26th Nordic Process Control Workshop (NPCW26): Clustering and optimization of nutrient removal in biological wastewater treatment

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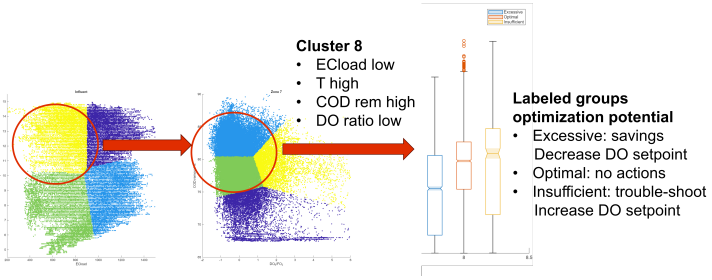

Clusters for inlet and intermediate zones. Labeled groups reveal optimization potential in DO setpoints.

In municipal water resource recovery facilities (WRRFs), the influent water temperature, flowrate, and nutrient composition fluctuate in daily, weekly and seasonal patterns, affecting biological activity, nutrient dilution, hydraulic retention time, and nutrient removal performance. Process control must ensure compliance with regulatory nutrient limits under these varying conditions. Identifying operational states and linking them to effective aeration strategies can support operators in optimizing energy use and nutrient removal [1]. This study developed variable combinations and clustering methods to characterize operational states in the Hias Process [2] in order to optimize nutrient removal performance and aeration energy use. A 18-month data set was pre-processed, time-delayed and labeled according to phosphorus removal performance (excessive, optimal, insufficient). Data exploration and correlation analysis, combined with process knowledge, revealed relationships such as inlet nutrient load (ECload) and the ratio of dissolved oxygen to aeration (DO ratio). Among tested clustering methods, K-means clustering demonstrated the best performance. The 82000 samples were divided into 13 clusters based on the variable combinations at the influent and intermediate zones. Visualization of the four largest clusters and analysis of the labeled subgroups using box plots highlighted key operational trends: The DO was the lowest and the NO_2 was the highest in the excessive groups, while the opposite applied to the insufficient groups. Lowering the DO setpoints in the excessive group could optimize the removal performance and reduce aeration costs. The insufficient group requires careful troubleshooting for possible process disturbances, and may require an increase in the DO setpoint if the NO_2 is too low. Future work will leverage these clusters and nutrient removal performance groups to develop and test real-time optimization and control strategies.

References

[1] Andreas Froemelt, Leon Zueger, Luzia von Kaenel, Daniel Braun, and Wenzel Gruber. Pattern recognition of operational states leading to n2o-emissions in full-scale biological wastewater treatment. *Water Research X*, 29, 2025. doi: 10.1016/j.wroa.2025.100336.

[2] Tiina M. Komulainen, Malik Baqeri, Katrine M. Jansen, Torgeir Saltnes, Alex T. Bech, and Olga Korostynska. Virtual sensors for the hias process. *Water Practice and Technology*, page wpt2024176, 07 2024. ISSN 1751-231X. doi: 10.2166/wpt.2024.176.

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