TOWARDS IMPROVED 1-D SETTLER MODELLING: CALIBRATION OF THE BÜRGER MODEL AND CASE STUDY

E. TORFS[1], P. VLASSCHAERT[1], Y. AMERLINCK[1], R. BÜRGER[2], S. DIEHL[3], S. FARÅS[3] AND I. NOPENS[1]

[1]BIOMATH, Model-based biosystem analysis and optimisation, Department of Mathematical Modelling, Statistics and Bioinformatics, Ghent University, Coupure links 653, B-9000, Ghent, Belgium,

[2]CI^{2}MA and Departamento de Ingeniería Matemática, Facultad de Ciencias Físicas y Matemáticas, Universidad de Concepción, Casilla 160-C, Concepción, Chile,

[3]Centre for Mathematical Sciences, Lund University, P.O. Box 118, S-221 00 Lund, Sweden.

INTRODUCTION

The operation and control of secondary clarifiers is still an important performance-limiting factor in conventional wastewater treatment plants (WWTP). Indeed, the performance of secondary clarifiers affects the effluent quality as well as the biomass inventory in the entire treatment plant. As biomass is the driving force for conversion processes and should be present at the desired location for the process to function in an optimal way, secondary clarifier operation will affect the performance of the entire treatment plant.

Furthermore, more intense rain events and longer draughts between rain events, caused by climate change, result in WWTPs that are temporarily overloaded both hydraulically and in terms of pollutant load. These peak events have a significant effect on the system’s biomass inventory. We therefore need to address the impacts of these new conditions by improving both infrastructure (improving design) and operational strategy and control. Mathematical modelling is a powerful tool to gain insight in how this is best accomplished. In this contribution we focus on operational optimization using simple ASM-based models (Henze et al., 2000).

Traditional layer models used to date for secondary clarifiers and available in most commercial simulation platforms (e.g. the model due to Takács et al. (1991)) do not sufficiently capture the settling dynamics. Under normal dry weather operating conditions, these models may behave reasonably well. However, their predictions under situations that diverge from normal operating conditions (e.g. peak flows due to rain events) loose realism. This is unsurprising since these models were not developed for the purpose we envision here, i.e. proper prediction of underflow and effluent concentrations and sludge blanket height under peak flow conditions. With this specific goal in mind, we require a more sophisticated model.

A new 1-D model which allows improved and more realistic simulation of secondary clarifiers has recently been presented (Bürger et al., 2011; Bürger et al., 2012). All implementation details can be found in Bürger et al. (submitted). This new model is based on the numerical solution of a governing partial differential equation (PDE) by appropriate methods.

The specific objective of this study is to calibrate this new 1-D model for a full-scale WWTP based on well-known settling velocity testing. Moreover, we illustrate the specific added value of the model's features on the predictions of biomass concentrations under both dry weather and storm weather conditions.

MATHEMATICAL MODEL

The new 1-D settling model is based on the following spatially one-dimensional PDE for the biomass C at time t and depth z from the feed level:

$$\frac{\partial C}{\partial t} = -\frac{\partial}{\partial z} F(C, z, t) + \frac{Q_{\mathrm{f}}(t) C_{\mathrm{f}}(t)}{A} \delta(t),$$

in which the first term on the right-hand side represents convective transport (due to feed flow, underflow and overflow) as well as particle transport due to gravity settling. The second term on the right hand side is a singular source term modelling the feed mechanism. (Q is volumetric flow rate, A is the constant cross-sectional area.)

To numerically solve the PDE, it is discretised by dividing the tank into a user-defined number of layers (N) around which a proper solids balance is imposed. The numerical solution of this PDE is quite challenging since the flux $F(C,z,t)$ is a discontinuous function of z. Simulating secondary clarifiers requires thus the implementation of a numerical scheme that deals with this discontinuous function in a mathematically correct way. Bürger et al. (2012) established this by computing the settling flux between two adjacent layers using the mathematically sound Godunov flux. This ensures that by increasing the number of layers, the numerical solution becomes more accurate and converges to the physically correct solution of the PDE. This is not the case for the traditional layer models used to date (e.g. Takács' model). In the Bürger model, the number of layers N can thus be set by the user depending on the desired accuracy and on the computational time available. Some guidance with respect to this will be provided in the full paper.

Additionally, the approach allows accounting for sediment compressibility and inlet mixing phenomena by extending the PDE by a compression function (d_{comp}) and a dispersion function (d_{disp}) which can be switched on or off by the user depending on the model study requirements. The resulting extended PDE is

$$\frac{\partial C}{\partial t} = -\frac{\partial}{\partial z}F(C,z,t) + \frac{\partial}{\partial z}\left(\left\{d_{\mathrm{comp}}(C) + d_{\mathrm{disp}}(z, Q_{\mathrm{f}}(t)\right\}\frac{\partial C}{\partial z}\right) + \frac{Q_{\mathrm{f}}(t)C_{\mathrm{f}}(t)}{A}\delta(t).$$

This study focuses specifically on the added value of the compression function since this has a significant impact on the prediction of the return sludge concentration and the height of the sludge blanket in the settler, which are two important operation and control variables during a storm weather event.

The following constitutive function is one way to describe the sediment compressibility with only two parameters.

$$d_{\mathrm{comp}}(C) = \begin{cases} 0 & \text{if } 0 \leq C < C_{\mathrm{crit}} \\ \dfrac{\rho_{\mathrm{s}} \,.\, \alpha \,.\, v_{\mathrm{s}}(C)}{g(\rho_{\mathrm{s}} - \rho_{\mathrm{f}})} & \text{if } C \geq C_{\mathrm{crit}} \end{cases}$$

With ρ_s and ρ_f the densities of the solids and the fluid, respectively, g the constant of gravity, v_s the settling velocity and α a compression parameter.

Compression will become active once the concentration exceeds a critical concentration (C_{crit}). Hence, the parameters α and C_{crit} together with those in the settling function v_s should be calibrated to fit the compressive and settling behaviour of a certain set of sludge. By measuring concentration profiles during batch experiments, De Clercq et al. (2008) have shown that letting C_{crit} depend on time during batch sedimentation, a better fit is obtained. Of course, this time-dependence should have some physical or biological explanation, which is not known yet.

CASE STUDY: THE EINDHOVEN WWTP

With a treatment capacity of 750,000 population equivalents (PE), the WWTP of Eindhoven (The Netherlands) is the largest treatment plant of Waterboard De Dommel and the third largest in The Netherlands. The incoming wastewater is treated in three parallel lines with a maximum hydraulic load of 26,000 m^3/h, each containing a primary settler, a biological tank and four secondary clarifiers. The biological tanks comprise a modified UCT configuration (Tchobanoglous et al. 2004). A process model of the plant, including the model by Takács to describe the secondary clarifiers, has been set up and calibrated for dry weather on an extensive set of online sensor data, in WEST (http://www.mikebydhi.com, Denmark; Vanhooren et al. 2003).

Although performing excellent in dry weather conditions, the full-scale plant model failed to give accurate predictions during storm weather conditions. Further study of the results showed that the model was not able to predict the dynamic sludge balance (division of sludge over biological tanks and secondary clarifiers), which is significantly distorted during storm weather conditions. Therefore, the more sophisticated Bürger model needs to be incorporated in the full-scale plant model to better predict the performance of the WWTP under storm weather conditions.

RESULTS AND DISCUSSION

Batch settling tests at different sludge concentrations were performed in the lab and the resulting data used to calibrate the traditional 10-layer settling model by Takács et al. (1991) and the new Bürger model. Figure 1 shows the data (symbols) and the corresponding predictions (solid lines) using the model by Takács. It can be seen that the Takács model is not able to accurately predict the settling data with one set of parameters for the different initial concentrations. Since the Takács model only accounts for hindered settling, the sludge will settle unrealistically well causing a severe under prediction of the suspension/liquid interface (sludge blanket height) at higher sludge concentrations.

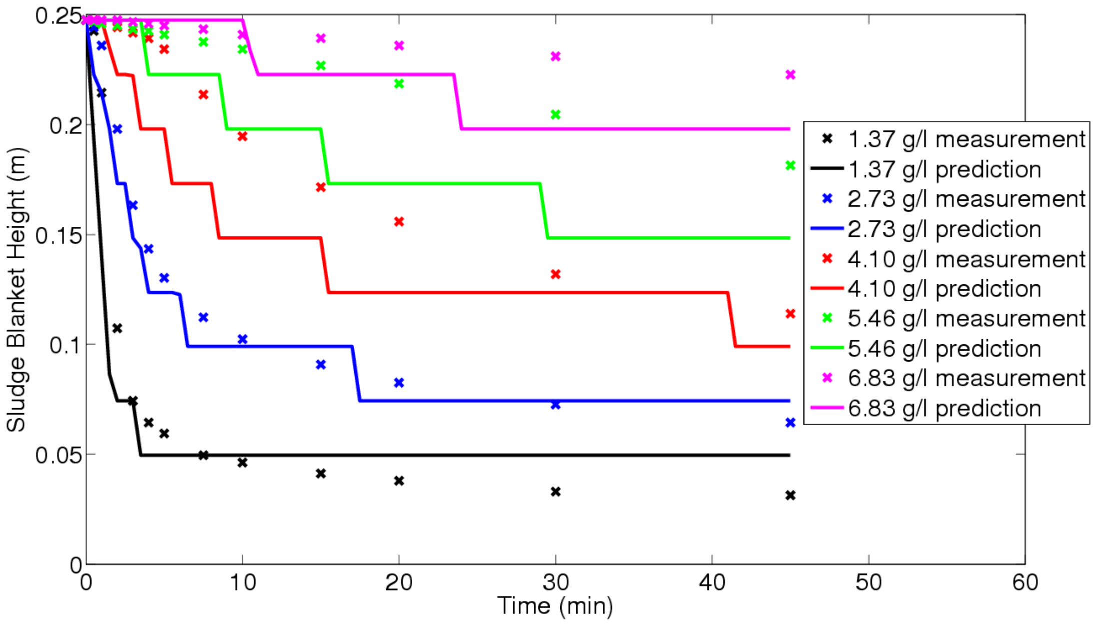
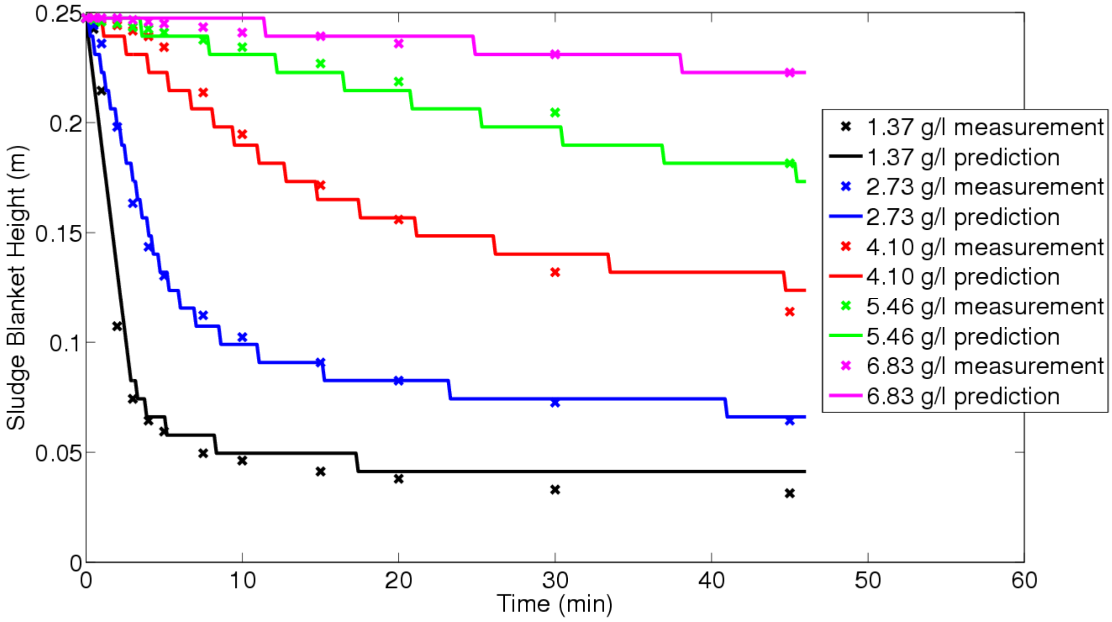


Figure 2 shows the same settling data (symbols) predicted by the Bürger model (solid lines) with the additional compression function active. By accounting for compressive settling, the height of the sludge blanket can be modeled in a more realistic way for all initial concentrations using a single set of model parameters.

This feature is especially interesting to use when variations in underflow concentrations occur (e.g. during storm events) as this will affect the biosolids concentration in the bioreactors and, hence, the conversion rates, which might lead modelers to calibrate kinetic parameters for a completely wrong reason and ruin the model's predictive power in e.g. a scenario analysis.



These results show that the new 1-D settler model allows describing the settling dynamics much more accurately with limited calibration effort. Obviously, further testing on other data sets is required, but these first results look very promising.

The presented calibrated clarifier model of Bürger will now be implemented in the full-scale model of the Eindhoven treatment plant in order to obtain better predictions of the settling behaviour under storm weather conditions. It will also be checked whether further calibration is needed.

REFERENCES

Bürger, R., Diehl, S. & Nopens, I. (2011). A consistent modelling methodology for secondary settling tanks in wastewater treatment. *Water Research*, **45:** 2247-2260.

Bürger, R.,Diehl, S., Farås, S. and Nopens, I. (2012). On reliable and unreliable numerical methods for the simulation of secondary settling tanks in wastewater treatment. *Comput. Chem. Eng*., **41**:93-105

Bürger,R. , Diehl, S., Farås, S., Nopens, I. & Torfs, E. (submitted). A consistent modelling methodology for secondary settling tanks: a reliable numerical method. Available at www.ci2ma.udec.cl/publicaciones/prepublicaciones/prepublicacion.php?id=85

De Clercq, J., Nopens, I. Defrancq, J. & Vanrolleghem, P. (2008). Extending and calibrating a mechanistic hindered and compression settling model for activated sludge using in-depth batch experiments. *Water Research,* **42:** 781-791

Henze, M., Gujer, W., Mino, T. & van Loosdrecht, M., 2000. Activated Sludge Models: ASM1, ASM2, ASM2d and ASM3. IWA Publishing, London.

Takács, I., Patry, G.G. & Nolasco, D. (1991). A dynamic model for the clarification-thickening process. Water Research, **25:** 1263-1271.

Tchobanoglous, G., Burton, F. and Stensel, H. (2003). *Wastewater Engineering: Treatment and reuse*, 4th Edition. Metcalf and Eddy, McGraw-Hill, New York, USA.

Vanhooren, H., M. Jurgen, A. Youri, C. Filip, V. Hans & V. Peter (2003) WEST: modelling biological wastewater treatment. *Journal of Hydroinformatics,* **5**:23.