

Wastewater Stressors Shape the Microbiome of Aerobic Granular Sludge

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Abstract:

Aerobic granular sludge (AGS) is a revolutionary biological treatment technology, which, due to its competitive advantages, has been increasingly implemented in full-scale wastewater treatment plants (WWTPs). WWTPs are frequently challenged by multiple stressors, including pharmaceuticals and fluctuating salinity, which not only increase the complexity of wastewater but also impair the biological treatment performance. However, the impact of such stressors on the compositional dynamics and ecological succession of AGS microbial communities remains understudied.

In this study, over four months a laboratory-scale AGS reactor was fed with domestic wastewater of fluctuating salinity that sporadically contained pharmaceuticals (tramadol and venlafaxine) and their metabolites at $\mu\text{g/L}$ levels. The effect of these stressors on treatment performance and bacteriome dynamics was assessed. The reactor performance was stable, achieving high removal efficiencies for organic carbon ($89.0 \pm 3.1\%$) and ammonium ($99.8 \pm 0.2\%$). Pharmaceuticals and their metabolites were removed by up to 85% and did not impair reactor performance. At the microbiome level, distinct bacterial niches emerged over time in response to wastewater compositional changes, reflecting the ecological flexibility of AGS bacteriome under stressful conditions. In the presence of multiple stressors, a diverse core emerged in the bacteriome, including nutrient removal-related taxa (e.g., *Nitrosomonas* and *Nitrobacter*), which were crucial for sustaining effective nitrification. Additionally, the enrichment of *Paracoccus* during pharmaceutical exposure underscored its key role in protecting functional bacteria and preserving granular system integrity.

This study highlights the potential of AGS systems to handle complex and fluctuating wastewater compositions, thanks to a versatile microbiome that sustains high treatment efficiency and prevents operational failure.

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