, 2005).

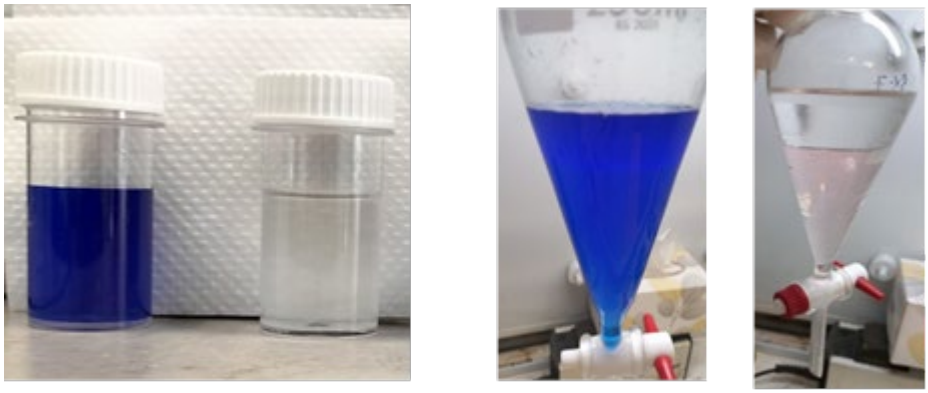

Fig. S9: Digital images of a) (left) initial aqueous solution containing 3.0 g/L Ni, 1.0 g/L Cu and 0.3 g/L Co and (right) 5% (v/v) Cyanex 272 in kerosene; b) phase disengagement of organic (upper layer) and aqueous (bottom layer) after extraction; c) phase disengagement of organic (upper layer) and aqueous phases (bottom layer) after stripping.

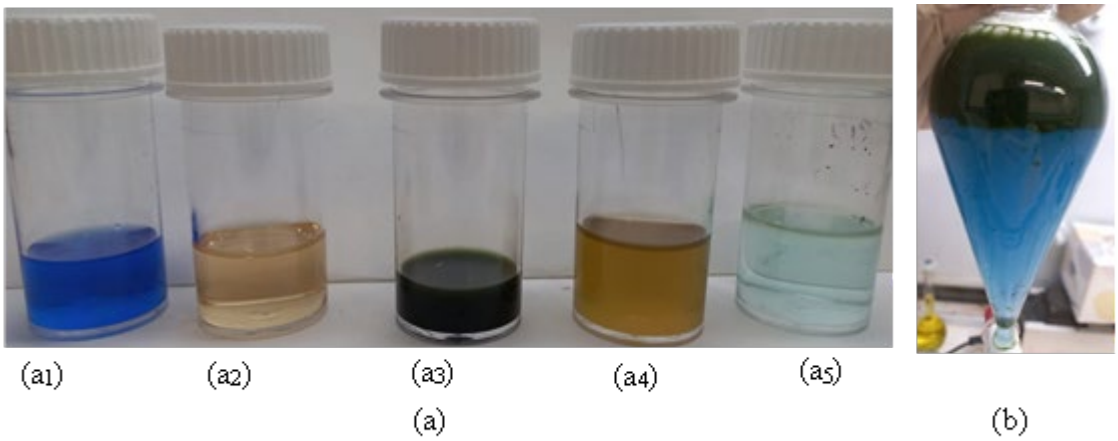

Fig. S10: Digital images of a): a_1) aqueous solution containing 2.88 g/L Ni and 1.0 g/L Cu; a_2) 30% (v/v) LIX-84IC in kerosene, a_3) Cu-loaded LIX-84IC, a_4) stripped Cu-loaded organic phase, a_5) Cu-containing stripping solution; b) phase disengagement of organic (upper layer) and aqueous phases (bottom layer).

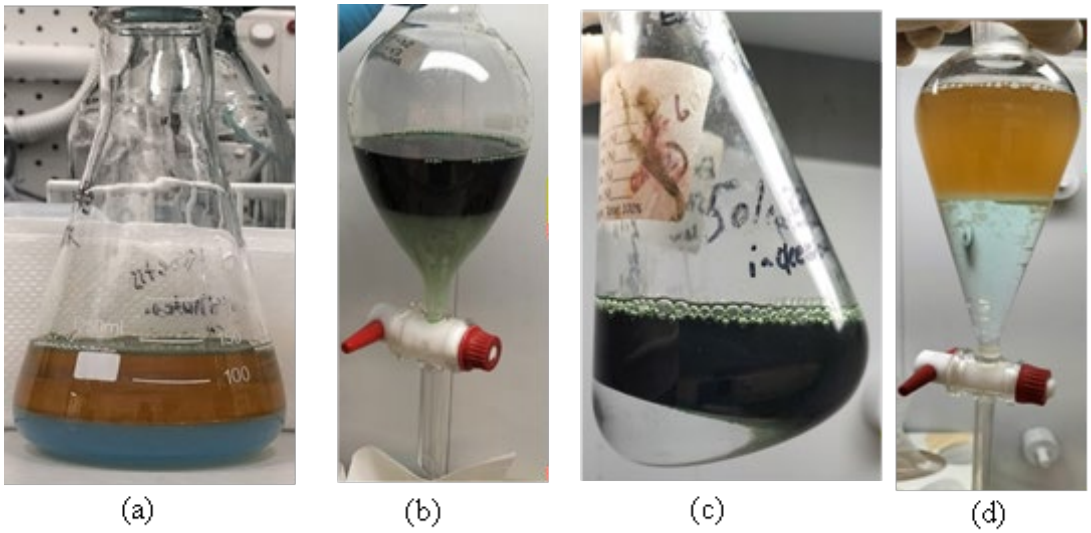

Fig. S11: Digital images of a): aqueous solution containing 2.34 g/L Ni (bottom layer), and 30% (v/v) LIX84IC in kerosene (upper layer) before extraction; b) phase disengagement of organic (upper layer) and aqueous phases (bottom layer) after extraction; c) aqueous solution containing 200 g/L H_2SO_4 (bottom layer), and Ni-loaded LIX84IC in kerosene (upper layer) before stripping; d) phase disengagement of organic (upper layer) and aqueous phases (bottom layer) after stripping.