

Anaerobic digestion of catechol wastewater in magnetite powder-added AnSBR system

Seonmin Kang¹, Minjae Kim¹, Joonyeob Lee^{1,*}

¹ Division of Earth Environmental System Science (Major of Environmental Engineering),
Pukyong National University, Busan 48513, Republic of Korea

Keywords: Anaerobic digestion, Catechol wastewater, AnSBR, Magnetite powder.

Presenting author email: kangseonmin@naver.com

Introduction

Catechol is a phenolic compound extensively utilized as a solvent in various industrial processes and is also a by-product of the degradation of numerous aromatic compounds. It is commonly detected in wastewater streams originating from industries such as olive oil production, winemaking, and leather tanning, with reported concentrations typically ranging from 200 to 1000 mg/L (Casa, 2003; Converti, 1990; Subramanyam & Mishra, 2008a). Notably, coal gasification wastewater has been found to contain substantially higher levels of catechol, reaching up to 5300 mg/L (Subramanyam & Mishra, 2008b). Owing to its high organic load and widespread occurrence, catechol constitutes a significant pollutant of concern in industrial wastewater treatment (Subramanyam & Mishra, 2008b). Owing to its high organic load and widespread occurrence, catechol constitutes a significant pollutant of concern in industrial wastewater treatment.

Anaerobic digestion (AD) is a biological treatment technology that employs methanogenic microorganisms to convert organic pollutants into methane under anaerobic conditions. This process not only treats pollutants but also enables the recovery of energy in the form of biogas, making it a sustainable option for treating industrial organic wastewater. Given the elevated chemical oxygen demand (COD) associated with catechol-laden effluents, anaerobic digestion emerges as a promising treatment strategy. However, catechol is known to exert strong inhibitory effects on methanogenesis, posing a significant challenge to the stability and efficiency of the process. Magnetite, a conductive mineral, has been demonstrated to facilitate direct interspecies electron transfer (DIET), thereby enhancing both the degradation of organic matter and methane production. Therefore, this study investigates the feasibility of a magnetite-supplemented anaerobic sequencing batch reactor (AnSBR) for the treatment of catechol wastewater, with a focus on evaluating accelerated AD and improved tolerance to catechol-induced inhibition.

Materials and Methods

Four lab-scale AnSBRs were operated: two with magnetite (CM reactors) and two without (CO reactors). Each reactor was fed with synthetic wastewater containing 10.0 g COD/L catechol as the sole carbon source. Magnetite was dosed at 20 mM. Anaerobic conditions were established using N₂:CO₂ gas (8:2), and the OLR was increased progressively by decreasing the hydraulic retention time (HRT) over 170 days. To evaluate the microbial community's tolerance to catechol, 28 anaerobic batch assays were conducted using inocula derived from each reactor (CA from CO, CMA from CM). Each bottle was fed with 1.0 g COD/L acetate and varying concentrations of catechol (0–9 g COD/L). Biogas production was monitored daily, and gas composition was analyzed via GC-TCD. Liquid samples were analyzed for catechol and VFAs by HPLC and GC-FID, respectively. SMA was calculated using the modified Gompertz model, and IC₅₀ values using a four-parameter logistic model.

Results and Discussion

Control reactors without magnetite supplementation exhibited process failure when operated at an OLR of 0.667 g COD/L/day, requiring a recovery period of more than 20 days to regain stability. In contrast, CM reactors supplemented with magnetite maintained stable performance even at this higher loading rate, corresponding to a 33% increase in OLR compared to the maximum stable operation of control reactors (CO: Stage 4, 0.5 g COD/L/day; CM: Stage 6, 0.667 g COD/L/day) (Figure 1,2). Furthermore, the maximum specific methane production rate in CM reactors reached 94.85 ± 1.02 mL CH₄/g VSS/day, which is approximately 18% higher than that of CO reactors (80.11 ± 12.92 mL CH₄/g VSS/day). These results demonstrate that magnetite supplementation not only enhances process stability under elevated loading conditions but also improves the efficiency of methane generation and catechol degradation in anaerobic environments.

To further investigate microbial tolerance, batch toxicity assays were conducted using inocula from each reactor. The inoculum from magnetite-supplemented reactors (CMA) and from control reactors (CA) were exposed to increasing catechol concentrations (0–9 g COD/L), with acetate provided as the substrate. The CMA group exhibited significantly greater tolerance to catechol toxicity, with an IC₅₀ of 1359 mg/g VSS and an IC₉₀ of 2911 mg/g VSS, compared to the CA group, which showed an IC₅₀ of 935 mg/g VSS and an IC₉₀ of 1341 mg/g VSS. These values indicate that CMA was able to alleviate catechol-induced inhibition by approximately 25.2% at the

IC50 level and 40.4% at the IC90 level, relative to CA (Figure 3). In addition, the lag phase for methane production in CMA was consistently shorter across all tested catechol concentrations, suggesting a more robust and resilient microbial response.

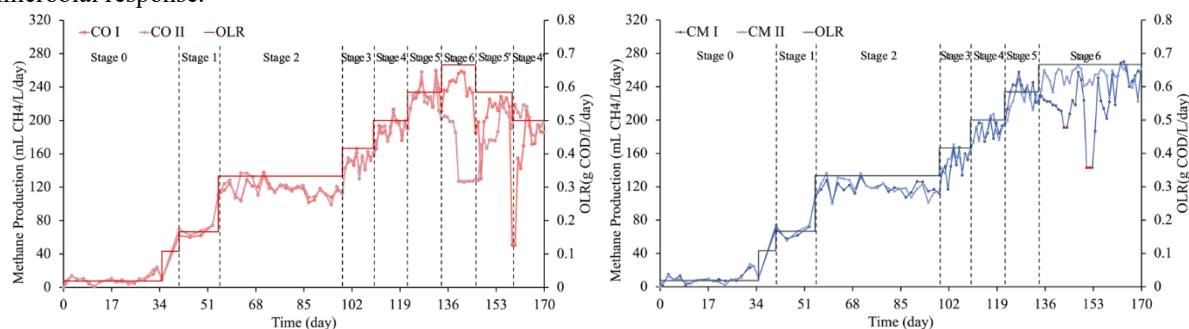


Figure 1. Methane production at various organic loading rates in the CO reactor (without magnetite supplementation) and the CM reactor (with magnetite supplementation).

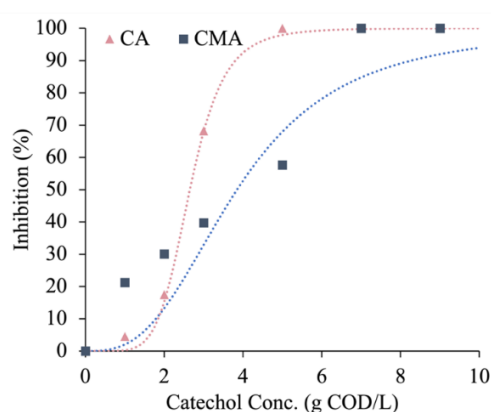


Figure 2. Anaerobic inhibition assay against catechol

Conclusion

These findings confirm that magnetite-supplemented AnSBR systems significantly enhance both operational stability and microbial resilience under catechol toxicity. Reactors supplemented with magnetite were capable of maintaining stable performance at higher OLR and demonstrated superior methane production efficiency compared to control reactors. Moreover, the enriched microbial consortia from magnetite-supplemented systems exhibited greater tolerance to catechol, as reflected in improved resistance to inhibition and shorter lag phases in methane production. These results indicate that long-term operation with magnetite promotes the development of a more robust and functionally adapted microbial community. Therefore, magnetite supplementation presents a viable strategy for improving the anaerobic treatment of catechol-containing industrial wastewater.

References

- Casa, R., D'Annibale, A., Pieruccetti, F., Stazi, S. R., Sermanni, G. G., & Lo Cascio, B. (2003). Reduction of the phenolic components in olive-mill wastewater by an enzymatic treatment and its impact on durum wheat (*Triticum durum* Desf.) germinability. *Chemosphere*, 50(8), 959–966.
- Converti, A., Zilli, M., Borghi, M. Del, & Ferraiolo, G. (1990). The fluidized bed reactor in the anaerobic treatment of wine wastewater. In *Bioprocess Engineering* (Vol. 5).
- Subramanyam, R., & Mishra, I. M. (2008a). Co-degradation of resorcinol and catechol in an UASB reactor. *Bioresource Technology*, 99(10), 4147–4157.
- Subramanyam, R., & Mishra, I. M. (2008b). Treatment of catechol bearing wastewater in an upflow anaerobic sludge blanket (UASB) reactor: Sludge characteristics. *Bioresource Technology*, 99(18), 8917–8925.

Acknowledgement

This research was financially supported by the Korea Ministry of Environment as Waste to Energy-Recycling Human Resource Development Project (YL-WE-21-002). This work was also supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. RS-2024-00358944). This research was also supported by Global - Learning & Academic research institution for Master's·PhD students, and Postdocs (LAMP) Program of the National Research Foundation of Korea (NRF) grant funded by the Ministry of Education (No. RS-2023-00301702).