Unlocking Sustainability in Wastewater Denitrification through Waste-Derived Volatile Fatty Acids

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Abstract

Carbon sources play a critical role in biological nitrogen removal during wastewater treatment, where strict total nitrogen limits on effluent discharge apply. Organic carbon sources serve as electron donors in the denitrification for heterotrophic denitrifiers. The growing need for improved denitrification driven by increasing influent loads in a limited area and stricter nutrient discharge standards has increased the demand for external carbon sources. Conventional carbon sources such as methanol or ethanol, used in wastewater treatment, are often derived from fossil fuels, raising environmental and economic concerns. Therefore, this thesis explores an alternative solution for carbon source provision in denitrification, i.e., waste-derived volatile fatty acids (VFAs). Several VFAs, e.g., acetic acid, propionic acid, and butyric acid, are generated during the anaerobic digestion (AD) of various organic waste materials as intermediate metabolites, which are a sustainable alternative that holds great promise for optimizing denitrification processes while mitigating environmental impacts.

In this thesis membrane bioreactors (MBRs) were applied for efficient production and extraction of VFAs from organic waste. This novel membrane separation technique led to particle-free VFAs at a high yield of 0.65 g VFAs/g VS_{fed}. However, this VFAs effluent contains impurities such as ammonium ions (NH_4^+) that can have adverse effects when applied in wastewater operations, especially in the denitrification process. Ammonium removal potential was explored using a low-cost natural zeolite, clinoptilolite. The VFAs effluent was subjected to an ion exchange process to remove ammonium. Under the determined optimum conditions, average removal efficiencies of 93 and 94% were found for NH_4^+ removal at 12 h equilibrium time for the synthetic and VFA effluents, respectively. Denitrification performance was investigated thoroughly, and denitrification rates were compared with those obtained using conventional carbon sources. Although methanol exhibits a faster nitrate (NO_3^-) removal capability than obtained using other carbon sources, there is a lack of synchronicity between the conversion of NO_3^- ions to nitrite (NO_2^-) and NO_2^- to N_2. However, relatively few issues have been encountered with using VFAs as a carbon source. Although adding VFA as the sole carbon source exhibited a slower denitrification rate than obtained with methanol, 50% of methanol can be replaced by waste-derived VFAs, achieving performance comparable to that obtained with pure methanol. In addition, further upgrading of waste-derived VFAs was complemented with the nanofiltration process before their application in wastewater treatment to increase their carbon content. It was observed that the chemical oxygen demand of VFAs increased up to 4.3 times (from 26.5 to 113.7 g/L). The concentrated waste-derived VFAs (after nanofiltration) could be used in the denitrification process of wastewater treatment. In conclusion, the use of waste-derived VFAs emerged as a potential sustainable alternative replacement of the conventional carbon sources for wastewater denitrification.

Keywords: volatile fatty acids, wastewater denitrification, ammonium removal, sustainable carbon source