UNIVERSITEIT GENT

FACULTEIT LANDBOUWKUNDIGE EN TOEGEPASTE BIOLOGISCHE WETENSCHAPPEN

Academiejaar 2002-2003

# COMPUTATIONAL FLUID DYNAMICS OF SETTLING TANKS: DEVELOPMENT OF EXPERIMENTS AND RHEOLOGICAL, SETTLING, AND SCRAPER SUBMODELS

# NUMERIEKE STROMINGSMECHANICA VAN BEZINKTANKS: ONTWIKKELING VAN EXPERIMENTEN EN SUBMODELLEN VOOR REOLOGIE, SLIBBEZINKING EN SLIBVERWIJDERING

door

**ir. Bob DE CLERCQ**

*Thesis submitted in fulfillment of the requirements*
*for the degree of Doctor (Ph.D) in Applied Biological Sciences*

*Proefschrift voorgedragen tot het bekomen van de graad*
*van Doctor in de Toegepaste Biologische Wetenschappen*

op gezag van

Rector: **Prof. Dr. A. De Leenheer**

Decaan: **Prof. Dr. ir. H. VAN LANGENHOVE**

Promotor: **Prof. Dr. ir. P. VANROLLEGHEM**

# Summary

During the last decades, most research focused on the biological treatment of wastewater. Settling tanks having the task to remove particulates by sedimentation only had a second priority. However, cleaned water leaving the wastewater treatment plant still contains particulates considerably contributing to the amount of waste, phosphorous and nitrogen compounds discharged into the receiving river. In this respect, a specialised European COST meeting on settling tanks (COST Action 624, 14-15 November 2002, Prague) acknowledged that there is still a considerable lack of process knowledge on settling tanks.

To fill these gaps in knowledge, the SediFloc project was started in 2000. It is a joint project of BIOMATH (Department of Applied Mathematics, Biometrics and Process Control) and PAINT (Particle and Interfacial Technology Group) at the Faculty of Agricultural and Applied Biological Sciences (Ghent University). SediFloc is an acronym merging "SEDImentation" and "FLOCculation". The ultimate goal of the project is to adequately model flocculation and deflocculation in the final settling tank, and accounting for hydraulic and physico-chemical influences. These modelling efforts increase our process understanding and better predictions of effluent quality should be possible.

As part of the project, this dissertation focused on the hydraulic and mechanical transport of solids in the settling tank. It aimed at implementing submodels for important physical phenomena into the Computational Fluid Dynamics (CFD) software Fluent (Fluent Inc., UK). CFD allows the computation of the velocity and solids distribution in the settling tank. In this respect, the solids removal mechanism was modelled and compared to literature. The development of submodels for solids sedimentation and rheology was conducted parallel to lab-scale experiments. Full-scale measurement campaigns, however, were essential to validate the model's predictions for local solids concentrations and flow field. Additionally, both lab-scale and full-scale investigations of sludge floc size distributions were performed.

Solids flow in the settling tank depends on many factors of which particulate properties, such as porosity and floc size, are very important. Above the solids blanket, discrete settling prevails; hence, the smaller the floc, the larger the drag it experiences, and the slower the floc settles. Process optimisation therefore consists of stimulating particle aggregation. Evaluation of any design modification improving flocculation is experimentally difficult because most particle sizers are unable to measure *in situ*. The Focused Beam Reflectance Method (FBRM) makes an exception though, and enables the *in situ* measurement using laser light reflection by particles. Preliminary experiments indicated that the focal point position of the laser largely influenced the size distributions obtained. For both inorganic and sludge particles, comparisons between FBRM, laser diffraction and image analysis revealed considerable discrepancies in size distribution attributed to the different measurement principles. The full-scale application of the FBRM to a secondary settling tank can be seen as the first attempt ever. At least for the case study conducted, the observation of invariable size distributions at high solids concentrations questioned the purpose of the feed well as flocculator. Possible hypotheses put forward are related to the zeolite dosage, high

concentrations and low shears prevailing in the settling tank. Dynamics could only be seen above the blanket where population balance modelling of the floc aggregation and breakup appears to be a promising application for the settling tank investigated.

Particulate properties not only affect discrete settling, but they also determine the rheological behaviour of the suspension. Viscous stresses are very important for the transport of momentum and, hence, they alter the velocity field and affect the solids distribution as well.

Because existing rheological models significantly differ in their model structure and associated parameters, research was conducted on three different full-scale treatment plant sludges. Appropriately measuring sludge rheology was found difficult due to solids settling and time-dependent thinning. This time-dependent thinning was shown to be important at high shear rates and resulted from a structural destruction of flocs. Experiments indicated that at least a two-level floc structure existed with different resistances to shear. Modelling time-dependent thinning in the solids blanket should not be considered as long as the particle size distribution observed remains invariant.

A new rheological model has been proposed that especially accounts for the sludge's behaviour at low shears. Comparison with widely used rheological models demonstrated that the solids blanket elevation is sensitive to viscosities at shears well below 1 $s^{-1}$. The results indicate the importance of rheology, its complexity and the fact that more research is needed to correctly model momentum transport in the solids blanket.

The proposed rheological model and the Takács solids settling velocity function calibrated by laboratory settling tests were implemented in a CFD model for a full-scale circular secondary settling tank. A 2D modelling approach was chosen to restrict the necessary computation time. Modelling the scraper mechanism in 2D inherently posed problems because its action is by definition 3D. Based on geometric considerations and the decomposition of the force exerted by the scraper on the fluid, a submodel for the scraper influencing the flow field was implemented in Fluent. The 2D modelling approach only allowed the consideration of the scraper's radial momentum. Comparison with both 3D simulations and measurements from literature confirmed the computed scraper velocities. Although small discrepancies between simulated and real scraper velocity occurred due to the way of implementation in Fluent, the submodel was believed to approximate the real 2D scraper behaviour. Simulations showed that the system's response on the scraper action very much depended on the rheology formulation applied. In this respect, the solids blanket elevation deteriorated when a yield stress occurred or high viscosities prevailed at low shears. Sludge acting as a Newtonian fluid did not pose problems though. This again stresses the importance of rheology on the solids transport efficiency in the settling tank.

Validation of the CFD model was conducted without applying this scraper submodel and with unsteady inlet boundary conditions. The latter allows a more powerful model validation. Simulated pseudo-steady-state solids concentration profiles corresponded well with measurements without any additional calibration. With strongly varying inlet flow rates, the predictions of underflow and effluent concentrations were good as well and only demanded for a lowering of the non-settleable solids concentration in the Takács settling velocity relation. The implementation of a flocculation submodel should resolve this issue though. The trend of solids blanket depth was also well resolved. On the other hand, hydrodynamics were confronted with flow-through curves measured under dynamic inflow conditions. Although simulated and measured flow-through curves showed similar features, the system's response did not correspond to the observed time of peak occurrence. Simulated tracer concentrations were too high as well. Discrepancies were believed to originate from a too small diffusion assumed. Future 3D simulations, or 2D simulations that account for swirl, and a proper turbulence model are believed to resolve the flow-through curve validation problems. Due to its large influence on the flow-through curve, the uncertainty on the solids distribution in the settling tank should be reduced by additional solids concentration measurements.

In conclusion, this dissertation focused on different aspects of the settling tank. As a result, much process knowledge has been gained, and CFD submodels were set up for solids settling, rheology and the scraper mechanism. Considerations about particle size distribution modelling have been made as well. The research conducted also demonstrated that CFD modelling in 2D enables the accurate prediction of solids distribution, whereas the hydrodynamics probably demand 3D modelling or 2D models that account for swirl effects.