

Electrochemically Engineered Nano-AgHg Amalgam for Ambient Gas-Phase Acetaldehyde Degradation

Introduction

Indoor air pollution has become a significant public health concern due to prolonged exposure to volatile organic compounds (VOCs) in confined environments. Among these pollutants, acetaldehyde is particularly hazardous due to its high volatility, toxicity, and classification as a probable human carcinogen [1]. Chronic exposure may lead to respiratory irritation, mucosal damage, and long-term health risks [2]. Traditional VOC mitigation strategies rely primarily on adsorption using activated carbon, zeolites, or porous polymers [3]. However, adsorption merely transfers contaminants from one phase to another and requires periodic regeneration, leading to secondary waste generation. Destructive technologies such as thermal catalytic oxidation are effective but demand elevated temperatures (200–400 °C), increasing operational energy costs [4]. Photocatalytic oxidation has also been explored, yet its efficiency is often limited under indoor lighting conditions [5].

Electrochemical oxidation presents a promising alternative because it enables pollutant degradation under ambient temperature and pressure conditions [6]. While liquid-phase electro-oxidative degradation of acetaldehyde has reached a relatively mature stage, gas-phase electrochemical degradation remains insufficiently developed due to challenges associated with solid–gas interfacial charge transfer and mass transport limitations [7]. Recent studies have demonstrated that gas-diffusion electrodes and membrane-coated catalysts can enhance electrochemical VOC removal efficiency [8]. Furthermore, mediated electrochemical oxidation processes have shown improved performance through redox-active electron mediators that accelerate pollutant mineralization [9].

In this study, we report the electrochemical heterogenization of a Nano-AgHg amalgam on a three-dimensional nickel foam substrate. The heterogenized alloy functions as a redox mediator and catalytic surface for gas-phase acetaldehyde degradation in a membrane-divided semi-solid electrolyte half-cell, bridging liquid-phase electrochemistry and gas-phase pollutant control [10].

Short Communication

Gabriela Walker*

Full Professor at National University, California

***Correspondence:** Gabriela Walker, Full Professor at National University, California.

E-mail: walkerg@nu.edu

Received: 23 Feb, 2026; **Accepted:** 30 March, 2026;

Published: 07 April, 2026.

Copyright: © 2026 Gabriela Walker. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited

Materials and Methods

Nickel foam (porosity >95%) was selected as the base electrode due to its high surface area and interconnected porous structure, which enhances gas diffusion and electron transport. Electrochemical heterogenization was performed in an aqueous solution containing Ag^+ and Hg^{2+} ions under potentiostatic control. Simultaneous electro-reduction of Ag^+ and Hg^{2+} led to formation of a nano-scale amalgam layer on the nickel substrate. Alloy formation was verified using X-ray diffraction (XRD), while surface morphology and elemental composition were examined using SEM–EDS. Electrochemical redox behavior was analyzed through cyclic voltammetry to evaluate electron mediation capability.

Gas-phase degradation experiments were conducted in a membrane-divided semi-solid electrolyte half-cell under continuous single-pass flow conditions. Online FTIR gas analysis was used to monitor acetaldehyde conversion in real time, and GC–MS was employed for identification of intermediate and final oxidation products.

Results and Discussion

Structural and Electrochemical Properties

XRD patterns confirmed successful formation of AgHg amalgam phases, with characteristic diffraction peaks cor-

responding to alloy structures rather than separate Ag or Hg crystalline phases. Similar alloy stabilization effects have been reported for bimetallic systems exhibiting synergistic catalytic behaviour [6].

SEM images revealed uniform nano-particle deposition across the three-dimensional nickel framework, preserving its porous architecture. The high surface-to-volume ratio enhances gas accessibility and active site availability, which is critical for solid–gas electrochemical reactions [8].

Cyclic voltammetry demonstrated distinct redox peaks corresponding to Ag/Hg redox couples. The enhanced current density compared to bare nickel foam indicates improved charge transfer kinetics. Such redox mediation has been shown to significantly accelerate VOC oxidation pathways in electrochemical systems [9].

Gas-Phase Acetaldehyde Degradation

Under ambient conditions, continuous single-pass operation achieved significant acetaldehyde conversion efficiency. FTIR spectra showed progressive decrease of characteristic acetaldehyde absorption bands, while formation of CO₂ was simultaneously observed, indicating oxidative mineralization. Comparable electrochemical VOC mineralization has been reported in all-solid cell configurations [7]. GC–MS analysis identified acetic acid and formate species as intermediate products, suggesting stepwise oxidation. The presence of these intermediates aligns with previously reported electro-oxidative degradation pathways of acetaldehyde [10]. The semi-solid electrolyte configuration ensured ionic conductivity while preventing electrode flooding, allowing stable long-term operation. Unlike adsorption-based methods, this system enables continuous degradation without saturation limitations [8].

Stability and Synergistic Effects

The Nano-AgHg amalgam demonstrated structural stability

and consistent catalytic performance over repeated cycles. The synergistic interaction between Ag and Hg likely enhances electron transfer kinetics and stabilizes reactive oxygen intermediates, facilitating rapid oxidation at ambient temperature [6].

The three-dimensional foam architecture further improves mass transport efficiency, minimizing diffusion resistance at the solid–gas interface [8]. These combined effects result in sustainable degradation performance suitable for indoor air purification applications.

Proposed Degradation Mechanism

Based on FTIR and GC–MS analyses, a plausible degradation mechanism is proposed:

1. Adsorption of acetaldehyde onto the Nano-AgHg surface.
2. Electrochemical generation of reactive oxygen species.
3. Oxidation to acetic acid intermediates.
4. Further oxidation to formate species.
5. Complete mineralization to CO₂ and H₂O.

Mediated electron transfer through the AgHg redox couple enhances reaction kinetics and lowers activation barriers for oxidation steps [9].

Conclusion

A sustainable electrochemical strategy for gas-phase acetaldehyde degradation at ambient temperature has been successfully demonstrated using an electrochemically heterogenized Nano-AgHg amalgam on nickel foam. The material exhibits enhanced redox activity, efficient charge mediation, and stable long-term operation in a semi-solid electrolyte half-cell configuration. The proposed approach provides a promising platform for next-generation indoor air purification technologies.

References

1. World Health Organization. “WHO guidelines for indoor air quality: selected pollutants.” (2010).
2. IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. “Consumption of alcoholic beverages.” In *Personal Habits and Indoor Combustions*. International Agency for Research on Cancer, 2012.
3. Yang, Ralph T. “Gas separation by adsorption processes.” 1987.
4. Liotta, Leonarda Francescal. “Catalytic oxidation of volatile organic compounds on supported noble metals.” *Applied Catalysis B: Environmental* 100, no. 3-4 (2010): 403-412.

5. Fujishima, Akira, Xintong Zhang, and Donald A. Tryk. "TiO₂ photocatalysis and related surface phenomena." *Surface science reports* 63, no. 12 (2008): 515-582.
6. Comninellis, Christos, and Guohua Chen, eds. *Electrochemistry for the Environment*. Vol. 2015. New York: Springer, 2010.
7. Kim, Dong Jin, Jiyeon Park, Gayoung Ham, Hyojung Cha, Dong Suk Han, Minho Kim, and Hyunwoong Park. "Deactivation-Tolerance of Heterojunction Anatase and Bronze TiO₂ in the Photocatalytic Mineralization of Toluene." *ACS ES&T Engineering* 4, no. 10 (2024): 2474-2484.
8. Wu, Xuanhao, Jiaxin Du, Yanxia Gao, Haiqiang Wang, Changbin Zhang, Runduo Zhang, Hong He, Gaoqing Max Lu, and Zhongbiao Wu. "Progress and challenges in nitrous oxide decomposition and valorization." *Chemical Society Reviews* 53, no. 16 (2024): 8379-8423.
9. Oturan, Mehmet A., and Jean-Jacques Aaron. "Advanced oxidation processes in water/wastewater treatment: principles and applications. A review." *Critical reviews in environmental science and technology* 44, no. 23 (2014): 2577-2641.
10. Govindan, Muthuraman, Dohyeon Yeom, Youngyu Choi, and Daekeun Kim. "Electrochemical Removal of Gaseous Acetaldehyde Using Ag-Hg Bimetallic Catalyst with a Liquid-Free Electrolyte." *Journal of The Electrochemical Society* 171, no. 3 (2024): 033501.

Citation: Gabriela Walker. "Electrochemically Engineered Nano-AgHg Amalgam for Ambient Gas-Phase Acetaldehyde Degradation." *J Environ Toxicol Res* (2026):120. DOI: [10.59462/3068-3505.3.1.120](https://doi.org/10.59462/3068-3505.3.1.120)