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# Computational Fluid Dynamics-based hybrid model for dissolved oxygen prediction in a full-scale wastewater plant

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**Abstract:** In wastewater treatment, due to the complexities of biological, chemical, and physical processes, accurate modelling of wastewater treatment plants' (WWTP) has been challenging. Deep Neural Network (DNN) models have emerged as a powerful tool for addressing this complexity, offering a way to improve the accuracy and efficiency of wastewater treatment models. DNN can identify complex, non-linear, patterns and relationships in data, making them ideal for predicting wastewater quality. Aeration is the most energy intensive process in wastewater treatment. Fluctuations in flow and load have a significant effect on WWTP's energy efficiency. In this study first a computational fluid dynamics (CFD) dissolved oxygen (DO) distribution model for a full-scale, deep, bottom aerated tank with as-build layout consisting of disc diffusers is made and then a DNN data model is developed based on the CFD model results in the same calculational domain. We propose a novel hybrid CFD - DNN DO distribution 3D model. The model was built with real large-scale plant data. The model predicts the hydraulic flow and the DO distribution pattern in the deep tank with dense aeration grid, providing a powerful tool to design and quantify aeration in a more adaptive and energy efficient way.

**Keywords**: Aeration; CFD; DNN, dissolved oxygen; WWTP

## Background

Aeration can make up 45 – 75% of the activated sludge (AS) plant's total energy demand (Rosso et al. 2008). In AS process, aeration of wastewater is needed to provide enough DO for microorganisms that metabolize organic matter and convert ammonia to nitrate (nitrification). Automated aeration control system keeps the DO levels in the aerated reactors at the desired setpoints. The oxygen requirement of the process is dynamic, due to variations in the plants loading, meaning that to sustain the desired DO setpoint, air flow to the system needs to be regulated (Gray et al. 2011). Currently DO is usually measured only from one fixed point located in the beginning of aeration line (consisting of multiple aerated zones in series) or from two fixed points, typically from the beginning and from the end of aeration line. Even when using the state-of-the-art aeration control system, DO is measured from one point per aeration zone. This data is then used to control the aeration of a complete aeration line or a single zone in the best case, leading to potential under- and over-aeration, causing lack of DO or increased energy consumption.

## Research project, introduction

The goal of this research project is to develop a model that reliably estimates the DO in all parts of the aeration zone and that is feasible to be used in real plant operation control, meaning that the computational capacity requirement needs to be accessible.

This study focuses on the development and testing of the DNN model to minimize the time and cost of the model calculations. We have earlier developed a CFD model for estimating DO distribution in Viikinmäki WWTP's (Helsinki, Finland) aeration line 5 aerated zone 5 (Ukkonen et al. 2024). This CFD model is used in this study.

**Research project, methods and results**

Zone 5 has dimensions: length 18 m, width 8.15 m and water depth 12.6 m. There is an aeration system on tank bottom with one aeration air inlet, consisting of total 560 membrane fine bubble disc diffusers (type Sulzer KKI215). We used commercial COMSOL 6.2 software for CFD and DNN modelling. The CFD model was validated with measured values from the five DO sampling points, including two deep sampling points (water depth 10 m). Based on the validated CFD model we made a DNN model for the same calculational domain. The 5-layer DNN model was trained with data derived from the CFD model. The 50 x 8 datapoint matrix contained 3 argument and 5 function columns. The DO values from the DNN models (total 5 DNN models, one for each sampling point) was compared with the DO values from the validated CFD model. Validations were done for two different parameter sets, corresponding to the measured, average sampling period parameter values. Sampling points are listed in Table 1.1. Sampling points together with flow profiles are presented in Figure 1.1.

**Table 1.1** Sampling points, sampling periods and DO probe specification

| Sampling point No. | Position (x, y, z) m | Sampling period(s) date | DO probe type | DO supplier/model |
|---|---|---|---|---|
| 1. Inlet, depth 0.5 m | (8.0, -2.5, 12.1) | a) 02.-03.10.2024<br>b) 24.-25.9.2024 | Galvanic | Atlas Scientific, Lab Grade |
| 2. Middle, depth 0.5 m | (0.0, -2.5, 12.1) | a) 02.-03.10.2024<br>b) 24.-25.9.2024 | Optical | Hach Lange, LDO Model 2 |
| 3. Outlet, depth 0.5 m | (-8.0, -2.5, 12.1) | a) 02.-03.10.2024<br>b) 24.-25.9.2024 | Galvanic | Atlas Scientific, Lab Grade |
| 4. Inlet, depth 10.0 m | (7.5, -2.5, 2.6) | a) 02.-03.10.2024 | Optical | PME, miniDOT® Logger |
| 5. Outlet, depth 10.0 m | (-7.5, -2.5, 2.6) | b) 24.-25.9.2024 | Optical | PME, miniDOT® Logger |

Notes: sampling point position measuring tolerance +/- 1 m, DO measuring tolerance +/-15%, coordinate system origo (0, 0, 0) in the middle of tank bottom.

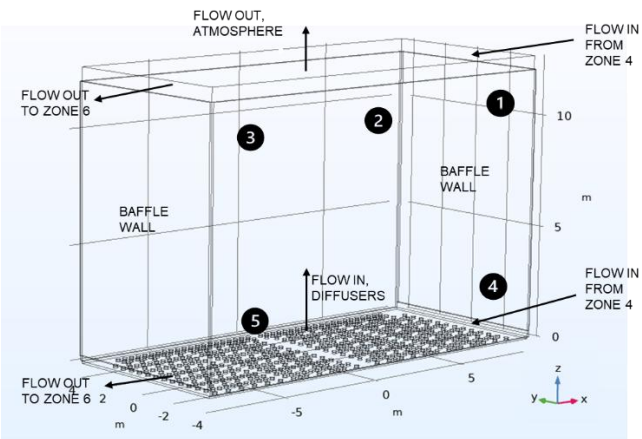


**Figure 1.1** Sampling points and flow profiles in aerated zone 5.

Average measured and simulated DO levels and validation errors are presented in Table 1.2. The visualized simulation results for the two sampling period cases are presented in Figure 1.2. Inlets are on the right and outlets on the left side of the aeration tank and at the bottom and top of the two baffle walls.

**Table 1.2** Sampling points: average measured and simulated DOs, validation errors.

| Sampling point and period | DO measured mg/l | DO CFD simulated mg/l | DO DNN simulated mg/l | Validation error % DO measured vs. DO CFD / DO measured vs. DO DNN |
|---|---|---|---|---|
| 1. a) | 3.08 | 3.03 | 3.40 | -1.7 / 9.4 |
| 1. b) | 2.95 | 2.97 | 2.57 | 0.7 / -14.8 |
| 2. a) | 2.42 | 2.11 | 2.27 | -14.7 / -6.6 |
| 2. b) | 2.29 | 2.02 | 1.90 | -13.4 / -20.5 |
| 3. a) | 1.89 | 2.07 | 2.36 | 8.7 / 19.9 |
| 3. b) | 1.76 | 1.86 | 1.80 | 5.4 / 2.2 |
| 4. a) | 2.02 | 2.00 | 2.37 | -1.0 / 14.8 |
| 5. b) | 1.76 | 2.02 | 1.91 | 12.9 / 7.9 |

Note(s): sampling point position measuring tolerance +/- 1 m, DO measuring tolerance +/-15%, CFD DO simulated tolerance +/-15%, DNN DO simulated tolerance +/-21%.

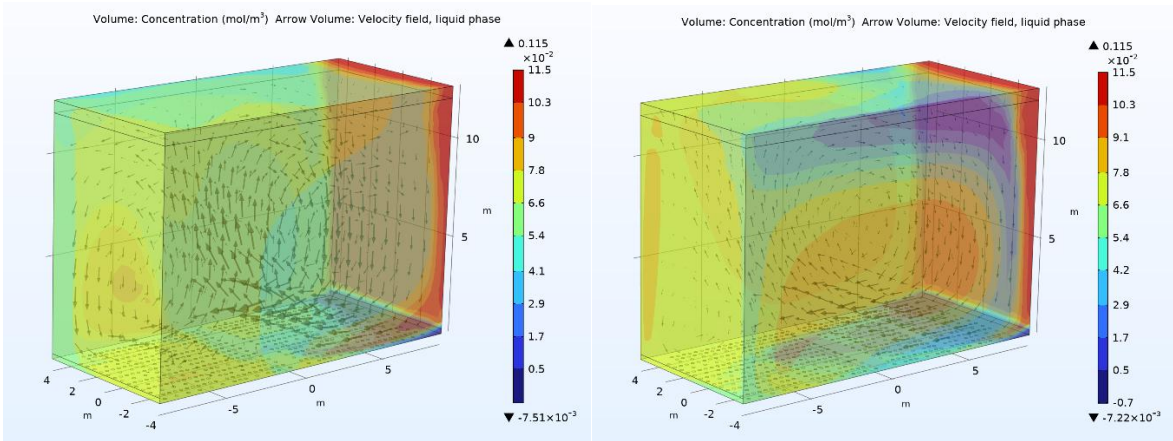


**Figure 1.2** CFD model at steady-state: DO distribution map and water velocity field, sample periods a) left and b) right, DO given in unit mol/m$^3$.

We found out that with as little as 50 datapoint training data and using only three arguments the DNN model predicted DO within 21% accuracy. This is a good result considering small training data set. DNN model calculated the results practically in real time whereas it took about 30 minutes for the CFD model to reach steady state. Using more datapoints should improve the DNN model accuracy. This will be tested in the future.

The developed DNN model shows potential as a solution to significantly speed up simulations and decrease the computational capacity requirement to a level allowing wide implementations in WWTPs for aeration design, operation control and energy optimization.

## REFERENCES

Gray, M., Kestel, S., & Stahl, T. 2011. Aeration System Design for Energy Savings. Proceedings of the Water Environment Federation, 2011(6), pp. 312-324.

Rosso, D., Stenstrom, M. K. & Larson, L. E. 2008. Aeration of large-scale municipal wastewater treatment plants: State of the art. Water science and technology: a journal of the International Association on Water Pollution Research. 57(7), pp. 973-978.

Ukkonen, P., Mulas, M. & Mikola, A. 2024. Novel dissolved oxygen distribution model of a full-scale aeration tank for a municipal wastewater treatment plant in a cold climate region. Journal of Water and Climate Change (2024). 15 (11), pp. 5698–5713.