Combining novel biomonitoring and modelling for process control and data validation in WRRFs

Initial WEST model results based on SENTRY input data and basic WWTP configuration

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INTRODUCTION

Background

Bioelectric sensors are innovative instruments for monitoring of loading and process status in water resource recovery facilities (WRRFs). Island Water Technologies has developed a bioelectric sensor, **SENTRY**, which measures Carbon Consumption Rate (CCR) or Microbial Electro Transfer (MET), an instantaneous measurement of the microbial activity associated to organic matter in wastewater. The sensor consists of a biofilm grown on a substrate upon which a constant voltage is applied. The biofilm is in contact with wastewater and electron transport occurs across the substrate as the biofilm oxidizes organic matter and uses energy. This induced current is measured and converted to a bioelectric signal, which is subsequently converted to a CCR measurement. SENTRY is used to track imbalance events (unusual influent toxicity) and higher organic loading to WRRFs [1], providing for relevant information in the operation and control of WRRFs.

Objectives

The **objectives** of this study were to explore the benefits in **combining bioelectric sensors (SENTRY) and process modelling (WEST) in full-scale WRRF operation**:

1) identification of potential correlations between sensor data and conventional indicators (COD and its fractions)
2) use of model predictions for anomaly detection and gap filling
3) virtual testing of feed-forward control strategies based on SENTRY signal as input

Figure 1 – SENTRY sensor

METHODS

Data collection and evaluation

Time-series data were collected from a SENTRY installation at a municipal WRRF in US (3.25 MGD dry weather capacity). The sensor is placed in mixing tanks upstream of grit removal, thus measuring CCR in the raw influent. Sensor data were evaluated against hourly influent flow and hourly chemical oxygen demand (COD) and daily composite oxygen demand index (ODI) measurements. For this purpose, a 10-day period was selected (January 2021, Figure 2), during which influent samples were collected with hourly frequency and measured for total COD and ODI concentrations.

Figure 2 – Time-series of SENTRY sensor data (CCR) and COD measurements for a 10-d period.

Influent and WRRF modelling

A model of the WRRF investigated was constructed using the software WEST (DHI A/S, Denmark). The model included an influent generator model, for dynamic simulation of influent flow and pollutant loads, and a model of the WRRF process configuration.

The **influent generator model** used publicly available data and information including catchment surface area, population, water consumption, industrial discharges and precipitation to generate influent data with high temporal frequency. The model was calibrated against available measurements for flow and COD. The **WRRF model** (Figure 3) was implemented to describe the existing treatment configuration was based on the modified ASM2d process model [2]. The model was subsequently extended with a customised controller and used to evaluate the benefits of a feed-forward control strategy based on SENTRY input data.

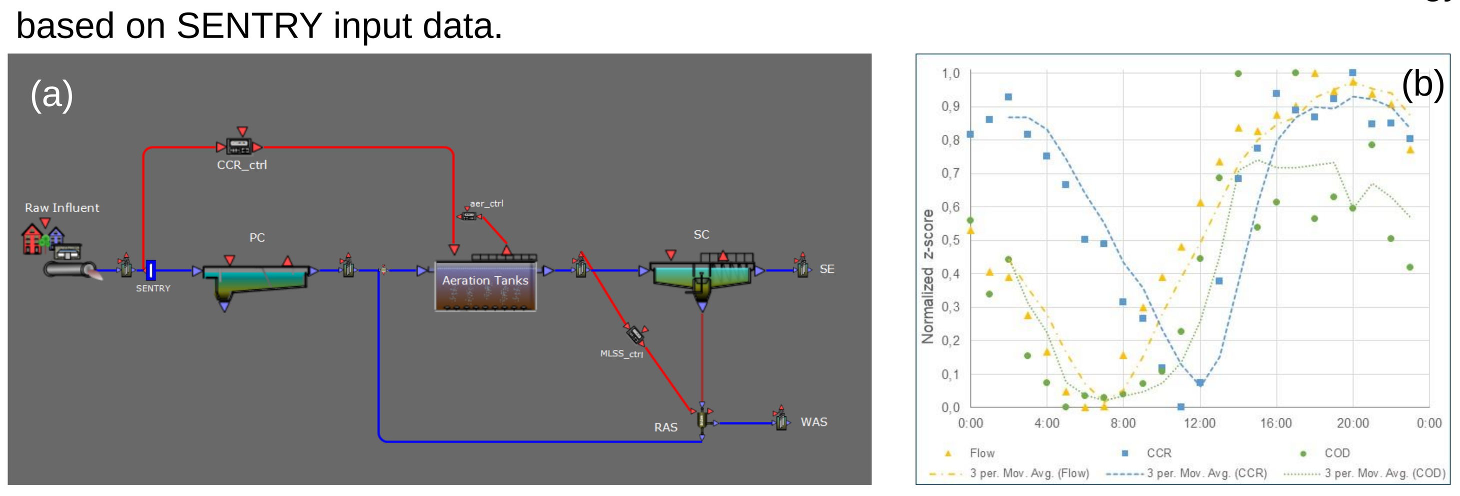

Figure 3 – WEST model of the WRRF with SENTRY-based feed forward control (a) and influent patterns (b).

CONCLUSIONS

Data from SENTRY showed potential for use in process control. Advanced control strategies for effluent organics and nitrogen and oxygen transfer efficiency optimizers may benefit from influent SENTRY data as a leading indicator of plant loading, enabling feed-forward and more predictive control.

The control strategy may benefit from accurate prediction of influent loading profiles, which could be obtained by combining SENTRY and the WEST influent generator model. Influent predictions may complement sensor data in case of data gaps, thus providing a **backup option during periods of sensor malfunctioning, anomalies, or maintenance**. On the other hand, SENTRY can inform about biological inhibition or changes to reported sludge yield, which may not be captured by models.

The combination of SENTRY and WEST modelling has shown promising results for application in digital twins of WRRFs. Measurement and prediction of influent loads can be used as input to an online process model of the WRRF, and the process efficiency for various operating strategies can be determined together with the relative effect on KPIs (energy efficiency, carbon footprint). Using SENTRY data as a proxy for COD concentrations may need to be revisited, and machine learning algorithms can be used to correlate the SENTRY data to COD-surrogate data as model input.

RESULTS and DISCUSSION

Correlation between SENTRY data and conventional indicators

Figure 4 presents correlations of CCR data against hourly COD concentration (left) and daily ODI concentrations (right) measured during the investigated interval. Interestingly, no correlation between CCR and COD is shown, while a **significant correlation is shown between CCR and ODI**. While a larger data set may be required to corroborate this finding, it is shown that ODI is a better descriptor of the microbial activity dynamics tracked by SENTRY. As shown in Figure 2, the bioelectric activity decreases while the COD follows a consistent diurnal trend, which could indicate an increase in inhibitory compounds that may affect biological treatment independently of influent COD loading.

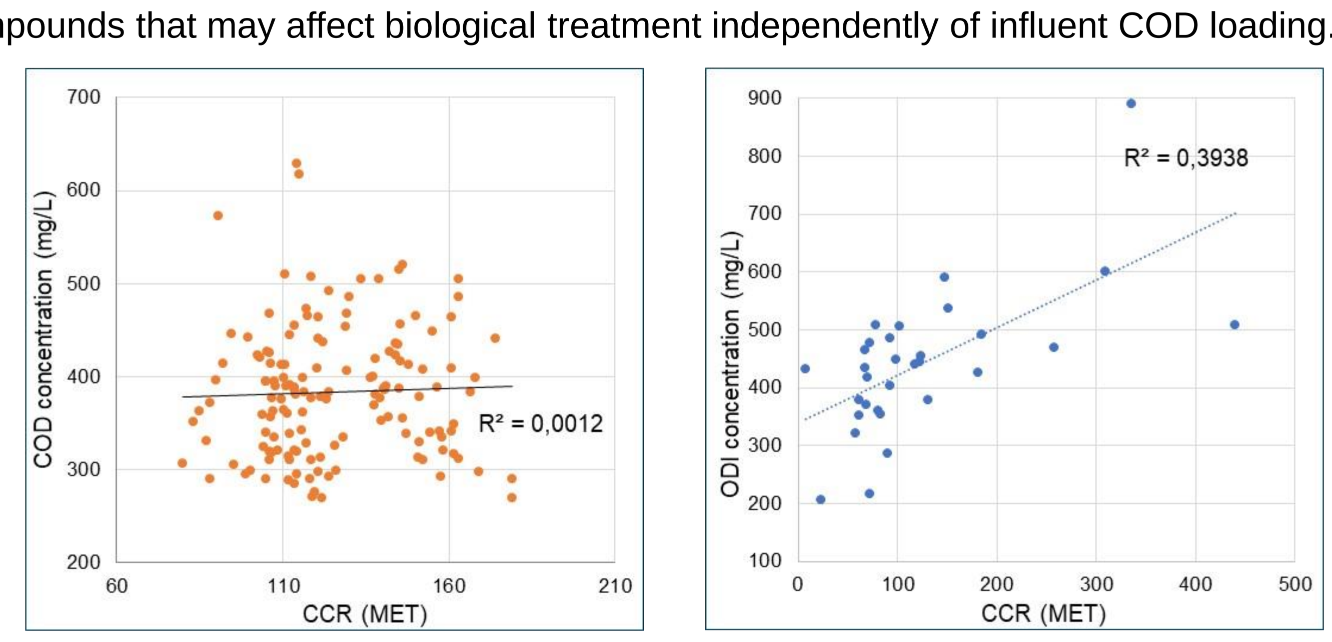

Figure 4 – Correlation between CCR and COD (left) and CCR and ODI (right) measurements.

Model-based influent prediction and gap-filling

While SENTRY provides for a high-frequency measurement of the degradable, non-inhibitory organic matter concentration in the influent, **accurate modelling of influent flow is required to describe and predict the influent organic loading**.

Influent flow predicted by the generator model showed strong agreement with measured data (Figure 5). Despite limitations in the resolution of rainfall data, the model proved capable of **predicting influent flow rate** during dry- and wet-weather conditions in at least two major events during the evaluation period (Figure 5a and 5b), with **potential for anomaly detection and automated gap filling** (Figure 5b).

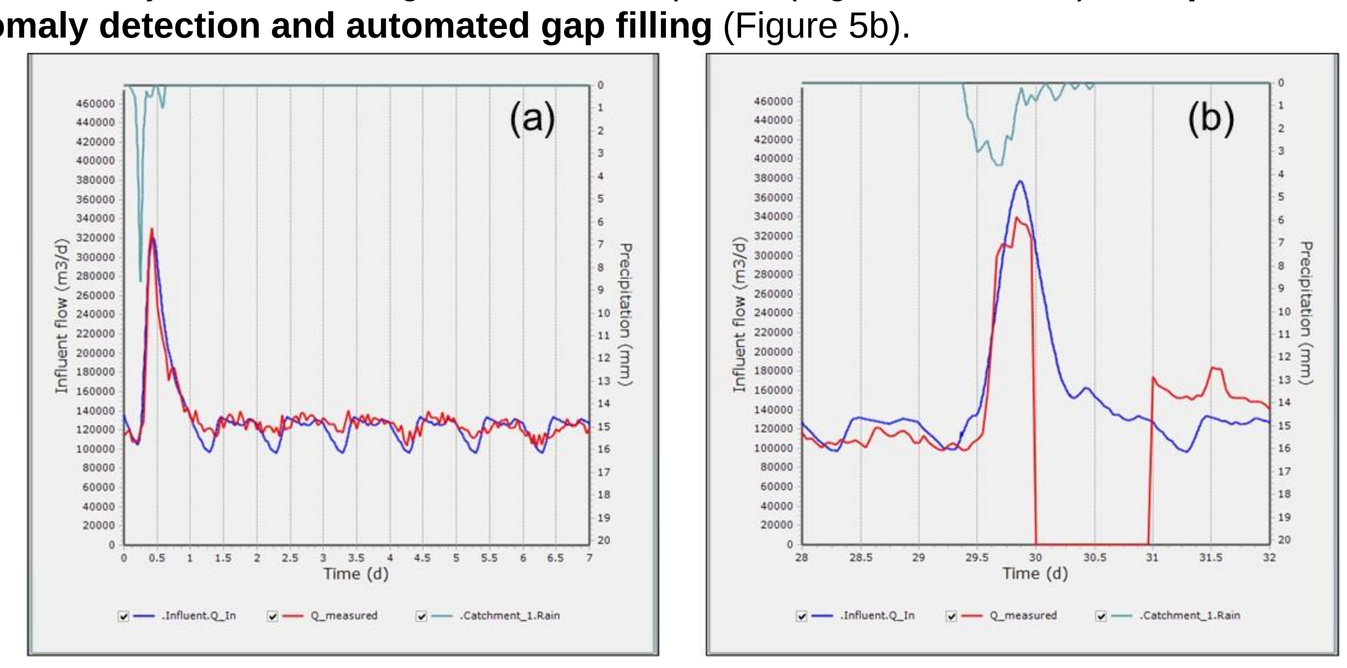

Figure 5 – Measured (red) and simulated (blue) influent flow to the WRRF.

Feed-forward controller: virtual evaluation

A feed-forward controller was tested in the virtual environment using the WRRF model in WEST to increase aeration during periods of high activity registered by the SENTRY sensor. The simulated high activity event is marked by a significant increase in organic loading at simulation day 70. **The SENTRY-based controller response significantly impacts simulated effluent quality (Figure 6), providing for reduction in both BOD and NH4-N effluent concentrations** as opposed to constant aeration.

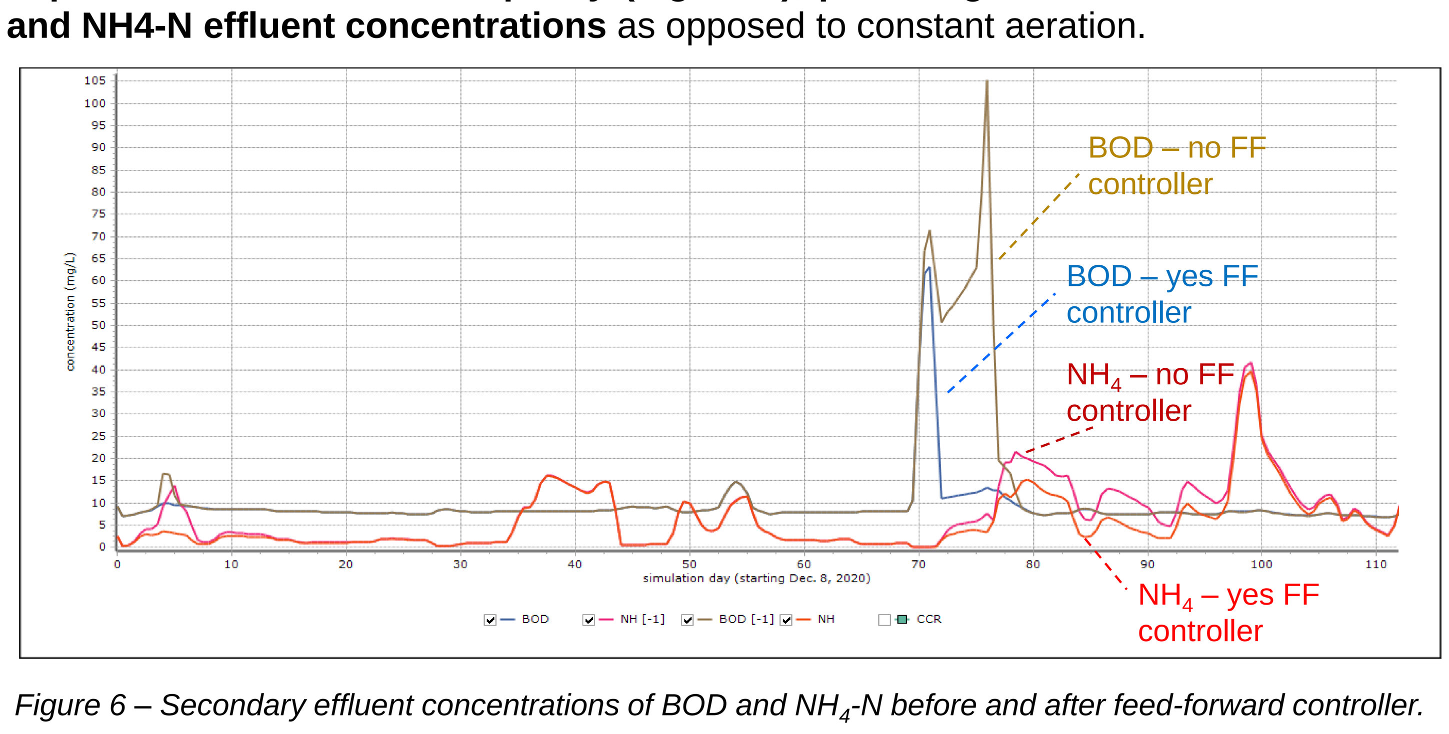

Figure 6 – Secondary effluent concentrations of BOD and NH_4-N before and after feed-forward controller.

References: [1] https://www.sentrywatertech.com/energy-optimization/influent-monitoring; [2] Gernaey, K.V., Jørgensen, S.B. (2004). Benchmarking combined biological phosphorus and nitrogen removal wastewater treatment processes. Control Engineering Practice 12, 357-373.