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Aeration System Modelling - Case Studies From Three Full-scale Wastewater Treatment Plants

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Summary of key findings

The water train of three WWTPs have been modelled following the procedures of the Benchmark Simulation Model (BSM) platform (Gernaey *et al.*, 2014). Additionally the aeration system has been modelled to evaluate airflows and energy performance. The results for the airflow model are presented. The chosen airflow model is shown to be easy to apply and calibrate and robust for practical modelling cases. By simply adjusting the SOTE-polynomial, number of diffusors and airflow limitations the model replicates the real data at a level of detail suitable for most purposes where the evaluation is based on longer time averages. For peak demand evaluation the whole treatment model with influent characterization, model calibration and controllers need to be more detailed than done here. Modelling the airflow is important to allow for evaluation of air consumption, aeration energy performance and for communication of simulation results to plant staff and operators.

Background and relevance

The development of mathematical models of wastewater treatment processes has been in progress for over 30 years. Today modelling and simulation are widely accepted tools for decision-making support in wastewater management (Daigger *et al.*, 2011). The term 'model' here represents an abstract mathematical representation of a real system. The model cannot - and does not intend to - be a complete representation of the subject system. Rather, it is important to select an adequately complex model for the intended use (Olsson, 2012).

For evaluating performance and efficiency of wastewater treatment plants (WWTPs) aeration of the activated sludge unit is one of the key processes. The conventional models, i.e. the IWA activated sludge model (ASM) family, are known to well describe the oxygen consumption for most practical applications. However, these bioprocess models normally use $K_{\mathrm{L}}a$ to describe the oxygen input. $K_{\mathrm{L}}a$ input is not a practical unit measured or controlled at the WWTPs and there are several reasons for extending the model to include airflow: *i)* airflow can easily be validated against measurements; *ii)* airflow can be used for detailed modelling of power consumption for aeration; and *iii)* airflow is more communicative towards professionals at the utilities. This paper describes the implementation of an aeration model applied to three recent modelling studies of Swedish WWTPs.

Material and methods

The model developed includes the main parts of the aeration system, such as oxygen transfer in the diffusors, pressure drop over diffusors and power consumption in blowers, see Fig. 1. In this paper only the oxygen transfer model for the diffusors is presented. The oxygen transfer model is adopted from Beltran (2013). The model by Beltran (2013) was chosen prior to alternative models, such as the one by Dold and Fairlamb (2001), for its physical mechanistic approach and transparency rather than empirical equations based on parameters that are hard to estimate. The model describes a non-linear relationship between $K_{\mathrm{L}}a$ and airflow according to Equation 1:

$$K_{\mathrm{L}}a = \alpha F(1.024^{T-20})\frac{OTE_{STP}x_{O2}\rho_{g,STP}}{V_L M_G \delta S_{o,sat,STP}}Q_{air} \qquad (1)$$

where α is the process water correction factor, F is the diffusor fouling factor, T is process water temperature, OTE is the oxygen transfer efficiency, x_{O2} the fraction of oxygen in dry air, ρ_g the density of air, V_L the reactor liquid volume, M_G the weighted molar mass of air, δ is the correction factor for liquid column pressure, $S_{o,sat}$ is the oxygen concentration in process water and Q_{air} the airflow. Index *STP* denotes standard temperature and pressure.

The oxygen transfer efficiency is a non-linear relationship specific for each diffusor type and installation, varying with submersion depth and diffusor density. In this model a polynomial fit of SOTE-data over the whole airflow range is used. SOTE-data for the three plants was retrieved and the model fitted to the data, see Fig. 2. For the three case studies no recent measurements for α values were available, and therefore values in the range of 0.6 to 0.8 were assumed.

The three WWTPs indexed 1 to 3 represent middle-sized to large WWTPs in southern Sweden. Common for all plants is that they are well equipped and controlled. The aeration control strategy for WWTP 3 is adopted from the Kruger STAR system (Rosen and Arnell, 2007) with intermittent aeration where the time periods of the aerated and not-aerated phases as well as the DO set-points are controlled based on feedback from on-line NH4-N and NO3-N measurements in the bio-reactor effluent. Basic information of the three WWTPs and their aeration systems are given in Table 1. The main purpose of modelling the three plants was to analyse future expansions plans and the evaluations were made on annual, quarterly or at most monthly basis. The water train of all three plants were modelled in Matlab/Simulink based on the BSM2 with the same selection of sub-models, except for the secondary clarifier that was modelled using the model by Burger *et al.* (2013) with 10 layers.

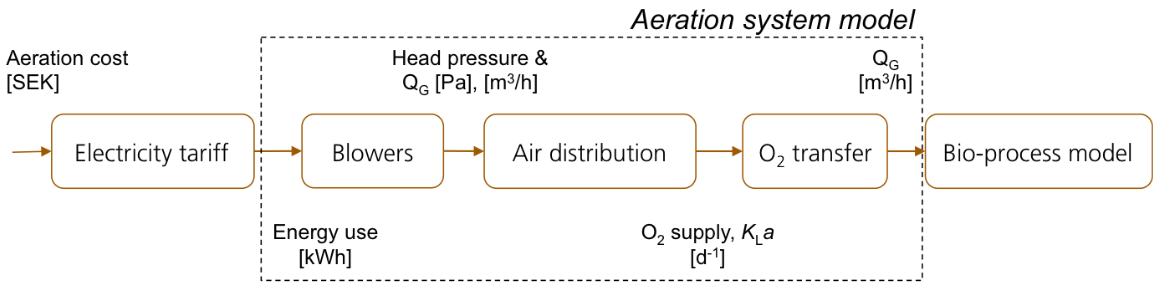

Figure 1 Schematic figure of the components included in the complete aeration model. Only the oxygen transfer over the aerators is presented here.

Table 1. Specifications of the three WWTPs in the case study.

	WWTP 1	WWTP 2	WWTP 3
Plant load [pe]	270 000	93 000	180 000
Water treatment train	Primary / MLE w precipitation / sec. clarifier / sand filters	Primary with CEPT / MLE with bio-augumentation / sec. clarifier / post precipitation & sed.	Primary with CEPT / ASP / sec. clarifier / post DN / post precipitation & sed.
ASP aerated volume	44 000	4 030	9 110
Diffusor type	Fine bubbled bottom aeration system with rubber membrane circular discs	Fine bubbled bottom aeration system with rubber membrane circular discs	Fine bubbled bottom aeration system with rubber membrane panels
Diffusor submersion depth [m]	10	3.5	3.5
Aeration control strategy	Fixed DO set-point	Fixed DO set-point	Intermittent aeration with controlled DO set-point based on NH_4-N and NO_3-N feedback

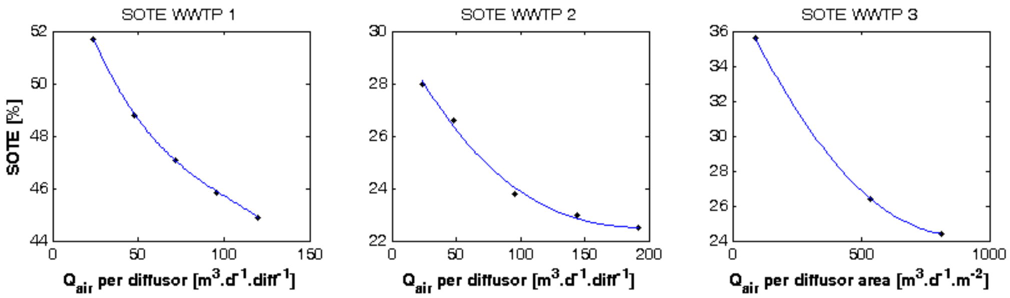

Figure 2 SOTE-data for the three WWTPs (black dot) at actual submersion depths and diffusor densities. Polynomial fit used in model (blue line).

Results

Resulting airflow curves for the three WWTP models are shown in Fig. 3 together with corresponding data. For WWTP 1 and 3 hourly average data were available but for WWTP 2 only daily averages. In Table 2 average airflows together with goodness of fit measures are presented. The goodness of fit is presented both as deviation of average airflows from averaged data and as normalised root mean squared errors evaluated with the Matlab `goodnessOfFit` function on step-wise averaged model outputs (hourly or daily) and data.

WWTP 1

In the model representing WWTP 1 four consecutive PI-controllers with four corresponding measurements were implemented. At the plant this advanced DO control set-up is only implemented for two out of five parallel lines. However, for this specific model purpose the parallel lines were modelled as one. As shown in Fig. 3, the modelled airflow is more smoothly controlled compared to the measurements but both the general air flow level and trends are captured. As for the averages and goodness of fit criteria in Table 2 the deviation is very small, only 4.4%, but the goodness of fit number not as good.

WWTP 2

As seen in Fig. 3 also the model results for the second WWTP in the study demonstrate a good fit with regard to the level and trends in airflows by only adjusting the SOTE curve and airflow limitations. Here the deviation is somewhat higher, 13%, but the goodness of fit much better. The WWTP 2 is the smallest plant and also less monitored and controlled than the other two. When calibrating the aeration model it is obvious that there are some effects not explained during the winter months (day 245 to 375). The drop in measured airflow around day 350 corresponds to a sharp peak in the ammonia concentration that the model fails to predict. Potentially the plant was exposed to some inhibitory or toxic events during this period.

WWTP 3

At the third plant the comparison is more difficult. The intermittent aeration strategy based on feedback of the treatment result makes the aeration go on-off with phases of varying length and time. At the plant the aeration phases for the 8 parallel lines are also shifted in time for practical reasons and the model simplification of reducing all the parallel lines into one cannot account for that shift. The model produces a good prediction of treatment performance. From the aeration model output in Figure 3 it can be seen that the aeration system goes on-off between 0 and the maximum air flow repeatedly and also that during some periods there are air supply limitations as the model predicts maximum airflows for the entire aerated phase. The hourly measured averages of the parallel lines are not suitable for comparison on a short time basis. However, the average values presented in Table 2 show that the deviation is only 5.3% and the goodness of fit is also adequate.

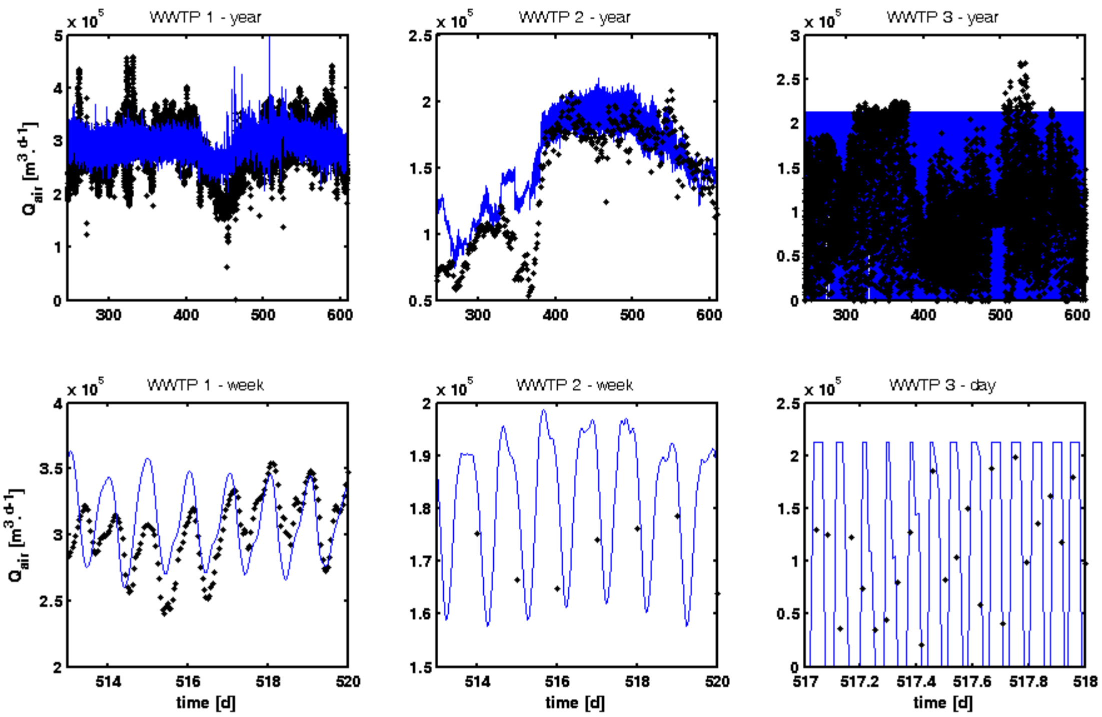

Figure 3. Total airflows from the three case studies – model (blue line) and data (black dot). Air flows over the whole evaluation period (top) and week or day selection (bottom).

Table 2. Goodness of fit of the airflow model for the three case studies. Airflow averages over the one year evaluation period for model and data, deviation between data and model averages. Goodness of fit value for the dynamic data.

	WWTP 1	WWTP 2	WWTP 3
Q_{air} model annual average [m^3/d]	2.96e+05	1.57e+05	1.10e+05
Q_{air} data annual average [m^3/d]	2.83e+05	1.39e+05	1.04e+05
Deviation [%]	4.4	13	5.3
Goodness of fit [-]	-8.6	0.032	-0.25

References

Beltrán, S., de la Sota, A., Villanueva, J.M. (2013) Model based optimization of aeration systems in WWTPs. ICA2013, 18-20 Sept., Narbonne, France.

Bürger, R., Diehl, S., Farås, S., Nopens, I., Torfs E. (2013) A consistent modelling methodology for secondary settling tanks: a reliable numerical method. *Wat. Sci. Tech.*, 68(1), 192-208.

Daigger, G. (2011) A practitioners perspective on the uses and future developments for wastewater treatment modelling. *Wat. Sci. Tech*., 63(3), 516-526.

Dold, P., Fairlamb, M. (2001) Estimating oxygen transfer KLa, SOTE and air flow requirements in fine bubble diffused air systems. WEFTEC2001 (pp. 780-791).

Gernaey, K.V., Jeppsson, U., Vanrolleghem, P.A., Copp, J.B. (2014) Benchmarking of Control Strategies for WWTPs. STR no. 23, IWA Publ., London, UK.

Olsson, G. (2012) ICA and me - A subjective review. *Wat. Res.*, 46(6), 1585-1624.

Rosen, C., Arnell, M. (2007) Plant-wide control of WWTPs. NordIWA2007, 11-14 Nov., Hamar, Norway.