Chapter 3

Understanding Corrosion and Materials Deterioration in Metal–Air Batteries

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ABSTRACT

Electrochemical energy storage and conversion (EESC) technologies are important to today's energy systems. They provide sustainable solutions to the growing global demand for efficient and green energy. Among them, metal–air batteries have emerged as promising candidates due to their high theoretical specific energies and energy densities. However, like many electrochemical systems, metal–air batteries are highly susceptible to corrosion and material degradation during operation. These batteries often operate under harsh environmental conditions. Corrosion not only compromises the structural integrity of the battery but also leads to reduced efficiency, safety concerns, and shortened lifespan. Understanding the mechanisms of corrosion in metal–air batteries is therefore essential for improving their durability.

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1. INTRODUCTION

Electrochemical energy storage and conversion (EESC) systems play a critical role in the transition to cleaner and more sustainable energy. The increasing demand for advanced energy storage technologies is underscored by the impact of climate change and the decline of finite fossil fuel resources. Renewable energy sources like wind, solar and hydro are inherently intermittent and require effective storage solutions (Sharmoukh, 2025). Additionally, as global strategies to lower carbon emissions intensify, the requirement for efficient, reliable, and environmentally friendly energy storage solutions continues to expand. EESC devices encompass several categories, including primary batteries (single-use), secondary batteries (rechargeable), fuel cells that convert chemical energy into electricity without storing it, and supercapacitors that store energy via charge separation (Bhattacharjee et al., 2023; Saji, 2024). Each devices operate differently (Detka & Górecki, 2023), and they are broadly adopted in electric and hybrid vehicles, portable electrical devices (laptops, mobile phones, wearable devices, etc.) (Fang et al., 2022), and power stations for space and stationary applications. Supercapacitors and fuel cells, offering unique advantages, are limited by low energy density or complex system requirements (Dissanayake & Kularatna-Abeywardana, 2024; L. Gao et al., 2025; Sebbani et al., 2025). Lithium-ion batteries, once considered the benchmark technology with widespread adoption in hybrid and electric vehicles (HEVs/EVs) and energy storage systems (Fang et al., 2022; Hasan et al., 2025), now face growing concerns related to resource limitations and safety. Limited lithium reserves and accelerated consumption present significant challenges, especially for large-scale energy storage applications (C. Liu et al., 2020). Aluminum-ion batteries have emerged as one of the most promising alternatives, offering ultrahigh volumetric capacity, enhanced safety, and cost-effectiveness, thanks to the abundance of aluminum (T.-T. Wei et al., 2021). Additionally, metal–air batteries are gaining attention as a new generation of devices capable of bridging the gap between high capacity and environmental sustainability, offering exceptionally high theoretical energy densities, lightweight design, and the possibility of using earth-abundant and low-toxicity metals (Chen et al., 2022; Chung et al., 2025; Salado & Lizundia, 2022). Despite huge advances in developing these systems, corrosion and material degradation remain major challenges as they reduce the performance, safety, and lifespan of EESC devices (Du et al., 2023). While Researches (Dilshad et al., 2025; Shabeer et al., 2025) underline their potential for transportation and grid-level storage, yet also emphasize that their commercialization depends on overcoming severe corrosion processes occurring at the anode-electrolyte interface.

In fact, corrosion is an irreversible phenomenon influenced by multiple factors, including material properties, environmental conditions, surface coatings, microbial

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