

Case Study on the Implementation of Deammonification for the Process Water Treatment of Munich WWTP's

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Abstract

The two-staged WWTP „Gut Grosslappen“ has a capacity of 2 mio. PE. It comprises a pre-denitrification in the first stage using recirculation from the nitrifying second stage. A residual post-denitrification in a downstream sand filter is required in order to achieve the effluent standards. Presently the process water from sludge digestion is treated separately by nitrification / denitrification. Due to necessary reconstruction of the biological stages, the process water treatment was included in the future overall process concept of the WWTP. A case study was conducted comparing the processes nitritation/denitritation and deammonification with nitrification/denitrification including their effect on the operational costs of the planned main flow treatment. Besides the different operating costs the investment costs required for the process water treatment played a significant role. Six cases for the process water treatment were compared. As a result, in Munich deammonification can only be recommended for long-term future developments, due to the high investment costs, compared to the nitritation/denitritation alternative realizable in existing tanks. The savings concerning aeration, sludge disposal and chemicals were not sufficient to compensate the additional investment costs. Due to the specific circumstances in Munich, for the time being, the use of existing tanks for nitritation/denitritation proved to be most economical.

Keywords Deammonification, Nitritation, Reject Water Treatment, Process Water Treatment, Two Stage Biological Treatment

Introduction

The Münchner Stadtentwässerung operates two wastewater treatment plants: WWTP I “Gut Grosslappen” and WWTP II “Gut Marienhof” with a capacity of 1 and 2 million population equivalents (PE) respectively. Both treatment plants consist of a mechanical pretreatment stage prior to two biological activated sludge stages. Since 2002, the effluent requirement for total nitrogen is as low as 13 mg N/L. Therefore extensive process technology is needed. Both WWTPs are currently operated with a two-staged denitrification concept combining a recirculation-denitrification in the first biological stage with a residual denitrification in the downstream sand filter (Böhm, 2007). Methanol is added to the sand filter as an external carbon source for post-denitrification. A simplified flow scheme of the process technology at WWTP I is depicted in Figure 1.

At WWTP I the dry weather influent amounts to approx. 3-3,5 m³/s, the combined influent (including stormwater) to a maximum of 10 m³/s. Raw wastewater is mechanically pretreated in screens, aerated grit chambers and primary settlement tanks. Primary sludge is thickened before reaching the anaerobic sludge treatment unit. The first biological stage consists of a cascade with

an anoxic denitrification zone (recirculation-denitrification) and an aerated zone with fine bubbles for COD removal. In the second cascaded stage nitrification takes place. Effluent of the second stage is partly returned to the inflow of the first biological stage for denitrification. A sand filter for the removal of suspended solids and pre-denitrification as a third stage is operated since 2008. Phosphorous removal is achieved through chemical precipitation in the aerated grit chamber and in the outflow of the second biological stage.

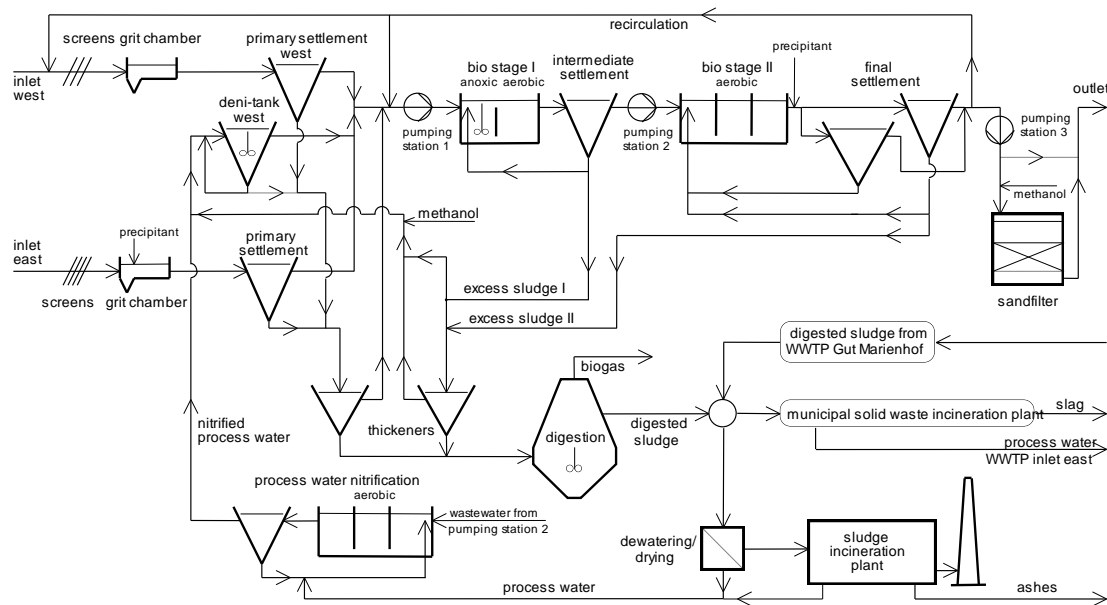


Figure 1: Simplified Process Technology Diagram of WWTP I “Gut Grosslappen”, Munich, Germany

Present process water treatment

The primary and secondary sludge produced at WWTP I is mechanically thickened prior to stabilization in mesophilic anaerobic digesters. The mean sludge residence time (MRT) is approx. 20 days. The digested sludge of WWTP II “Gut Marienhof” is pumped to WWTP I as well.

Currently, approximately 75 % (mean value) of the digested sludge of both WWTPs is treated and incinerated at a sludge incineration plant (SIP) located at WWTP I. The sludge is dewatered, partially dried and incinerated in a fluidized bed furnace. The dewatering and drying liquor produced at the SIP is collected for separate process water treatment. Due to local conditions this process water is mixed with cooling water, low in nitrogen, resulting in slightly lower overall nitrogen concentrations compared to typical process water.

The remaining sludge is pumped to a municipal combined heat and power plant (CHP) in Munich for dewatering and combustion. Sludge liquor produced at the centrifuges in the municipal CHP is currently not collected separately but returned to the WWTP I via the common combined sewage system. In the future, it is planned to treat the entire sludge amount of both WWTPs at WWTP I (SIP and CHP). Therefore, the entire dewatering liquor will be available for separate process water treatment and further relieve the main stream. It is expected that in this future scenario the dilutive cooling water can be separated from the process water.

The separate treatment of process water from dewatered anaerobically digested sludge can significantly reduce the nitrogen load of the main stream and improves the overall nitrogen elimination. Especially for two staged waste water treatment plants the nitrogen load of the process water can reach up to more than 20 % of the nitrogen load in the inflow of the plant. Despite the very low volume of the collected process water representing less than 1 % of the daily inflow, the nitrogen load sums up to 25 % of the influent nitrogen load at WWTP I in Munich (Böhm, 2007).

The process water contains Ammonium-Nitrogen concentrations ranging from 400 to 600 mg $\text{NH}_4\text{-N/L}$. In spite of the dilution by cooling water, its temperature is about 40 °C due to the mixing with vapours from the sludge drying plant before the centrifuges.

Therefore, process water from sludge treatment is nitrified since 2005 in separated activated sludge reactors of the 2nd biological stage. The reactors are equipped with a separate secondary clarifier and sludge pumping station. This existing structure can currently be used for separate process water treatment. If the prognosticated increase in waste water of 20 % eventuates, the reactors currently used for separate process water treatment will be needed in the main stream. In this case, new reactors will have to be build for the process water treatment.

Mass balance calculations showed, that the capacity of the anoxic part of the first biological stage is not sufficient for the denitrification of the recirculation stream and the nitrified process water. Therefore a no longer used primary sedimentation tank was modified into a denitrification tank. Besides the nitrified process water supernatant from the excess sludge thickeners was added in order to provide a source of organic substrate. Additionally, a small portion of excess sludge from the 1st biological stage was added for inoculation with active heterotrophic biomass. If required, methanol can be fed into the tank. A detailed description can be found at Böhm (2007).

Motives for case study

Due to the state of the 1st biological stage concerning the structure and the technical equipment a reconstruction of the 1st biological stage is required. A renovation proved not to be economical. One important aspect of the new process design of the new construction is the implementation of a wastewater bypass to the 2nd biological stage (Figure 2). This will stabilize the 2nd nitrifying stage by improving the sludge properties. Through the bypass a denitrification zone in the 2nd stage will also be possible in order to optimize the nitrogen elimination in the main flow.

In line with the optimization of the nitrogen removal in the main flow the process water treatment was integrated into the new overall process concept. Ammonium-rich process water is particularly suited to be treated by high rate processes which achieve a rapid elimination of nitrogen with a very limited COD requirement. Suitable processes are nitritation and deammonification (Fux et al., 2006). Therefore, a case study was conducted in order to find the most economical process water treatment matching the new overall process.

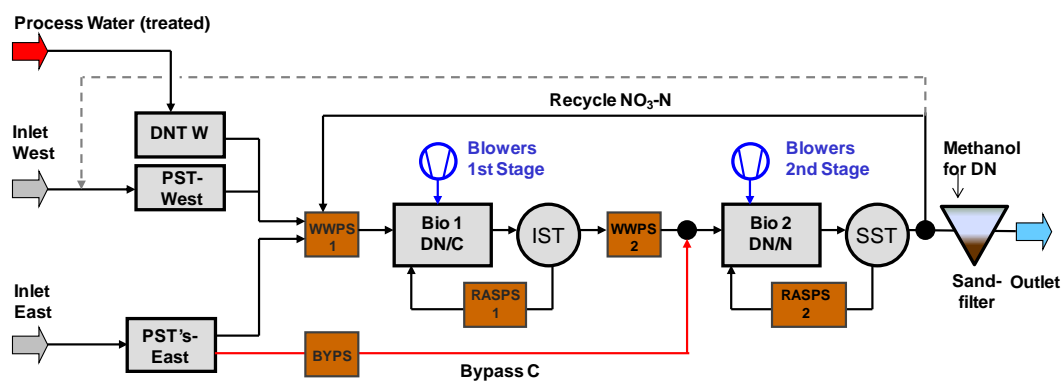


Figure 2: Flowscheme WWTP I “Gut Grosslappen”, Munich, Germany

Nitritation

The process of nitritation/denitritation is based on the partial oxidation of ammonium to nitrite followed by denitritation. In contrast to the entire oxidation of ammonium to nitrate, up to 25 % of

the oxygen demand can be saved. For the denitrification process approximately 40 % of the carbon required for regular denitrification can be saved.

Due to the possible savings in operation costs, the existing process water treatment was modified concerning the oxygen supply in order to enhance nitrification in fall 2009. Through high temperatures and ammonium concentrations combined with limited aeration, nitrite oxidation was inhibited. Within three weeks of operation, the nitrate concentration in the effluent of the activated sludge tank could be reduced to below 10 mg/L NO₃-N. Ammonium concentrations could be reduced from 572 mg/L NH₄-N to <50 mg/L NH₄-N (median values 2010). For the entire year of 2010, the good effluent results could be kept constant. The average degree of degradation was 75 %.

Deammonification

Deammonification or anammox is an aerobic/anoxic process for autotrophic nitrogen removal wherein NH₄⁺ is oxidized by nearly 50 % to NO₂⁻ and subsequently the residual ammonia is converted together with the nitrite as electron acceptor to molecular nitrogen (N₂ gas) (Li et al., 2004). Already in the late 1970s, the existence of anaerobic ammonia-oxidizing (anammox) bacteria was postulated (Innerebner et al., 2007). Over recent years these lithotrophic members of the nitrogen cycle have been identified as planctomycete-type bacteria with a very low growth rate; doubling time is 11 days. Meanwhile, full scale applications of the deammonification process were successfully implemented e.g. in Zürich (CH), Strass (AUT) or Hattingen (GER). Due to the only partial oxidization of ammonium, approximately 40 % of the oxygen demand and 100 % of the carbon needed for nitrification and denitrification can be saved (Siegrist et al., 2003). Therefore a significant reduction in operational costs is possible. For the WWTP Werdhoelzli in Zürich, Switzerland, the cost estimate for construction and operation per kg N_{elim}/m³ was estimated to 0.9±0.1 for deammonification (nitrification/anammox) compared to 1.6±0.1 for conventional nitrification/denitrification (Siegrist et al., 2003).

Case Study

In the case study the following cases for the treatment of process water from sludge dewatering were defined as shown in Figure 3. The cases are classified according to the process used for nitrogen removal (nitrification, nitritation and deammonification), the location referring to the use of an existing structure or the construction of a new structure (major effect on investment costs!) and the amount of process water treated separately (only SIP or entire process water).

Case	1	2	3	4	5	6
Process	N/DN	Nitritation/DN	Deammo	Deammo	Deammo	Deammo
Location	Existing structure	Existing structure	Existing structure	New structure	Existing structure	New structure
Treated water	Process water SIP	Process water SIP	Process water SIP	Process water SIP	Process water SIP + CHP	Process water SIP + CHP

Figure 3: Classification of the alternatives investigated (SIP: sludge incineration plant located at the WWTP, CHP: municipal combined heat and power plant)

Case 1: Nitrification/denitrification is the basis for the comparison of the operational and investment costs for all alternatives. Existing aeration tanks with a total volume of 9.600 m³ are used for nitrification. The volumetric load is 0.25 – 0.27 kgN/m³. Partly denitrification (about 30 %) is carried out in a separate tank (former PST) with methanol as well as high-load WAS from the first stage as an external carbon source. Only process water SIP is treated separately.

Case 2: Nitritation (75 %) can be achieved in the activated sludge tanks of case 1 by limiting the oxygen concentration in the tanks. Little modifications are necessary, partly denitrification is achieved in the following converted settling tank through addition of surplus sludge from the 1st biological stage. Only process water SIP is treated separately.

Cases 3-6 are based on deammonification of the process water SIP (cases 3 and 4) and the entire process water (cases 5 and 6) respectively. It is assumed that for cases 3 and 5 the existing tanks will not be needed in the main stream and can therefore be used for process water treatment. Basis for cases 4 and 6 is a new construction for the process water treatment with a volume of 11.000 m³. The characterization of the process water is displayed in Table 1.

Table 1: Process water characterization

		Process water SIP (with cooling water)	Process water CHP	Total process water (without cooling water)
Flow	m ³ /d	4515	1285	3855
NH ₄ -N	kg/d	2455	1295	3645
TN	kg/d	2985	1490	4160
COD	kg/d	4200	1525	4695

Operational Costs: Process water treatment and its effects on the main stream

For the comparison of the different alternative treatment possibilities the operation costs were examined in detail. On the one hand the operational costs of the treatment itself were calculated. On the other hand the effects of the process water treatment on the operational costs of the main stream were estimated (as displayed in Figure 4).

Basis for the comparison of the operational costs (process water treatment and main stream) for all cases was case 1: nitrification of the process water with separate denitrification (nitrogen removal with external methanol: 30 %). For this case study the actual operational costs of the main stream were not calculated but the discrepancy between operational costs of the main stream in combination with case 1 and with the other cases.

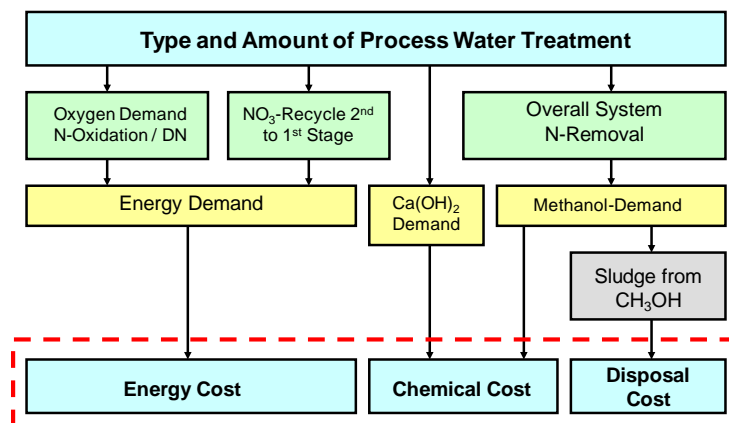


Figure 4: Considered operational cost types of the main stream and the process water treatment

Concerning the operation costs of the process water treatment system itself the reduction of oxygen demand for the partial ammonia oxidation was considered. Furthermore, it was assumed,

that no external carbon source (methanol) is required as well as a complete reduction of calcium hydroxide for stabilization of the pH for cases with deammonification. Concerning case 2: nitrification, the hydrated lime dosage was considered to be equal to the amount needed for nitrification.

For all cases, the resulting effluent concentrations after the second stage were calculated in dependency of the process water treatment. A steady-state model of the nitrogen balance, partly based on modified approaches of the DWA A131 guideline, has been applied. In Munich, effluent requirements concerning N_{tot} have to be fulfilled for the period May-October. In order to achieve effluent concentrations below the required 13 mg N/L post-denitrification is necessary in the sandfilter with methanol.

The influence of the process water treatment (case 1 - 6) on the main stream was calculated using the following factors:

- Discrepancy in oxygen demand in the main stream according to different effluent concentrations of the different process water treatments
- Discrepancy in pumping costs for the recirculation. Due to improved process water treatment less nitrogen has to be oxidized in the second stage and the N/COD ratio in the first stage is reduced. In order to utilize the increased denitrification capacity in the first stage for denitrification, an increased stream has to be recycled from the 2nd to the 1st stage.
- Discrepancy in methanol dosed in the sandfilter according to the nitrogen concentrations after the second stage
- Discrepancy in sludge disposal based on sludge production due to methanol dosing in the sandfilter
- Discrepancy in energy consumption in the sandfilter due to necessary backwashing. A linear correlation was assumed between the required backwashing frequency and the amount of methanol dosing.

For cases 5 and 6, the operational costs of the process water treatment include the treatment of the entire process water. For cases 1 to 4, it is considered, that only process water SIP is treated separately in contrast to process water CHP, which has to be treated together with the general inflow in the main stream. Operational costs were calculated for main stream and the process water treatment according to the process water volumes treated.

Investment costs

As investment costs all costs have been considered that are required to implement the process water treatment in the new main stream treatment process. The resulting annuities were calculated based on an interest rate of 3 % and a lifespan for construction of 30 years and 15 years for technical equipment (see Table 3).

No investment costs were considered for case 1 since the processes nitrification/denitrification are already installed at the WWTP I. Only limited investment costs of 600.000 € were calculated for case 2. They mainly result from glas fibre cover over the aeration tanks in order to avoid odor emissions.

For the implementation of the deammonification process significant adjustments are necessary. Adjusted mechanical and electrical equipment is needed for the planned SBR reactors. Furthermore, structural investment is needed for the glas fibre cover (odor emissions) and

insulation, required due to the lack of exothermic processes in the deammonification plant. Included are also the structure itself (cases 4 and 6) as well as the fortification of partition walls in the existing structure required because of different water levels in adjacent SBR units (cases 3 and 5). Investment costs for cases 3 and 5 amount to 5,7 mio.€, for cases 4 and 6 to 10 mio.€.

Results and discussion

In times of increasing energy costs, this factor was investigated in depth. Energy consumption for aeration of the process water treatment decreases according to the stoichiometric oxygen demand for only partial oxidation. Additionally, the savings for aeration in the main stream are included. These result from lower effluent values of the process water treatment and for cases 5 and 6 from treatment of the total process water; process water CHP does not have to be treated in the main stream.

Table 2: Calculated effluent values of the 2nd biological stage for cases 1-6

		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Effluent concentration 2nd biological stage	mg N _{inorg} /L	15,5	12,8	11,2	10,8	8,5	7,8
N_{inorg}-load to sandfilter	kg N _{inorg} /d	4.500	3.500	3.300	3.200	2.500	2.300

The calculated effluent concentrations and loads to the sandfilter represent the yearly average, whereas the effluent requirements (13,0 mg N_{inorg}/L) have to be fulfilled in 2-hour composite samples (see Table 2). The calculations show, that improved effluent values of the process water treatment result in better effluent values of the main stream. These are mainly caused due to an enhanced denitrification capacity in the 1st biological stage. In order to profit from this, an increased recirculation from the 2nd biological stage is necessary. This, however, results in an increased pumping effort and therefore higher energy costs. The additional energy demand for pumping amount to approximately 6.500 kWh/d, varying slightly according to the different cases (see Figure 5).

As a consequence of the reduced effluent values of the 2nd biological stage less methanol has to be dosed in the sandfilter for post-denitrification. This results in decreasing energy demand of the sandfilter, mainly due to reduced back-wash intervals.

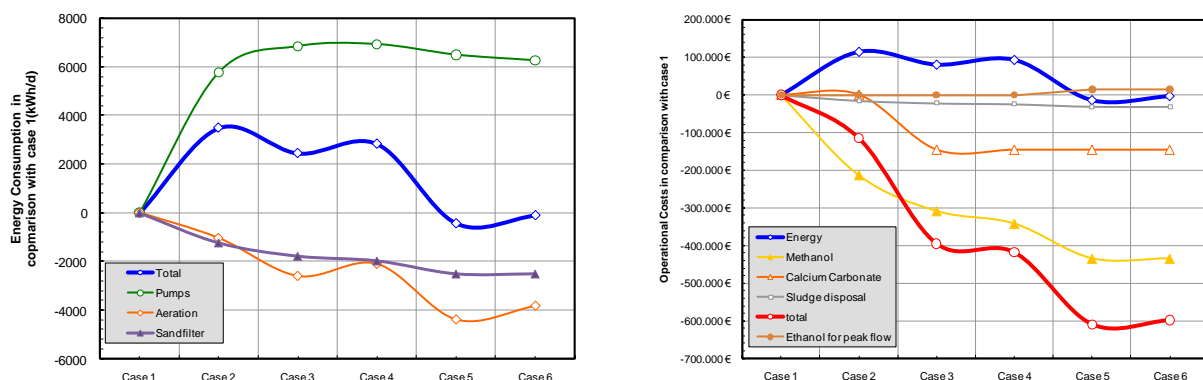


Figure 5: Energy demand and operational costs for cases 2-6 compared with case 1

As a result of the high energy demand for the recirculation, the energy balance is slightly positive only for cases 5 and 6. For cases 2, 3 and 4, an additional energy demand of approximately 3.500 and 2.500 kWh/d respectively is required.

The positive effect of the increased pumping costs are reduced effluent nitrogen concentrations, which lead to a reduction of methanol dosing in the sandfilter. For cases 5 and 6, the methanol savings sum up to approximately 1.500 t/a. It is assumed, that no post-denitrification is necessary in order to achieve the effluent requirement for cases 5 and 6. Therefore, the sandfilter is no longer needed for denitrification. In order to guarantee the effluent requirements during peak flows that lead to a reduction of the possible recirculation, 15.000 €/a were calculated for the dosing of e.g. ethanol in the biological stage.

Methanol is the most important factor regarding the operational cost savings for all cases (see Figure 5), resulting in higher savings than the increased energy demand.

A side effect of the reduced methanol dosage in the sandfilter is the reduced sludge disposal resulting from sludge growth in the sandfilter.

Hydrated lime is not needed for pH-stabilization in the deammonification process and leads to savings of approximately 145.000 €/a for cases 3-6.

A compilation of the operational cost savings of the overall system for all cases is shown in Table 3. Significant savings can be realized for all cases compared with case 1. Even implementation of nitrification (case 2) results in approximately 100.000 € annual savings. Maximum savings of approximately 600.000 €/a are possible if the total process water is treated separately with deammonification (case 5 and 6). If only process water SIP is treated (case 3 and 4, deammonification) savings in the range of 400.000 €/a are possible.

Table 3: Compilation of results for operational cost savings and amount of annuity

		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Operational cost savings	€/a	0	-114.000	-395.000	-418.000	-609.000	-598.000
Amount of annuity	€/a	0	35.000	422.000	677.000	422.000	677.000
Annual costs / savings	€/a	0	-79.000	27.000	259.000	-187.000	79.000

In addition to the saving in operational costs, the amount of annuities according to the relevant investment costs are also displayed in Table 3. It is obvious, that especially for cases 4 and 6, the annuities for the new structure are significant.

Due to the local conditions, that currently activated sludge tanks of the 2nd biological stage can be used for the process water treatment, cases 3, 4 and 6 are not economically advantageous. Of course, this changes drastically, if the tanks are needed for the main stream in the future.

As for now, case 2: nitrification is the most economical process water treatment: annual savings of approximately 80.000 € were calculated. As soon as the total process water will be available, the savings could reach almost 190.000 €/a, when deammonification is implemented (case 5).

A reevaluation of this case study is planned as soon as the enhancement of WWPT I will be completed in 2015. At that time, a reliable prediction whether the activated sludge tanks will permanently be available for process water treatment can be expected.

Conclusions

Within the scope of a general enhancement project of Munich's WWTP I "Gut Großlappen" a case study was conducted concerning the future process water treatment. Six cases were analyzed with different treatment processes, different process water volumes and different investment costs concerning the structures.

One focus of this detailed study was to include the influences of the process water treatment on the main stream and calculate the resulting changes in operational costs.

The following conclusions can be drawn:

- * The influence on the main stream and its operational costs is significant and influences the decision on process water treatment.
- * Significant operational costs can be saved with nitrification and more by implementing deammonification for process water treatment.
- * In order to profit from an improved process water treatment, a high recirculation from 2nd to 1st biological stage in the main stream is necessary. This results in significantly increased pumping effort and therefore in higher energy costs.
- * The savings are mainly caused by a significantly reduced methanol demand for post-denitrification of the main stream in order to meet legal requirements.
- * The amount of annuities caused by necessary investments for the process water treatment can exceed the operational cost savings.
- * In Munich, the deammonification process is only economically advantageous if process water from dewatering at both incineration plants is treated in an existing structure.
- * Immediate implementation of deammonification for the process water treatment at Munich`s WWTP I proved not to be economically justifiable, but will be reevaluated after completion of the enhancement of WWTP I.
- * Meanwhile, nitrification of the process water will be continued, leading to an estimated annual saving in operational costs of approximately 80.000 € compared to conventional nitrification.

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