# Generation of diurnal variation for influent data for dynamic simulation

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**Abstract** When using dynamic simulation for fine tuning of the design of activated sludge (AS) plants diurnal variations of influent data are required. For this application usually only data from the design process and no measured data are available. In this paper a simple method to generate diurnal variations of wastewater flow and concentrations is described. The aim is to generate realistic influent data in terms of flow, concentrations and TKN/COD ratios and not to predict the influent of the AS plant in detail. The work has been prepared within the framework of HSG-Sim (Hochschulgruppe Simulation, http://www.hsgsim.org), a group of researchers from Germany, Austria, Luxembourg, Poland, the Netherlands and Switzerland.

**Keywords** Activated sludge, diurnal variation, dynamic simulation, influent data, modelling

## Introduction

Design guidelines for activated sludge (AS) plants that are based on static models such as the German DWA A131 (2000) are common practice in many countries. Over the last decades numerical models for AS plants (Henze et al., 2000) have been becoming more popular and are generally used as a powerful tool to increase the detailed knowledge on the process and system behaviour, for optimisation studies (e.g. performance evaluation, operational optimisation, controller design, and conceptual process design), for training and teaching, and for model-based process control (Gernaey et al., 2004; Langergraber et al., 2004). Especially in German speaking countries numerical models are hardly used in the design process (Alex et al., 2007). The use of numerical models enables fine tuning of the plant design by including the evaluation of the dynamic behaviour as well as the design of control strategies.

To use dynamic simulation, in the optimisation of design diurnal variation of the influent data is required. If there are only few or no measurements available these influent data have to be generated. Gernaey et al. (2006) presented a method that is based on the pollutant load from each person in a catchment and considers also the layout of the sewer network. In this paper a simple approach to model diurnal variations that uses input data derived from the design of AS plants is presented. The aim is not to produce the exact diurnal variations that can be expected in reality, but to generate input data for dynamic simulations with a realistic pattern for flow and concentrations in the case that no measured data are available.

## Methods

### Input variables

The input variables to calculate the diurnal variation are data one gets from the design of the AS plant, i.e. daily averages of the dry weather flow and mean concentrations of Chemical Oxygen Demand (COD), Total Kjehldal Nitrogen (TKN) and Total Phosphorous (TP). It is assumed that the daily influent dry weather flow $Q_m$ and concentrations for COD, TKN and TP ($C_{COD,m}$, $C_{TKN,m}$, and $C_{TP,m}$, respectively) based on 24 hour composite samples are given.

### Calculation of the flow and concentrations of the wastewater streams

The overall wastewater flows and concentrations are modelled as sum of different wastewater streams (infiltration water, nitrogen rich wastewater – i.e. urine with flush water, and domestic wastewater without urine). Rainwater is not considered in this paper assuming that design optimization is carried out for dry weather flows only. Different wastewater streams are assumed to have constant concentrations and variable flows. Beside flow the concentrations for COD, TKN and TP are considered. Unusual values (e.g. TKN/COD ratios) shall be avoided.

To describe the periodic flow pattern four parameters are used: The minimum and maximum flow, $Q_{min}$ and $Q_{max}$ (described by the form parameters $f_{Q,min}$ and $f_{Q,max}$) and the times when they occur, $t_{min}$ and $t_{max}$, respectively. To describe nitrogen dynamics the following parameters are used: $f_{N,max}$ = ratio $C_{TKN,max}/C_{TKN,mean}$, $f_{min,U}$ = % fraction of minimum urine flow rate to mean urine flow rate, and $\Delta t_{N1}$ and $\Delta t_{N2}$ = shift of TKN minimum and maximum relative to minimum and maximum flow

For the mathematical formulation of the periodic patterns 2nd-order Fourier series are used. For the wastewater flows this results in the following equations:

$$\begin{aligned}
Q_{\inf}(t) &= Q_{\inf} = const \\
Q_u(t) &= Q_u + a_1 \cdot \sin(\omega t) + a_2 \cdot \cos(\omega t) + a_3 \cdot \sin(2\omega t) + a_4 \cdot \cos(2\omega t) \\
Q_d(t) &= Q_d + b_1 \cdot \sin(\omega t) + b_2 \cdot \cos(\omega t) + b_3 \cdot \sin(2\omega t) + b_4 \cdot \cos(2\omega t)
\end{aligned} \quad (1)$$

where $\omega = 2\pi/T$; T = 1 day, $a_1 \ldots a_4$, $b_1 \ldots b_4$ are constant parameters. To determine the 8 constant parameters ($a_1 \ldots a_4$, $b_1 \ldots b_4$) 8 equations are required. Two equations can be derived from each of the following boundary conditions: (i) minimum flow $Q_{min}$ occurs at $t_{min}$, (ii) maximum flow $Q_{max}$ occurs at $t_{max}$, (iii) minimum urine flow at $t_{min} - \Delta t_{N1}$, and (iv) maximum TKN concentration at $t_{max} - \Delta t_{N2}$.

As a first step of implementation flows and concentrations have been fitted to measured data to derive general form parameters. Therefore measured data (flow, COD and TKN from two-hour composite samples from the influent of AS tanks) have been collected in total for

19 AS plants in Austria (17) and Germany (2) with plant sizes between 4'000 and 150'000 PE. The input data (daily influent dry weather flow, daily mean concentrations of COD, TKN and TP, and the flow and concentrations of infiltration water and urine) and the form parameters have then been used to generate the diurnal variation data.

## Results and discussion

### Comparison with measured data

The form parameters ($Q_{min}$, $t_{min}$, $Q_{max}$, $t_{max}$, $f_{N,max}$ , $f_{min,U}$, $\Delta t_{N1}$ and $\Delta t_{N2}$) have been estimated by fitting the equations to the measured data of flow, COD and TKN. The total flow has been fitted to measured flow data. Figure 1 compares the measured and modelled flow for an AS plant with 7'000 PE and concentrations of COD and TKN for an AS plant with 40'000 PE, respectively. In general, a good fit to the measured data could be observed.

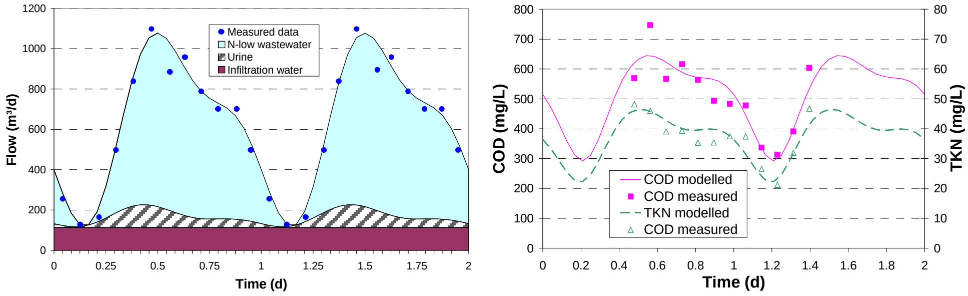


**Figure 1** Comparison of measured and modelled flow (left) and concentrations of COD and TKN (right).

### Derivation of general model parameters

Based on the estimation of the form parameters for all 19 data sets their dependence from the size of the AS plant (expressed as PE) has been investigated. A set of equations has been derived form correlations analysis for all form parameters (not shown). No dependency from the plant size could be found for $f_{N,max}$ and $\Delta t_{N2}$; the parameters describing the behaviour of the TKN maximum. Table 1 gives calculated values for the form parameters using the equation derived for plant sizes from 5'000 to 200'000 PE.

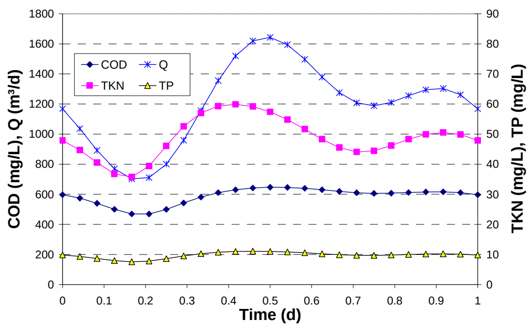


**Figure 2** Modelled diurnal variations for a 10'000 PE plant.

### Example for application

As an example the generation of diurnal variations for an AS plant with 10'000 PE is shown in Figure 2. The input data used are: daily influent dry weather flow (1'200 m³/d), daily mean concentrations of COD, TKN and TP (600, 50 and 10 mg/L, respectively), the flow and concentrations of infiltration water ($f_{Q,inf}$ = 0.25; 25, 5 and 0.5 mg/L for COD, TKN and TP, respectively) and urine ($f_{Q,inf}$ = 0.10; 300, 400 and 30 mg/L for COD, TKN and TP, respectively), and the form parameters according to Table 1.

**Table 1** general model parameter set.

| Parameter / PE | 5'000 | 10'000 | 20'000 | 50'000 | 100'000 | 200'000 |
|---|---|---|---|---|---|---|
| $f_{Q,min}$ (-) | 0.49 | 0.58 | 0.66 | 0.77 | 0.85 | 0.93 |
| $t_{min}$ (h) | 3.6 | 4.4 | 5.2 | 6.2 | 7.0 | 7.8 |
| $f_{Q,max}$ (-) | 1.43 | 1.37 | 1.30 | 1.21 | 1.14 | 1.08 |
| $t_{max}$ (h) | 10.8 | 11.3 | 11.9 | 12.6 | 13.1 | 13.7 |
| $f_{N,max}$ (-) | 1.60 | 1.60 | 1.60 | 1.60 | 1.60 | 1.60 |
| $f_{min,U}$ (-) | 0.28 | 0.37 | 0.46 | 0.58 | 0.67 | 0.76 |
| $\Delta t_{N1}$ (h) | 0.15 | 0.18 | 0.22 | 0.26 | 0.30 | 0.33 |
| $\Delta t_{N2}$ (h) | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 |

### Summary and conclusion

A simple method is presented to generate diurnal variations for input data for dynamic simulations in the case of no measured data are available. The input data required for the model are either available from the design process or simply to collect and are:

- the daily influent dry weather flow and mean concentrations of COD, TKN and TP,
- the flow and concentrations of infiltration water and urine (with flush water), and
- the form parameters as summarised in Table 1.

By using this model, realistic diurnal variations for influent data for dynamic simulations can be generated. Having the objective – to produce realistic data sets – in mind the results show an excellent quality. Alex et al. (2007) show how to get simulation results that are in compliance with the results from steady-state design models of AS plants. As an additional step this contribution links design of AS plants to fine tuning of planning using dynamic simulations by introducing a method to generate realistic influent data sets.

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