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# Control of an Up-flow Anaerobic Sludge Blanket Reactor treating blackwater

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**Abstract:** In this work, we implement, analyse, and control an up-flow anaerobic sludge blanket (UASB) reactor model treating blackwater with 71 state variables, 7 measured outputs, and 1 controlled input. We propose a cascade control structure, where the outer loop regulates the reactor effluent organic matter by manipulating the wastage sludge flow-rate. The inner loop controls the amount of sludge in the reactor by discharging the excess sludge. We test the controller under a continuous dynamic influent flow-rate, considering typical variations in a wastewater treatment plant, and compare it with an open-loop scenario. Preliminary results show that the proposed structure enhances the methane production while ensuring a stable operation, with an automated sludge discharge.

**Keywords**: UASB reactors; wastewater treatment plants; control systems; cascade control.

## Introduction

Recent studies show the worsening of the present global water scarcity, reporting an insufficiency that accounts for its availability and quality (Jones, 2024). Wastewater treatment plants (WWTPs) play a crucial role in addressing these situations, given that recovered water and resources can be reused, for example, in agriculture, industries, and power generation (Kesari, 2021). Up-flow Anaerobic Sludge Blanket (UASB) treatment can significantly contribute to resource recovery by allowing contextual wastewater treatment, biogas production and nutrient reclamation. UASB reactors are well-suited for warm climate regions, such as Brazil where more than one-third of WWTPs use UASB as the primary treatment for organic compounds removal, often followed by post-treatment, e.g., maturation ponds or constructed wetland (von Sperling, 2016).

Motivated by the need to achieve a control tool for high and stable performance for UASB treatment of blackwater, the state-space model provided by Boiocchi et al. (2022) is used as an environment for control development and testing. The model considers the biological processes, the system's transport of sludge particles, and the variation of sludge bed volume. Gas stripping, organic matter composition, and reaction rates follow the state-of-the-art model for anaerobic digestion processes by Batstone et al. (2002). The model was calibrated by Boiocchi et al. (2022) to represent a 5-Liter lab-scale UASB reactor treating blackwater. The working volume of 4.69 L comprises the sludge bed and sludge blanket zones. The remaining 0.31 L is given to a three-phase separator, that redirects the treated effluent, the produced biogas, and the remaining sludge particles to their respective paths. The model properties such as stability, controllability and observability, were analysed to understand relations between the system's states, inputs and outputs (Maciel, 2024). The model was proven to be stable by producing bounded outputs when bounded inputs are applied. Based on its structure, it was found to be both controllable and observable, suggesting the potential of achieving effective control.

## Cascade control structure

In this work, a control strategy regulating the effluent COD using the cascade control structure is designed (Figure 1). The outer control loop compares the measurement from an effluent COD

sensor ($COD_m$) with the reference ($COD_{ref}$). The error is used by the controller $C_1$ to determine the volume of sludge bed $V^A_{ref}$. The error between $V^A_{ref}$ and the current sludge volume measurement ($V^A_m$) is used by the inner control loop $C_2$ to determine the wastage sludge flow-rate ($Q_w$) to be removed.

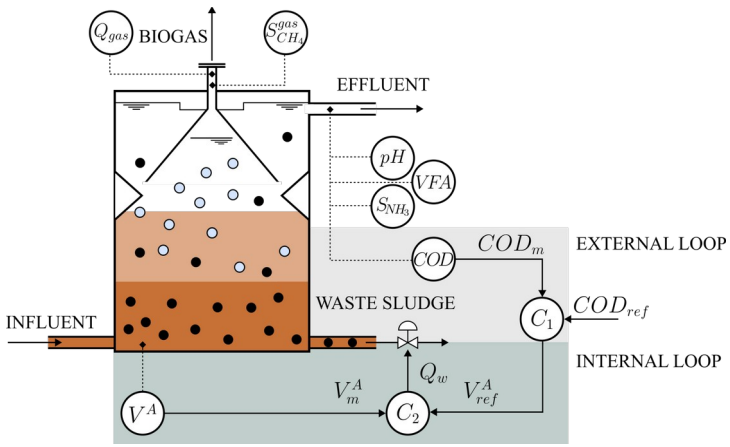



**Figure 1** Schematic of the UASB reactor and the control structure used.

The control is tested for disturbance rejection, considering variations in the influent wastewater flow-rate (Figure 2) generated according to Gernaey et al. (2011), while the influent load is kept constant as in Boiocchi et al. (2022), with an influent COD of 8.61 gCOD/L. The setpoint for effluent COD is set to 1 gCOD/L, which corresponds approximately to 88% COD removal.

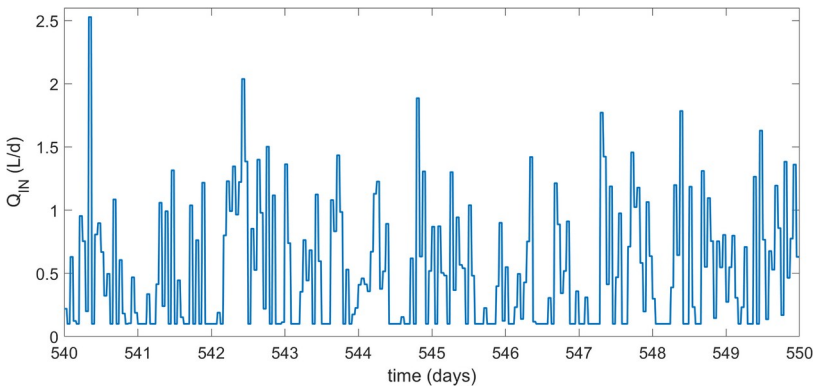
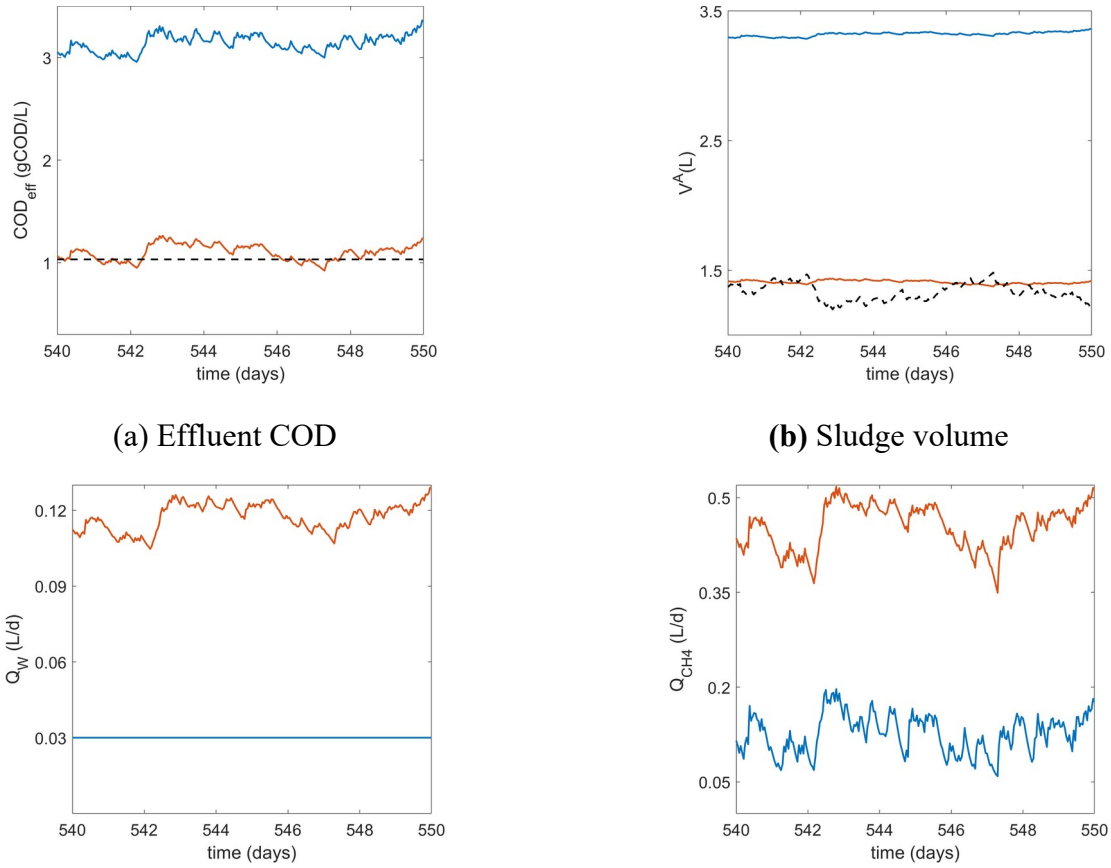



**Figure 2** Dynamic influent flow-rate used in the simulations.

## Results and discussion

Closed-loop performance is compared to an open-loop configuration where the wastage sludge flow-rate is fixed at 0.03 L/d to avoid sludge overflow from the reactor. Overall simulation results, covering a 200-day period beginning when the system stabilizes on day 350, are summarized in Table 1 while Figure 3 shows open- and closed-loop results for a 10-day period. Figure 3a and 3b show that the effluent COD and the sludge volume set references are tracked despite the variations in $Q_{IN}$ by adjusting $Q_w$ (Figure 3c). As a result, the produced flow-rate of methane gas is increased in the controlled system (Figure 3d).




(a) Effluent COD

**(b)** Sludge volume

**(c)** Sludge discharge

**(d)** Methane gas

**Figure 3** Simulation results for dynamic influent flow-rate (cascade control in red; open-loop in blue and setpoints in dashed black).

**Table 1** Average results over the last 200-day period of dynamic influent flow simulation.

| | Effluent COD (gCOD/L) | Sludge volume (L) | Sludge discharged (L/d) | Methane gas produced (L/d) | Methanisation efficiency (%) |
|---|---|---|---|---|---|
| Open-loop | 2.92 | 3.26 | 0.03 | 0.115 | 19.7 |
| Closed-loop | 1.07 | 1.43 | 0.10 | 0.405 | 71.0 |

The methanisation efficiency is calculated according to Equation 1, where $Q_{CH4}$ is the flow-rate of the methane gas produced, $K_{CH4toCOD}$=0.35 L/gCOD is a conversion factor to obtain the COD equivalent of $Q_{CH4}$, $COD_{IN}$ is the influent concentration, and $Q_{IN}$ is the influent flow-rate.

$$ME = \frac{Q_{CH4}}{K_{CH4toCOD}\, COD_{¿}\, Q_{¿}} \times 100 \qquad (1)$$

## Conclusion and future perspectives

In this work, a cascade control strategy is developed to achieve low effluent COD concentrations from a UASB reactor treating blackwater by manipulating the wastage flow-rate. The presented control strategy, tested on a validated model, shows good performance in terms of set point

tracking, which enabled a good and stable operation of the UASB reactor. By tracking the effluent COD to the set reference, the UASB reactor effluent can be safely discharged after due post-treatment. These preliminary results highlight the potential to maximise the methane production of the UASB reactor and advanced control strategies need to be further investigated to maximise biogas while maintaining the effluent COD at acceptable levels.

**REFERENCES**

Batstone, D.J. et al. 2002. The IWA anaerobic digestion model No. 1 (ADM1). *Water Science and Technology*, 45(10), 65–73.

Boiocchi, R. et al. 2022. Modeling and optimization of an upflow anaerobic sludge blanket (UASB) system treating blackwaters. *J. of Environmental Chemical Engineering*, 10(3), 107614.

Gernaey, K.V., Flores-Alsina, X, Rosen, C., Benedetti, L., Jeppsson, U. 2011. Dynamic influent pollutant disturbance scenario generation using a phenomenological modelling approach, Environmental Modelling & Software, 26(11), 1255-1267.

Jones, E.R., Bierkens, M.F.P. & van Vliet, M.T.H. 2024. Current and future global water scarcity intensifies when accounting for surface water quality. *Nature Climate Change*, 1–7.

Kesari, K.K., Soni, R., Jamal, Q.M.S., Tripathi, P., Lal, J.A., Jha, N.K., Siddiqui, M.H., Kumar, P., Tripathi, V. & Ruokolainen, J. 2021. Wastewater treatment and reuse: a review of its applications and health implications. *Water, Air, & Soil Pollution*, 232, 1–28.

Maciel, A.F.F. 2024. *Analysis and Control of an Anaerobic Sludge Blanket Reactor*. Bachelor's thesis. Federal University of Ceara, Fortaleza, Brazil.

von Sperling, M. 2016. *Urban Wastewater Treatment in Brazil*. Inter-American Development Bank, Washington, DC, USA.