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Hydrodynamic - biokinetic model integration applied to a full-scale WWTP

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Abstract: Mixing has a major impact on the performance of large bioreactors in wastewater treatment plants. Non-uniform distribution of components such as dissolved oxygen can influence the process rates and hence the overall performance. Therefore more detailed knowledge of the system with respect to local concentrations can be very useful for process optimization and control. This paper presents integration of Computational Fluid Dynamics (CFD) modelling with a biokinetic model for a full-scale activated sludge tank of a municipal wastewater plant. First, the hydrodynamic model was constructed, simulated and validated. Secondly, the Activated Sludge Model No. 1 (ASM1) model was integrated by means of scalars and source and sink terms in order to simulate the biological processes. Results of the combined CFD - biokinetic model are evaluated based on expert judgement as well as currently available data from the outlet of the reactor and sensors present in the reactor. Regions of bad mixing are observed and their impact on process rates is clearly shown as a major finding of the study.

Keywords: Wastewater treatment, Computational Fluid Dynamics, Activated Sludge Modelling, model integration

Introduction

Wastewater treatment plant (WWTP) modelling and activated sludge modelling in particular have become increasingly popular for plant design and optimization. However, in all these efforts, detailed spatial variations in the bioreactors are typically not taken into account although they could have a significant impact on the predictions. Thus these models are unsuitable for design evaluation, e.g. the influence of geometry, propellers and aerator design. Computational Fluid Dynamics (CFD) is one of the methods to account for spatial effects and study the influence of design parameters and phenomena at local scale. Currently, this modelling framework is typically used for design and troubleshooting. However, it is also a powerful tool to get more insight into the impact of local conditions on overall reactor performance.

Studies have shown that improved systemic model structures can be generated by incorporating knowledge from CFD (Alex et al., 1999 & 2002). Glover et al. (2006) evaluated the potential combination of CFD and activated sludge modelling (ASM) for both pilot and full-scale systems and concluded that CFD can provide a correct description of the oxygenation capacity of the system. Furthermore, Le Moullec et al. (2011) used CFD results to create a compartmental model for a pilot plant reactor showing better results than the conventional systemic approach, i.e. tanks in series (TIS), and requiring less computational power than CFD. Rehman et al. (2013) demonstrated the potential impact of sensor location in a badly mixed system on controller performance with such a CFD-derived compartmental model. In these previous studies, however, the ASM modelling was never truly integrated with the CFD modelling. This contribution presents the results of a fully integrated CFD-ASM model for a full-scale WWTP with a particular focus on the detailed modelling of the aeration system since it influences both the biokinetics and mixing and aeration constitutes the major part of operational costs in an activated sludge WWTP.

Material and Methods

Only one of the aeration tanks (AT) of the wastewater treatment facility in Eindhoven (The Netherlands) is modelled in this study. It concerns the outer ring of a circular carrousel type bioreactor where mixed liquor enters from the middle anoxic ring and leaves the reactor at the bottom after passing through the whole reactor in clockwise direction (Figure 1).

At first, the geometry of aeration tank was created in the commercial tool AutoCAD® taking into account all the details which can influence the reactor hydrodynamics. Next, the design was meshed with a commercial mesh generator tool (ICEMCFD). Different meshes (0.7 and 1.5 million cells) were generated (Figure 2) to check for grid independence. Subsequently, CFD simulations for the hydrodynamics part were performed in FLUENT (ANSYS). The mixture model was used for modelling the multi-phase (gas/liquid) flow and turbulence was modelled with the realizable k-ε model. Standard water and air properties (density, viscosity, etc.) were used and the effect of gravity was also incorporated in the solution of the equations.

In order to validate the hydrodynamics, velocity measurements were performed with the help of an Acoustic Doppler Current Profiler (ADCP) at two bridges (B1 & B2) (Figure 1). Measurements at the third bridge were too disturbed by aeration and could not be used. Time-averaged axial and tangential velocity components at different depths were measured at three radial locations at each bridge (A, B & C).

In the next step, the model was integrated with the biokinetic ASM1 model (Henze et al., 1987) by means of a user-defined function, given the objective to describe carbon and nitrogen removal. Computational requirements to achieve convergence for the steady-state solution increased significantly from a few hours to 1-2 days by including all the biokinetic equations. The influent flow and composition was collected from specific WWTP data to be used as inlet boundary conditions.

Results and conclusions

The absolute velocity magnitude derived from the ADCP-measured tangential and axial fluid velocity components along with CFD predictions at the B2 location are shown in **Error! Reference source not found.**. Velocity profiles at locations B1 and B2 are slightly over predicted, although the trends with respect to depth are captured quite well. This can have many reasons (e.g. data were collected under dynamic conditions whereas the model was run in steady state using the average inflow rate) and needs further investigation. In Figure 4 &Figure 5 the flow variation and non-ideal mixing in the reactor can be observed. Figure 6 shows the velocity vector plot in the vertical cross section of the reactor (in the aerated region). This clearly shows macromixing patterns with 2 major “dead” zones which will have lower mass transfer. These regions are averaged out when using simpler models (such as TIS modelling). These findings are similar to observations made by Gresch et al. (2011a, b).

Some results of the local concentrations of oxygen and ammonium from the ASM-CFD model are given in Figure 7Figure 8 clearly showing some non–uniformity. Figure 9 shows the impact of dead zones over the local concentrations of oxygen and ammonium. In the full paper, the impact of these findings on the way systems are currently modelled will be discussed as well as the link to sensor location. It is obvious that an integrated ASM-CFD model provides much more information about the detailed system behaviour which can be adopted in improved design and optimisation.

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Figures and Tables

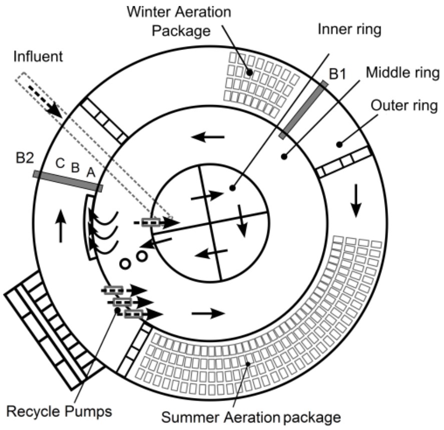

Figure 1 Design scheme of the reactor

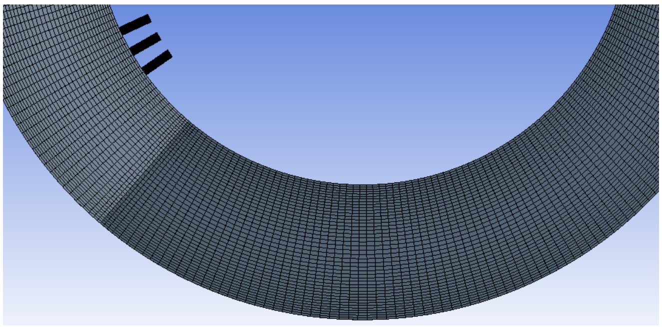

Figure 2 Top view of the reactor mesh

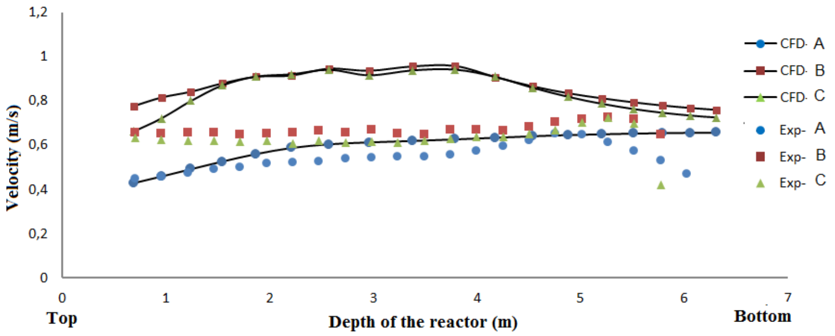

Figure 3 CFD compared to experimental measurements at location B2 (A: Near the inner wall, B: In the middle and C: Near the outer wall)

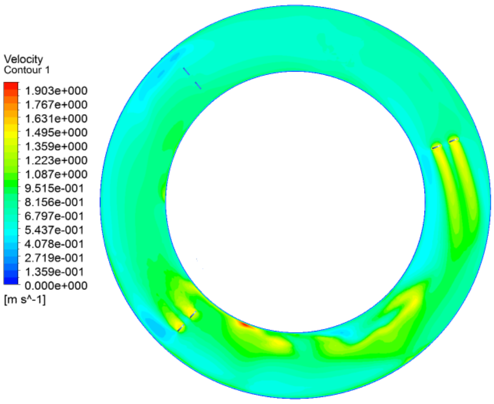

Figure 4 Velocity contour plot at 3m depth

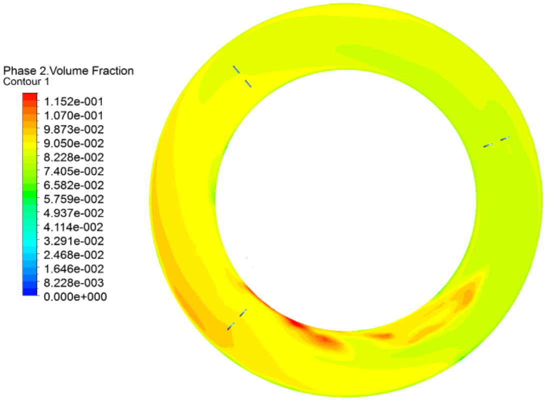

Figure 5 Air volume fraction contour plot at 3m depth

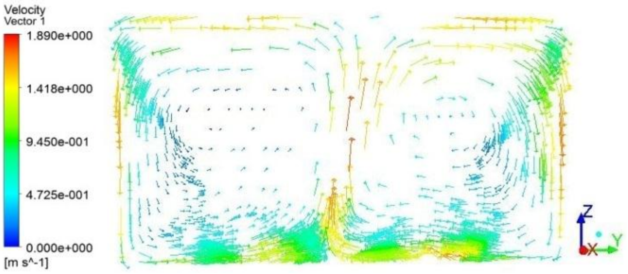

Figure 6 Velocity vector plot at the vertical cross-section in the aerated region of the reactor

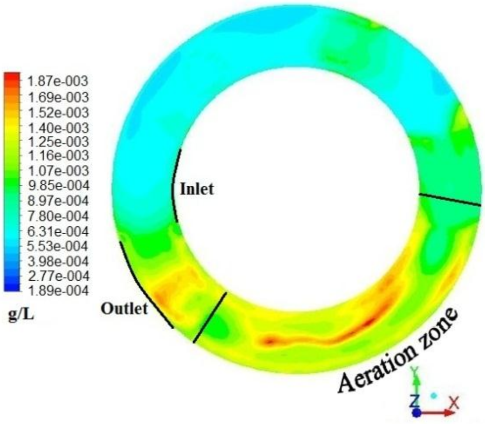

Figure 7 Oxygen conc. contour plot at 3m depth

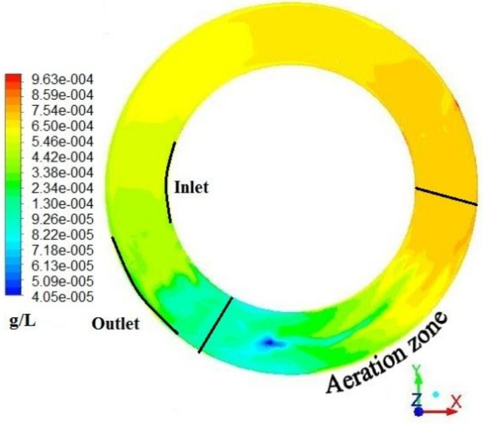

Figure 8 Ammonium conc. contour plot at 3m depth

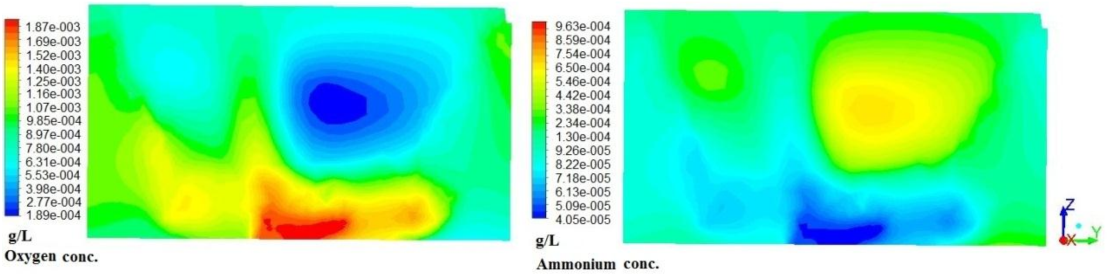

Figure 9 Oxygen and ammonium conc. plot at vertical cross-section of the reactor in the aerated region