# Peroxide-Assisted Extraction of Cobalt from Spent Lithium-Ion Batteries: Comparative Study of Citric Acid and Hydrochloric Acid Leaching

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**Abstract**

Recovery of cobalt from spent lithium-ion batteries (LIBs) offers an important pathway for recovering critical metals while reducing dependence on primary resources. This study compared cobalt extraction from spent LIB cathodic material using citric acid as an organic leachant and hydrochloric acid (HCl) as a mineral-acid benchmark. The effects of temperature, acid concentration, hydrogen peroxide ($H_2O_2$) concentration, solid-to-liquid ratio, and leaching time were investigated using a one-factor-at-a-time approach. Leach solutions were analyzed by ICP-OES to quantify cobalt extraction. Citric-acid leaching was strongly influenced by temperature and $H_2O_2$ addition. Cobalt extraction increased from 21.1% at 30 °C to 79.7% at 90 °C after 110 min. Increasing $H_2O_2$ from 0 to 3 vol% increased cobalt extraction after 5 min from 20.4% to 66.4%, demonstrating the strong influence of peroxide on initial dissolution kinetics. At 90 °C and 20 g $L^{-1}$ solids, 1.5 M citric acid achieved 73.4% cobalt extraction after 50 min. HCl exhibited substantially faster cobalt dissolution and lower sensitivity to temperature in the presence of $H_2O_2$, achieving approximately 87% extraction after 110 min in the temperature series. Peroxide-assisted HCl also produced rapid initial extraction, while increasing $H_2O_2$ beyond 1 vol% provided limited additional long-term benefit. Overall, HCl provided superior cobalt extraction kinetics, whereas citric acid offers a promising alternative where reduced corrosivity and environmental impact are prioritized. Approximately 1.5 M citric acid with 1 vol% $H_2O_2$ at elevated temperature provides a practical basis for further optimization of cobalt recovery from spent LIBs.

**Keywords:** cobalt recovery; lithium-ion batteries; citric acid; hydrochloric acid; hydrogen peroxide; hydrometallurgy; leaching