Summary

Biological techniques for nitrogen removal from wastewater streams that convert ammonium to nitrite only (i.e. the so-called nitritation reaction) and prevent further oxidation of nitrite to nitrate, display distinct advantages in comparison to conventional nitrification-denitrification over nitrate. In the SHARON process, stable nitrite formation is achieved by working at high temperature (about 35°C) and neutral pH (about 7). An appropriate sludge retention time is maintained to keep in ammonium oxidizing biomass, while washing out the nitrite oxidizing biomass, which grows slower than the ammonium oxidizing biomass under these conditions. In the last few years, the coupling of a partial nitritation process, in which about 50% of the ammonium is converted to nitrite, while the remaining 50% is not converted, with a so-called Anammox process, in which ammonium and nitrite are converted to nitrogen gas, has gained a lot of interest. With a combined partial nitritation-Anammox process, low nitrogen effluent concentrations can be obtained, while up to 63% aeration cost savings are realized, the need for external carbon source is completely omitted and sludge and CO_2 productions are very low in comparison with conventional nitrification-denitrification over nitrate.

The SHARON partial nitritation process for coupling with an Anammox process, is the focus of this thesis. It is very well suited to treat wastewater flows with high ammonium concentrations. A typical application is the reject water stream, originating from sludge digestion, dewatering and/or drying. In chapter 2, the SHARON partial nitritation process is compared with other biological treatment techniques for reject water. It is clear that the process selection strongly depends on the specific conditions and requirements in terms of efficiency, effluent quality, process compactness and associated operating and investment costs. The best option is mostly found among bio-augmentation techniques and processes based on nitritation, the combined SHARON-Anammox process being an example of the latter.

An extensive model of a SHARON reactor has been developed (chapter 3), describing both liquid and gas phase dynamics, with special attention devoted to pH calculation, for which a general procedure has been developed. The resulting model has been validated at the full-scale SHARON reactor in Sluisjesdijk. For the simulation work carried out in this thesis, it has been judged sufficiently accurate to qualitatively represent the behaviour of a realistic SHARON reactor.

As a good knowledge of process dynamics is essential for control purposes, a theoretical study has been carried out with respect to the occurrence of multiple equilibrium points in SHARON partial nitrification models. The stability of these equilibrium points has been analyzed as well (chapter 4). Particular attention has been paid to the influence of microbial characteristics and to the translation of these findings into practical implications. Three equilibrium points have been found in case nitrite oxidizers are not limited by ammonium and no inhibition takes place: a wash-out point, an equilibrium point corresponding with only nitrite formation and an equilibrium point corresponding with nitrate formation. The dilution rate and the influent ammonium concentration determine which equilibrium point is (quasi) globally asymptotically stable and will usually be reached. Further results indicate that product inhibition does not affect the number of equilibrium points, while substrate inhibition is clearly a source of additional equilibrium points.

The usefulness of controlling a SHARON reactor with fixed design in view of its coupling with an Anammox process, is addressed in chapter 5. Several possible operating modes for the SHARON reactor, differing in control strategies for O_2, pH and the produced nitrite:ammonium ratio and based on regulating the air flow rate and/or acid/base addition, are systematically evaluated. The results are quantified through an operating cost index (OCI). Best results are obtained by means of cascade feedback control of the nitrite:ammonium ratio produced by the SHARON reactor through setting an O_2 set point that is tracked by adjusting the air flow rate, combined with single loop pH-control through acid/base addition.

In chapter 6, the issue of coupling models with different state variables is addressed. The continuity-based interfacing method (CBIM) is applied to study the effect of reject water treatment with a SHARON-Anammox process on a plant-wide scale. The Benchmark Simulation

Model no. 2 (BSM2) is used to simulate the behaviour of a complete wastewater treatment plant, not only including the activated sludge process, but also the processes describing sludge treatment. The CBIM approach is followed to develop interfaces between the models ASM1/-SHARON, SHARON/Anammox and Anammox/ASM1. At the same time, this generally applicable approach is further refined and particular issues when coupling models in which pH is considered as a state variable, are pointed out.

The actual plant-wide evaluation of reject water treatment is described in chapter 7. A scenario without sludge treatment and therefore without reject water was compared with one in which untreated reject water is recycled to the main plant and one in which the reject water is treated with a combined SHARON-Anammox process before recirculation. It is shown that recirculation of the untreated reject water stream, representing 21% of the total influent ammonium load, unacceptably worsens the total nitrogen concentration in the effluent of the BSM2 WWTP. The effluent quality improves significantly by treatment of the reject water stream with a SHARON-Anammox process before recirculation. Although the yearly operating cost savings resulting from reject water treatment with a SHARON-Anammox process as such only partly warrrant the associated investment costs, it is a promising option to meet the required effluent limits and prevent the WWTP from loosing its permit.

In chapter 8, the control strategy of the SHARON reactor for treatment of the BSM2 reject water, is optimized and the interaction between reactor design and the usefulness of control is assessed. The best performance of the SHARON and Anammox reactor in terms of Anammox effluent quality (ammonium) is obtained with combined cascade O_2-control and pH-control in the SHARON reactor. However, it has also been shown that a better conversion efficiency of the combined SHARON-Anammox process does not necessarily results in lower operating costs on a plant-wide scale. Besides, at different SHARON reactor volumes, different control strategies have been found optimal. For a moderately large reactor, good results have been obtained by controlling the aerobic retention time through cyclic reactor operation, and at the same time applying oxygen control during the aerobic phases. When using a smaller reactor volume, pH control becomes necessary as well.

Chapter 9 closes this thesis with general conclusions and perspectives for future research.