The Right Process Measurement Technology for Nitrogen Degradation

In the wastewater treatment sector, the main focus of attention is the elimination of nitrogen and phosphorus. This is a measure of the efficiency of a sewage treatment plant and is used to determine the wastewater charges. New process ideas, additional treatment methods and advanced measuring and control programs therefore repeatedly set new records. The first prerequisite for successful optimisation measures, however, is transparency. Without an insight into the microbiological processes, and without a detailed overview of their numerous interactions, it is impossible to understand what is currently happening. Transparency means knowledge of the relevant substances in the wastewater at the right time, at the right places, in the appropriate treatment phase. Appropriate recommendations about instrumentation, together with concrete data from the Markt Schwarzenfeld sewage treatment plant, can be an aid to reaching the right decisions.

The Nitrogen Balance in Municipal Wastewater

General

Nitrogen is present in wastewater in a variety of compounds. The properties of these compounds differ widely. When they are discharged into surface waters, they can deplete the oxygen content of the water, have a toxic effect on fish or serve as a nutrient.

It is therefore important to know the composition of the nitrogen compounds in municipal wastewater and how they change during the various phases of wastewater treatment. Additional loads may be generated, e.g. by the sludge liquor (process water) formed during sludge treatment (thickener, mechanical dewatering) or by large-scale dilution by infiltration water, which can bring about a reduction in the nitrogen concentration.

In municipal wastewater, human excretions are the main contributors of nitrogen (N). Most of the nitrogen is in the form of urea, which is a constituent of urine. The average amount of nitrogen excreted per person per day is about 11 g. The nitrogen concentration in raw municipal wastewater, expressed as TKN (organic nitrogen + NH_4-N), is between 50 and 60 mg/l, whereby the NH_4-N content is greater than the proportion of organic nitrogen *(Fig. 1)*.

Inflow to the sewage treatment plant

Assuming an average daily inflow of 150 l wastewater and 50 l infiltration water per head of population, the concentration can be calculated as 11,000 mg TKN/(P.d): 200 l/(P.d) = 55 mg/l (ATV-DVWK guideline A-131 "Dimensioning of single-stage activated sludge plants")

In practice, the nitrogen concentrations are sometimes lower. This is usually attributable to a large volume of infiltration water or a large proportion of industrial wastewater. Urea and other organic nitrogen (org. N) start to degrade to ammonium nitrogen (NH_4-N) in the sewers. This conversion is referred to as ammonification. The longer the flow path to the sewage treatment plant, the greater the degree of ammonification.

Recommendation: EVITA INSITU 4100 sc

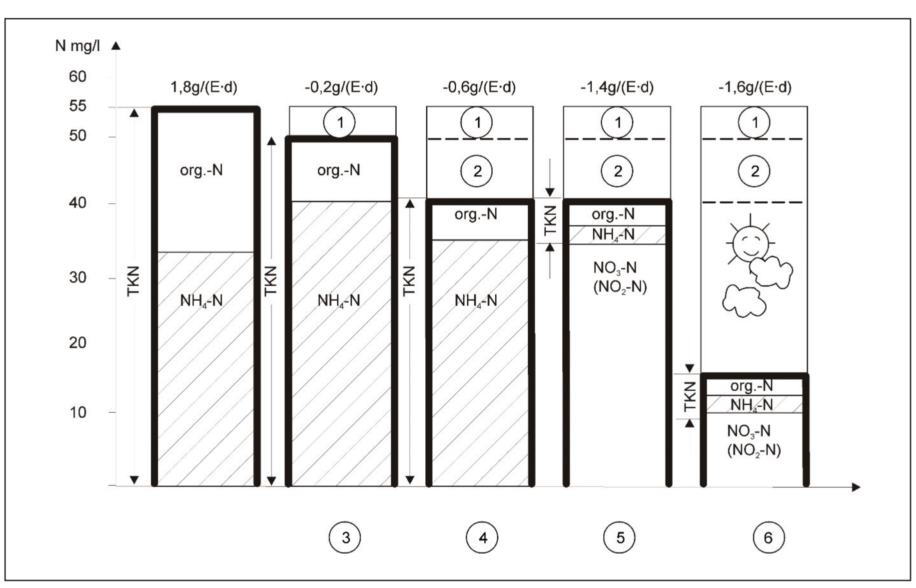

Fig. 1: Nitrogen balance in wastewater
1 Primary sludge, 2 Excess sludge, 3 Mechanical treatment, 4 Biological, only carbon degradation, 5 Biological, with nitrification, 6 Biological, with denitrification

After mechanical treatment

The process of ammonification continues during the mechanical phase, so that more organic nitrogen is converted to NH_4-N. The sludge that settles out during the primary treatment contains a mass of about 1 g N/(P.d). This corresponds to a nitrogen content of about 5 mg/l, which has been removed from the wastewater.

Recommendation:
EVITA INSITU 4100 sc, AMTAX sc

After biological cleaning (carbon degradation only)

Virtually all the nitrogen is now present as NH_4-N and is strongly oxygen depleting. In the biological phase, organic material is converted into bacterial mass and drawn off as excess sludge. In order to form this biomass, nitrogen in a concentration of about 2 g N/E is needed, which corresponds to 10 mg/l N, which is removed from the water at this point.

After nitrification

In the aeration tank, NH_4-N is oxidised to nitrite (NO_2-N) and then to nitrate (NO_3-N) in the presence of sufficient oxygen. This also occurs in low-rate trickling filters and rotating biological contactors. This process is called nitrification or nitrogen oxidation. If the sludge has aged sufficiently or the BOD_5 sludge loading is low and the limiting conditions are favourable, the NH_4-N content in the outflow is less than 3 mg/l, and usually less than 1 mg/l. The nitrate acts as a nutrient in surface waters. The nitrogen balance in the sludge changes only slightly if the oxygen concentration in the aeration tank is higher than 1 mg/l.

Recommendation: EVITA INSITU 4100 sc, AMTAX sc, NH4D sc

After denitrification

In non-aerated (anoxic) tanks or zones, the bacteria are no longer supplied with oxygen and are therefore forced to absorb nitrate (NO_3-N), which they then break down, making oxygen available for respiration. They emit the nitrogen to the water as gas (N_2), which escapes to the air. This process is known as denitrification. Readily degradable carbon compounds play an important role in this, as they are either directly respired or adsorbed, partially incorporated and subsequently processed.

Recommendation: NITRATAX plus/eco sc

TKN (Total Kjeldahl Nitrogen)

This is the sum of the organic nitrogen and ammonium-nitrogen (org. N + NH_4-N). It is of interest with regard to the nitrogen load in raw wastewater or after mechanical cleaning. At high levels of COD degradation, the concentration of organic nitrogen in the outflow is so low that it can be neglected.

Total nitrogen in the outflow ($N_{tot.\ inorg.}$)

According to the Wastewater Charges Act (AbwAG), dischargers of wastewater into surface water must pay a charge for the total discharged inorganic nitrogen. According to the Wastewater Ordinance and the Wastewater Charges Act, the total nitrogen ($N_{tot.\ inorg.}$) is defined as the sum of NH_4-N, NO_3-N and NO_2-N – i.e. organic nitrogen is not included. Efficient nitrogen elimination can reduce N_{tot} below 12 mg/l.

Recommendation: AMTAX sc, NITRATAX plus/clear sc

Total nitrogen (ToTN)

To distinguish this from N_{tot} in the outflow, the sum of organic and inorganic nitrogen is abbreviated as ToTN. The measurement is above all necessary in the inflow, where the content of organic nitrogen (org. N) can be 20 mg/l or more.

Figure 2. Waste water treatment plant

Optimisation of the Biological Treatment Phase

(Markt Schwarzenfeld sewage treatment plant)

An example from a sewage treatment plant shows how control measures can have a decisive influence on degradation processes and how savings in wastewater charges can offset the investment costs.

Previously

The wastewater in the inflow to the sewage plant in Markt Schwarzenfeld was a major challenge for the treatment process. The BOD corresponded to a population equivalent (PE) of about 14,000, the nitrogen load corresponded to a PE of about 20,000, and the phosphorus load corresponded to a PE of about 25,000. The irregular composition of the wastewater was caused by pretreated wastewater from a milk processor. The pretreatment was responsible for relatively little BOD, but for more than 50% of the total nitrogen load in the sewage treatment plant inflow. A positive secondary effect was that the water was warm, so that temperatures in the aeration tank were always above 11°C.

After the mechanical treatment in the sewage treatment plant, unfavourable flow conditions in the flow splitter unit caused the wastewater to reach the upstream denitrification stages of the 2-channel system not in equal volumes but in the ratio of 70:30. Furthermore the minimal dwell times and low BOD values prevented efficient denitrification from occurring.

In the following aerated section, a single oxygen line supplied the unequal volumes of wastewater in the two channels with equal amounts of oxygen. In the absence of any form of control system, the differences in oxygen content ranged from 1 mg/l to 5 mg/l.

The result
A N_{tot} value of 12-18 mg/l in the outflow and a specific energy consumption of 0.40 kWh/m³ wastewater.

Today:
The composition of the wastewater could not be influenced, of course, but simple structural changes to the flow splitter unit ensured that the wastewater is now evenly distributed over the two channels. The change from upstream denitrification to intermittent operation generated much greater denitrification capacity, so that effective nitrogen degradation takes place during long non-aerated phases, despite the shortage of carbon. Separate oxygen lines and 2 annular piston valves *(Fig. 3)* enable a fuzzy controller (an intelligent, self-learning control system) to regulate the oxygen supply in response to the loading.

How does a self-learning control system function?

The task of this controller in Schwarzenfeld is to ensure that the aerators for the two channels function as efficiently as possible. It receives information from two oxygen probes (located in the middle of the aeration tank) and one ammonium and one nitrate process meter (at the end of the aeration phase). The absolute measured value and the increase in concentration per unit of time are monitored (gradient of the time-course curve).

The time-course curves of 27 and 28 June 2007 *(Fig. 5)* provide a good insight into the everyday functioning of a fuzzy controller. In the late evening of 27 June the controller switched off the aeration of both channels and allowed the wastewater inflow to slowly increase the ammonium concentration. The nitrate content remained at a very low 2 mg/l NO_3-N despite the adequate denitrification time, as the inadequate carbon supply made itself felt here as the strongest limiting factor. At 0.8 mg/l NH_4-N the aeration was switched on alternatingly in both channels, so that ammonium degradation occurred and the nitrate values increased. (This alternating method of operation cuts electricity costs, at least in Bavaria, because uneven consumption of electricity with marked peaks is "penalised" by higher charges.) A purely time-controlled aeration system would switch on repeatedly during the night to no purpose, thus wasting energy. The previous energy consumption of 0.40 kWh/m³ wastewater has been reduced to 0.28 kWh/m³ wastewater with the new controller.

Fig. 3. Operation manager Thomas Hutz checks the new annular piston valves

The result:
30% lower energy costs, Ntot < 5 mg/l and a COD around 20 mg/l are impressive figures that clearly express the efficiency of this control system. The cooperation between the Markt Schwarzenfeld sewage treatment plant and ELO Consult GmbH is therefore yielding a long-lasting payoff.
In actual fact, the overall cost of the system optimisation was zero, as the following list of financial items shows. The successful reduction in nitrogen levels by more than 20% *(Fig. 8)* resulted in a repayment of the wastewater charge which exceeded the investment costs *(Fig. 9)*.

Parameter	Before	After
N_{tot}	12-18 mg/l	< 5 mg/l
COD	25 mg/l	approx. 20 mg/l
Energy use	0.40 kWh/m³	0.28 kWh/m³ (-30%)

Fig. 6: Impressive performance data in Schwarzenfeld

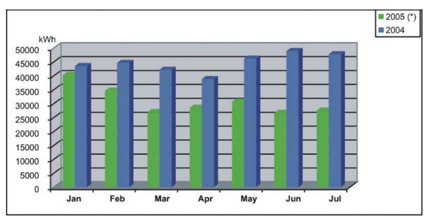

Fig. 7: Energy requirement of the sewage plant (calculated values for 2005, based on the wastewater volume in 2004)

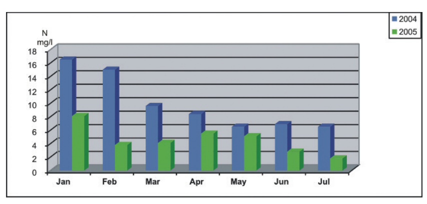

Fig. 8: N_{tot} in the outflow

Financing of the Optimisation Measure:

(All amounts in euros)	-	+
Investment	94,520.08	
Repaid wastewater charge 2002*		40,387.74
Repaid wastewater charge 2003*		31,324.00
Repaid wastewater charge 2004*		33,145.82
Interim balance:		**10,337.48**
Energy savings (gross) since 2005 annually		14,597.64
Savings on wastewater charge (gross) 2005		10,808.41
*through nitrogen reduction of more than 20%		

Fig. 9: Zero-cost plant optimisation

Recommended Instrumentation

AMTAX sc ammonium process photometer
High-precision process meter for continuous determination of the ammonium concentration. Sample preparation using integrated filter probe, isolated, weatherproof enclosure, outdoor or indoor installation. Evaluation and operation through SC 1000 Controller. Measurement method: GSE (gas-sensitive electrode); measuring range: 0.05 - 20 mg/l NH_4-N; measurement uncertainty: 3% +0.05 mg/l; response time (T_{90}): 5 min including sample preparation; measurement interval: 5-120 min; dimensions: (L x H x B) 540 x 720 x 390 mm

NH4D sc ISE ammonium process probe
Affordably priced ammonium process probe for continuous direct in-fluid determination of the ammonium concentration. The patented reference system excludes any possibility of electrode poisoning. A soil-insensitive salt bridge reduces cleaning work and prevents dilution of the electrolyte. Evaluation and operation through SC 1000 Controller. Measurement method: ISE (ion-selective electrodes for ammonium and potassium, pHD reference); Measuring range: 0.2 - 1000 mg/l NH4-N; measurement uncertainty: with standard solutions 5% of reading +0.4 mg/l; response time: <2 min; calibration: sensor code (precalibrated sensor head); inline matrix correction; maximum flow: <4 m/s; dimensions: 350 x 44 mm (length x diameter).

EVITA INSITU 4100 sc ammonium sensor
Precise ammonium sensor fur continuous sample-free direct in-fluid determination of the ammonium-nitrogen concentration. Patented ion filter. Evaluation and operation through SC 1000 Controller with GSM module. Measurement method: photometric measurement by the indophenol blue method; measuring range: 0...20 mg/l NH_4-N; measurement accuracy: +/-10% of the real concentration; measurement interval: 10 times per second; dimensions: diameter 355 mm, height 600 mm; minimum flow rate: 0.01 m/s;

NITRATAX plus/clear/eco sc nitrate process probe
Stainless steel process probe for the sample-free determination of the nitrate and nitrite content. UV absorption measurement, reagent-free. The probe can only be operated and its signals can only be displayed in connection with the SC 100 or SC 1000 display unit. For in-flow installation a flow-through cell is necessary.

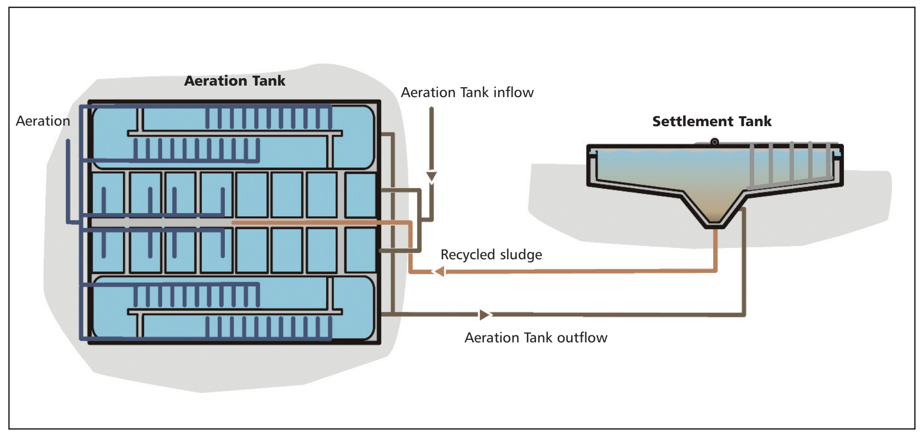

Fig. 4: Schematic diagram of the biological treatment phase

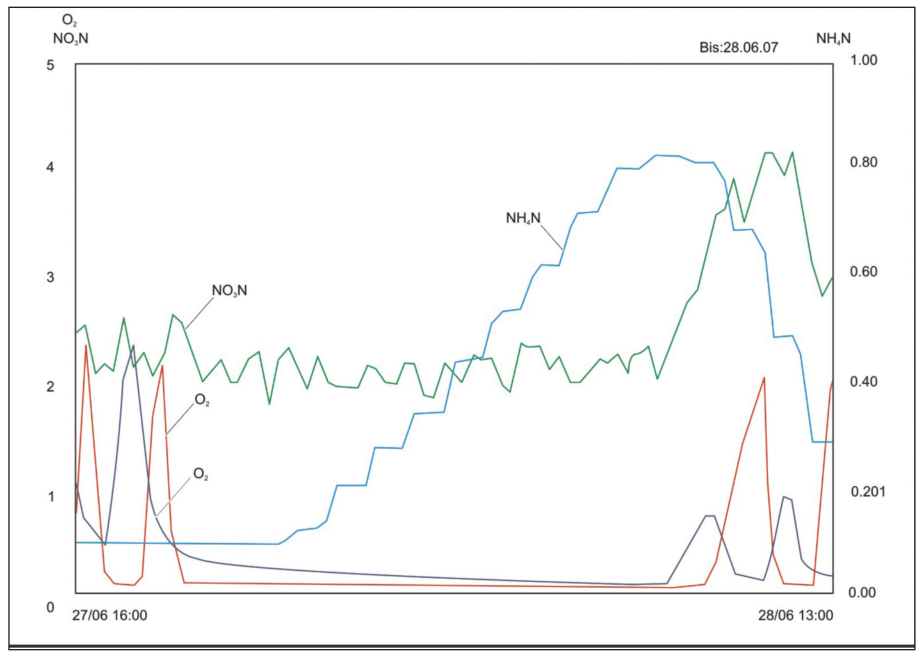

Fig. 5: Input data for the fuzzy controller (O_2 values from both channels)

Technical data of the sewage treatment plant:
BOD: 14,000 PE,
N: 20,000 PE,
P: 25,000 PE
Qt= 3500 m³/d, Qm= 10,000 m³/d
[Qt = dry weather flow;
Qm = storm water flow]
Volume of aeration tank: 8100 m³

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