



Selective separation of cobalt versus nickel by split-phosphinate complexation using a phosphonium-based ionic liquid

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Received: 16 September 2022 / Accepted: 22 December 2022 / Published online: 2 January 2023
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Abstract

The rising demand of metals for batteries is calling for advanced methods to separate metallic mixtures in mineral ores and electronic waste. In particular, the extraction in separate form of nickel and cobalt are focusing attention because these metals are used in cathodes of lithium-ion batteries. Here we developed the selective separation of cobalt versus nickel using a green ionic liquid, trihexyl(tetradecyl)phosphonium bis-2,4,4-(trimethylpentyl)phosphinate, from an HCl leached solution of spent lithium-ion batteries. More than 99% of cobalt was selectively extracted versus nickel at ionic liquid concentration of 0.8 mol/L, chloride ion concentration of 3.0 mol/L, equilibrium pH of 5.0, temperature of 333 K, and organic-to-aqueous phase ratio of 2/3. The corresponding separation factor of cobalt-to-nickel is 1097. Recovery of cobalt back in the aqueous phase was achieved by stripping with 2.0 mol/L H₂SO₄.

Keywords Liquid · Liquid extraction · Critical metals · Cobalt–nickel separation · Ionic liquid

Introduction

Owing to the characteristics of ferromagnetic, mechanically hard, and corrosion resistance, cobalt is high in demand as a critical raw material for metal alloys and cathode materials of lithium-ion batteries. Its co-existence in naturally occurring ores like, lateritic ores, cobaltite, and skutterudite, along with the *d*-block elements of similar chemical properties (mainly nickel) has remained challenging to efficiently separate cobalt over nickel (Flett 2004). The usual hydrometallurgical extraction of cobalt primarily follows leaching in acid solution (Liu and Lee 2016; Reddy 2007), which undergoes to a downstream separation process to recover

high-pure cobalt metal/compounds. Besides the hydrometallurgical processing of primary/secondary materials, the presence of cobalt and nickel in wastewater effluents also poses severe stress to the environment, which requires to be handled appropriately (Adeleke et al. 2017; Ilyas et al. 2018; Oyekanmi et al. 2017, 2019). In the recent past, liquid–liquid extraction has commonly gained attraction due to a greater mass transfer coefficient and high loading capacity exhibited by the organic solvents, not only for cobalt–nickel separation but also to separate other multi-metals' solutions (Nagib and Abdelhameed 2015, 2017; Srivastava et al. 2015).

Traditionally, the organophosphorus acidic extractants like, di-(2ethylhexyl)phosphoric acid, 2-ethylhexylphosphonic acid, and bis-(2,4,4-trimethylpentyl)phosphinic acid have been widely applied for the extraction of cationic cobalt over other metal impurities, mainly over Ni²⁺ (Sattar et al. 2020). On a standard condition, the pH_{1/2} extraction values for cobalt and nickel separation are determined to be Co²⁺ = 3.68 and Ni²⁺ = 3.86 using di-(2ethylhexyl)phosphoric acid which significantly changed to be Co²⁺ = 4.2 and Ni²⁺ = 5.7 using 2-ethylhexylphosphonic acid; however, the maximum separation values of Co²⁺ = 4.2 and Ni²⁺ = 6.2 are exhibited by bis-(2,4,4-trimethylpentyl)phosphinic acid (Devi et al. 1998). On the other hand, amine extractants have been employed to extract anionic species of cobalt from highly acidic chloride solutions (Sayar et al. 2009). To

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