Summary

In municipal wastewater treatment, the wastewater is transformed in clean water and solid matter. In order to get the clean water the solids are most often separated from it by gravity in a clarifier. The clarifier is therefore crucial for the overall performance; improper operation results in a washout of solids, increasing the concentration of effluent particulate pollutants and involuntarily wasting mixed liquor. Violation of effluent permits and deterioration of the receiving waters is then the unavoidable result, with long-term release of nitrogen, phosphorus and COD as the solids degrade.
The settling characteristics of activated sludge are obviously important for the performance of the clarifier and, hence, the efficiency of the wastewater treatment plant. The operation of a clarifier can be improved by a better understanding of the settling properties.

This dissertation focuses on the settling properties and a 1D batch/continuous settling model. It aimed at finding a model that describes this settling behaviour, i.e. a batch settling model, and to develop, to this end, measurement techniques that give more information about the settling behaviour. Two detailed full-scale measuring campaigns were performed and used as input for a 1D continuous settling model that describes the full-scale behaviour of a circular clarifier and that incorporates the batch settling model.

Novel measurement techniques were developed, which give solids concentration profiles and pressure profiles with sufficient accuracy during the batch settling of activated sludge.
A novel non-invasive measurement technique borrowed from nuclear medicine, using a solids radiotracer and gamma cameras was used to obtain high time and spatial resolution solids concentration profiles during the batch settling of activated sludge in a pilot-scale column with a height of 1 m. This non-invasive technique does not disturb the settling process, does not alter the settling characteristics of the activated sludge, gives profiles every minute, and is capable of measuring in a range of 0-25 g/l with high accuracy. Dynamic solids concentration profile measurements were performed for sludges of 2 different municipal wastewater treatment plants, and at 3 different initial solids concentrations. The high-resolution profiles give a quantitative representation of the settling process and can be used for a better understanding and modelling of the process. The results reveal hindered and compression settling and show a time-dependent compression solids concentration.
For measuring the excess pore pressure profiles during batch settling of activated sludge, a pilot-scale set-up has been built, which consists of a settling column, a water-filled column and a differential pressure transducer with sufficient accuracy. The pressure of the water in the sludge, i.e. the pore pressure, was measured at 15 points

along the height of the settling suspension. The measurements are however not as good and as detailled as the concentration profile measurements but they confirm compression settling from the sludge blanket height downwards. More work is needed to improve this measurement technique.

The high-resolution batch settling experiments were used to develop a fundamental batch settling model, i.e. a model which is based on the fundamental mass and force balances for water and solids. Such a model is generally described by two functions, a hindered settling flux function and an effective solids stress function. Observed initial settling velocities and inverse modelling calculations of the experimental data were used to obtain a relationship for these two functions. This resulted in the power function of Cole (1968), limited by imposing a maximum settling velocity, for the hindered settling flux function and a logarithmic function for the effective solids stress function, together with a time-dependent compression solids concentration. This time-dependent compression solids concentration is located at the sludge blanket height and can be readily calculated. The resulting batch settling model excellently describes the settling behaviour and this for sludges originating from two different wastewater treatment plants. When the settling behaviour, i.e. the parameters of the batch settling model, is identified, it can be used as the basis for (1D, 2D or 3D) models which attempt to describe the full-scale behaviour of a clarifier. Since the batch settling model describes the settling behaviour better than any other reported model, these (1D, 2D or 3D) models can be used e.g. to make better designs and set-up better control strategies.

For calibration and validation of a 1D continuous settling model, which incorporates this batch settling model, two detailed full-scale measuring campaigns were performed, one for building and testing and one for validating. These provided measurements of solids concentration profiles in the clarifier, sludge blanket heights, concentrations of the relevant flows (feed, recycle and effluent), and batch settling curves at different solids concentrations and sludge volume index (SVI). One campaign was performed on an operational secondary circular centre-fed clarifier of a municipal WWTP. The other one was performed on a primary circular centre-fed clarifier of another municipal WWTP, which was used as a secondary clarifier. Since the effluent of this test clarifier was sent to the aeration thanks, the latter set-up allowed to have overflow of sludge (no effluent restrictions). During the studied period, the feed and recycle flow rates were changed frequently and the settling properties changed. The study showed that it is not straightforward to perform full-scale experiments: it is impossible to set all variables to desired values (feed solids concentration, settling properties) and the daily operation of the WWTP may not be disturbed, but on the other hand it influences the experiments (e.g. maintenance works had effect on settling properties and feed solids concentration). There is not always someone present on-site to solve problems, one needs reliable and appropriate sensors/pumps that remain stable with time, ... Nevertheless, the results were very satisfying. The effect of variations in recycle and feed flow, feed solids concentrations and settling properties could in most cases be clearly identified and confirmed the expectations. The two sets of full-scale experimental data were used to build, test and validate a 1D continuous settling model.

The settling behaviour of the activated sludge of the full-scale experimental data was predicted with the batch settling model on the basis of the measured batch settling curves. Instead of using a maximum settling velocity for the Cole (1968) hindered settling flux function, the Vesilind function (Vesilind, 1968) was used for the lower solids concentrations, together with the condition that the flux function is differentiable at a transition solids concentration between both functions. The agreement with the experimental batch settling curves is excellent. The batch settling model is incorporated in the 1D continuous settling model by the following modifications: (i) setting the compression solids concentration equal to the concentration that is found at a location of 5 layers below the location of the highest concentration gradient of the simulated solids concentration profile, (ii) defining the feed layer location at the compression solids concentration location and (iii) making a parameter of the effective solids stress function dependent on the average solids concentration in the clarifier. Simulations with the 1D continuous settling model showed the need for the addition of a dispersion term to the model. Two dispersion coefficients, one in the clarification zone and the other in the thickening zone, were added to the model and estimated with measured solids concentration profiles. Dispersion clearly improved the simulation results but the model needs further improvement. When this is done, the 1D continuous settling model can be used for operation and control.