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Impact of Environmentally Relevant Antibiotics and Heavy Metals on Anaerobic Digestion of Waste Activated Sludge

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Anaerobic digestion is a key technology for sewage sludge stabilization and renewable energy recovery in the form of biogas. However, the increasing presence of emerging contaminants, such as antibiotics and heavy metals, in wastewater streams raises concerns regarding process stability and efficiency. These compounds, even at environmentally relevant concentrations, may interfere with microbial activity. Additionally, their co-occurrence may lead to complex interactions, potentially resulting in synergistic or antagonistic effects, as well as contributing to the co-selection of antibiotic and metal resistance.

This study investigates the effects of clarithromycin and copper and zinc on anaerobic digestion of waste activated sludge. Batch experiments are conducted using anaerobic reactors operated under controlled conditions. The tested compounds are introduced both individually and in combination. The applied concentrations reflect levels typically reported in wastewater and sludge, ensuring environmental relevance.

The results indicate that the impact of antibiotics and heavy metals on anaerobic digestion of waste activated sludge depends strongly on the type of metal and its concentration. The presence of clarithromycin alone did not result in substantial changes in biogas production compared to the control, suggesting limited inhibitory effects at environmentally relevant levels. However, clear differences were observed when antibiotic was combined with metals. In particular, systems containing copper exhibited a dose-dependent response: lower concentrations were associated with enhanced biogas production (326 mL CH_4/gVS), while higher concentrations led to a pronounced decrease in process efficiency (76 mL CH_4/gVS. This may be linked to the dual role of copper as both an essential trace element supporting microbial enzymatic activity and a toxic compound at elevated levels. In contrast, zinc-containing systems showed more moderate effects, with no clear inhibitory trends observed under the tested conditions. The results suggest that anaerobic microbial communities demonstrate a relatively high resilience to low-level contaminant exposure, while combined stress can significantly influence process performance. This work was supported by the Polish National Science Center (Project No. 2024/55/B/NZ9/00815).