Impacts of separate rejection water treatment on the overall plant performance

B. Wett* and J. Alex**

* Department of Environmental Engineering, University of Innsbruck, Technikerstr. 13, A-6020 Innsbruck, Austria (E-mail: bernhard.wett@uibk.ac.at)

** Institute for Automation and Communication, ifak Magdeburg, Steinfeldstr. 3, D-39179 Barleben, Germany

Abstract A separate rejection water treatment appears as a high-tech unit process which might be recommendable only for specific cases of an upgrading of an existing wastewater treatment plant. It is not the issue of this paper to consider a specific separate treatment process itself but to investigate the influence of such a process on the overall plant performance. A plant-wide model has been applied as an innovative tool to evaluate effects of the implemented sidestream strategy on the mainstream treatment. The model has been developed in the SIMBA environment and combines acknowledged mathematical descriptions of the activated sludge process (ASM1) and the anaerobic mesophilic digestion (Siegrist model). The model’s calibration and validation was based on data from 5 years of operating experience of a full-scale rejection water treatment. The impact on the total N-elimination efficiency is demonstrated by detailed nitrogen mass flow schemes including the interactions between the wastewater and the sludge lane. Additionally limiting conditions due to dynamic N-return loads are displayed by the model’s state variables.

Keywords Ammonia; energy balance; nitrogen return load; plant-wide modelling; rejection water; sludge digestion

Introduction

As is commonly known the internal nitrogen return load from dewatering digested sludge represents a significant load addition that a wastewater treatment plant has to cope with. Recent research has focused on the development of biological partial flow strategies adapted to the extreme ammonia concentration of rejection water (e.g. Teichgräber, 1993; Kolisch, 1996; Wett et al., 1998; Koch et al., 1999; Mulder et al., 2000). Hence different types of such a unit process are well established in the literature but their impact on the overall plant performance is difficult to generalise about. The impact on the total system behaviour addresses various fields like treatment efficiency, alkalinity and energy balance (oxygen input and methane output). In order to identify these effects data from 5 years of operating experience are used in conjunction with a model of the entire treatment plant.

Case study and measurement data

The WWTP Strass (200,000 pe) provides a two-stage biological treatment (A/B plant). The high loaded A-stage with intermediate clarification and a separate sludge cycle eliminates 55% of the organic load. N-elimination in the low loaded B-stage is operated by pre-denitrification. Aeration and internal cycle are controlled by on-line ammonia measurement. Rejection water from sludge digestion is treated separately with an efficiency of 90%, which reduces the internal nitrogen return load from 16.3% to 1.6%. Figure 1 resumes the nitrogen fluxes between the 4 main subsystems of the treatment plant Strass – high loaded A-stage, low loaded B-stage, sludge treatment and a SBR for rejection water treatment (2 months mean values, June and July 2000).

All presented nitrogen fluxes have been calculated from flow measurements and on-line
concentration measurements (wastewater) or analyses from composite (wastewater) and grab samples (sludge, biogas). The resulting nitrogen mass balance shows a gap of about 0.33 g N/pe (3.4%). Attention has been paid to possible stripping effects during sludge treatment. Analyses of the biogas detected a mean nitrogen release of 0.37 g N/pe (3.8%) and after digestion ammonia stripping (about 0.20 g N/pe or 2%) from the stored rejection water and dewatered sludge occurs. It should be noted that sludge conditioning with lime causes a pH value of about 12 which drives ionised ammonia NH$_4^+$ almost completely to the unionised volatile form NH$_3$.

The flow chart indicates a nitrogen flux of 43.4% of the influent load bound to the waste sludge flow. The mass of total suspended solids in the daily waste sludge flux from the A-stage is almost twice as high as that from the B-stage. This difference might be traded off by the fact that secondary sludge shows higher nitrogen fractions than highloaded A-stage sludge and primary sludge. Relatively high nitrogen content in secondary sludge is reported by Jardin et al. (2000) – the average nitrogen content per g volatile suspended solids is 2.5 to 5 times higher in secondary sludge than in primary sludge. The same authors report from data analyses of 200 wastewater treatment plants in Germany resulting in an average return load from sludge treatment of 1.48 g N/pe. Due to the 2-stage-concept and a long retention time in the digesters the return load at Strass achieves 1.6 g N/pe (16% of the nitrogen influent load). Separate rejection water treatment lowers the ammonia load to 0.16 g N/pe and the residual nitrite flux is reduced instantly in contact with the raw wastewater.

The observed increase of the yearly nitrogen elimination efficiency of the mainstream treatment at Strass was 11% from 78% to 89% (Figure 2). The operation of the side stream process has two load effects on the mainstream treatment, significant reductions on both the nitrogen return load and the problematic load variations. Since sludge dewatering facilities are usually operated only during daytime working hours the nitrogen return load superimposes with the peaks of daily influent load variations.

Another benefit from separate rejection water treatment concerns the alkalinity balance of the total system. Additional H$^+$ proton fixation due to enhanced denitrification and equalisation of the H$^+$ production during nitrification result in an increase of the buffer capacity. Especially in the case of soft water, as at Strass, the pH-value is prevented from decreasing to a nitrification rate limiting range around 6.5 (Figure 3).

The main contributions to the energy balance are the energy demand of the aeration system and the energy production from biogas. A relevant reduction of the stoichiometrical oxygen demand can be achieved if the nitrogen from the rejection water is almost exclusively elimi-
nated via the nitrite route. A separate treatment system for rejection water with high ammonia concentrations and temperatures can take advantage of inhibitory conditions for nitrite oxidisers. An additional potential for energy saving can be detected in the mainstream treatment where less intensive aeration for nitrification minimises coupled aerobic sludge stabilisation processes. The total saving in aeration energy at Strass sums up to about 11% from 25.0 kWh/1000pe·d in 1996 to 22.2 kWh/1000pe·d in 2000. Less aerobic sludge stabilisation might also enhance the methane production. No significant increase of the biogas output has been revealed by the mean annual measurement values (Figure 4) or by modelling.

**Plant-wide modelling**

The plant-wide model has been developed in the SIMBA environment based on Matlab-Simulink (SIMBA, 1999). Unit processes of wastewater treatment and sludge thickening and dewatering are calculated by model blocks according to Activated Sludge Model No.1 compounds-, parameters- and processes conventions (Henze et al., 1987). The anaerobic degradation of dissolved and particulate organic substances can be roughly subdivided into four phases:

![Figure 2](https://iwaponline.com/wst/article-pdf/48/4/139/423392/139.pdf)

**Figure 2** Improvement of the N-elimination efficiency after the implementation of the side stream process

![Figure 3](https://iwaponline.com/wst/article-pdf/48/4/139/423392/139.pdf)

**Figure 3** Measured daily minimum and maximum pH-values of the influent- and effluent flow at the WWTP Strass indicating the influence of the rejection water treatment on the alkalinity balance
1. hydrolysis
2. acidogenous phase (fermentation)
3. acetogenous phase
4. methanogenous phase

To find a model which is suitable to describe these steps, it can be stated that today a wide range of model proposals for the anaerobic digestion processes are available. The applied sludge digestion model follows the suggestions of Siegrist et al. (1993) which consider the processes and conditions of the mesophilic sludge fermentation in a sufficient degree and is at the same time simplified enough to serve as a model base for simulations. This model allows the prediction of the following core parameters:

- degree of stabilisation
- biogas flowrate and composition
- pH-value and alkalinity
- concentrations of volatile organic acids
- nitrogen release

Siegrist et al. improved this model to a total of 20 compounds. The model is based on physical, chemical and biological processes and is valid for a temperature range of 30 to 40°C. The biological processes of the mesophilic sludge fermentation are realised in the model by 5 biomass types. The decay rates for the biomass given in the original model seem to be very high compared to other reference literature data. This leads to very low biomass concentrations and accordingly to an indifferent performance in the case of high load variations. For this reason, modified decay rates from literature were used (Ogurek, 2000).

Aiming to achieve the compatibility of both models and accurate mass conservation, conversion blocks have been introduced (see Appendix). Finally the model calculates the system with a total biological retention time of about 2 months either with a closed cycle between the wastewater lane and the sludge lane or with a reduced load from a separate rejection water treatment (Figure 5). For the calculation of activated sludge processes a standard kinetic parameter set (Bornemann et al., 1998) has been applied and unknown input variables (wastewater characterisation) have been calibrated.

Results and discussion
The first simulation run describes the conventional operation without rejection water treatment. Figure 6 presents a plot of the nitrogen mass flow scheme created by the new SIMBA output graphic tool. Total Kjeldahl nitrogen and oxidised nitrogen (NO₂ + NO₃) are shown

![Figure 4](https://iwaponline.com/wst/article-pdf/48/4/139/423392/139.pdf)
separately. The calculated total nitrogen treatment efficiency results in an elimination rate of 75.7%. Separate rejection water treatment considered in the second simulation run improves the N-elimination rate up to 82.3%. A satisfying fit with data from the modelled operation period (83.7% in Figure 1) has been achieved. The calculated improvement of the N-elimination efficiency of about 7% is significantly below the measured mean annual improvement of 11%. This difference can be explained by the fact, that the relief from the N-return load is more beneficial at cold wastewater temperatures. During the modelled operation period (June and July 2000) the temperature showed a mean value of 14.3°C while during the highloaded winter season it is about 8 °C. A simulation to those run under similar conditions presented in Figure 6 but at a temperature of 8°C indicates an increase of the N-elimination of 9.3% due to separate rejection water treatment.

Still the question remains whether such an improvement can be achieved by less effort. A storage tank to equalise the peak loads from sludge dewatering instead of a separate treatment would be the simplest measure. Therefore the next simulation run considers the same conditions as above but assumes a total equalisation of rejection water (i.e. a constant return load during 24 hours). The calculated results reveal no significant benefit from such a measure. The efficiency of the nitrogen elimination is improved by 0.6% in the winter and 2.2% in the summer respectively (Table 1). These results have been confirmed by experiences at the WWTP Strass where tentative night-shift operation of sludge dewatering facilities showed no significant effects on the performance of the nitrogen elimination.

In Figure 7 a closer look at the dynamics of nitrogen elimination processes under the influence of load peaks from sludge dewatering is presented. The first plot shows rather constant nitrate concentration profiles in the pre-denitrification zone (0 mg NO₃-N/l) and at the effluent (5–6 mg NO₃-N/l). In case of conventional operation (peak loads of untreated rejection water) an increasing ammonia effluent concentration (controlled variable) signals a demand for additional aeration volume. As soon as the aeration is switched on in the pre-denitrification zone, the nitrate concentration is immediately driven up to more than 12 mg NO₃-N/l and still to more than 10 mg NO₃-N/l in the effluent. The delayed decrease of the nitrate concentration indicates a lack of readily degradable carbon.
Another limiting condition is demonstrated by the alkalinity profiles. During the same period of extreme ammonia loading most of the buffer capacity in the nitrification zone is used (decrease of alkalinity from 1.4 mM/l to 0.4 mM/l). This decline of alkalinity implies a significant decrease of the pH-value and a slow-down of the nitrification rate.

Finally the impact on the energy balance of the total plant needs further investigation.

Table 1 Simulated efficiencies of the nitrogen elimination at the WWTP Strass applying different operation modes: Conventional treatment without any specific measures, load equalisation by storage and finally separate rejection water treatment

<table>
<thead>
<tr>
<th>Season</th>
<th>Operation</th>
<th>N-elimination (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>Conventional</td>
<td>75.7</td>
</tr>
<tr>
<td></td>
<td>Equalisation</td>
<td>77.9</td>
</tr>
<tr>
<td></td>
<td>Rejection water treatment</td>
<td>82.3</td>
</tr>
<tr>
<td>Winter</td>
<td>Conventional</td>
<td>65.9</td>
</tr>
<tr>
<td></td>
<td>Equalisation</td>
<td>66.5</td>
</tr>
<tr>
<td></td>
<td>Rejection water treatment</td>
<td>75.2</td>
</tr>
</tbody>
</table>
State variables (degradable organic compounds) of the calibrated model reveal that digestion of the waste sludge of the B-stage contributes only about 20% to the total methane production. Hence the potential for improvement of the methane output is not significant within a 2% range. The saving of aeration energy exclusively in the B-stage due to advanced denitrification and reduced nitrification was calculated to be 17%.

Conclusions
In order to offer a detailed insight into the plant-wide system behaviour, nitrogen flow charts have been presented and energy fluxes have been investigated. The improvement of the nitrogen elimination of the entire treatment plant with separate rejection water treatment is in the range between 7% (simulated at high wastewater temperatures) and 11% (measured annual mean value). The relief from the N-return load results in a higher process stability. Otherwise high N/COD ratios might cause – as demonstrated in the case study – decreasing denitrification rates and therefore a lack of alkalinity and as a further consequence a slowdown of the nitrification rate. A storage tank for an equalisation of the return load instead of a separate treatment appears to be insufficient because during night-time municipal wastewater lacks an additional denitrification capacity (low concentrations of organic matter).

References

Appendix
Conversion of COD-fractions at the two interfaces between the activated sludge model (ASM1) and the anaerobic digestion model of Siegrist (Ogurek, 2000)