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Review

Efficient Metal Extraction from Dilute Solutions: A Review of Novel Selective Separation Methods and Their Applications

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Abstract: Notable increases in metal consumption and declining ore grades in recent decades have stressed the significance of dilute solutions as secondary sources of valuable metals. Moreover, environmental considerations and the imperative of sustainable development have further emphasized their treatment. Therefore, finding an efficient solution for separating metals from dilute solutions has attracted the attention of numerous researchers. This paper reviews the purification processes of dilute solutions and highlights key achievements of published research works. Although this study focuses on evaluating the efficiency of recently developed aqueous-phase purification methods, such as immobilized ligands, ionic liquids, and air-assisted solvent extraction, the application of conventional processes to treat these solutions, such as solvent extraction, ion exchange, membranes, chemical precipitation, and adsorption are also briefly outlined. To provide a comprehensive assessment, more than 200 research articles were reviewed, and their key findings are stated in this study. This research contributes to the advancement of knowledge of metal recovery from dilute solutions and sheds light on the dynamic evolution of this field.

Keywords: dilute solution; hydrometallurgy; leaching; low-grade ores; AMD; concentration and purification; metal recovery

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1. Introduction

Dilute solutions, whether generated naturally in mines as acid mine drainage (AMD) [1,2] and acid rock drainage (ARD) [3,4] or produced from various industrial processes, represent a significant resource of valuable metals. The ever-growing demand for these metals has urged the extraction of low-grade ores with complex mineral compositions. Hydrometallurgical methods have emerged as an appropriate approach for recovering metals from such challenging ores. Notably, the pregnant leach solution (PLS) obtained during the leaching stage of low-grade ores, typically employing heap or bio-heap leaching methods, represents an example of dilute solutions.

Dilute solutions are characterized by metal concentrations in the range of parts per million (ppm). These low concentrations impart significant challenges for metal extraction and make the process complex and demanding from the efficiency point of view. Therefore, regarding an economic and technical perspective, conventional methods such as solvent extraction using a mixer-settler are impractical for these solutions. In fact, the low concentration of metals renders the extraction process inefficient and costly, necessitating the exploration of alternative methods or technologies to achieve viable metal recovery [5–8].

Meanwhile, AMDs that contain various potentially toxic elements cause environmental challenges by altering ambient pH levels, depositing metals in surface water streams, and disrupting marine and riverine ecosystems [9,10]. Table 1 shows the metal concentrations of some AMDs and acidic solutions in mines. For instance, the AMD from the Iron Mountain mine in the USA contains notable concentrations of Fe, Cu, and Zn, ranging from 13–19 g/L,