発表資料

Municipal wastewater treatment in Germany – state of the art

K.-H. Rosenwinkel, Institute for Water Quality and Waste Management,
Leibniz University of Hanover (ISAH), Welfengarten 1, 30167 Hanover, Germany

Introduction

In the EU the Wastewater Directive is an emission–based regulation which defines required effluent quality in terms of COD, BOD and nutrient concentration. As various bodies of water (e.g. the Baltic Sea) are becoming eutrophic, the imission and watershed integrated management approach is being adopted in EU as well. The new EU water-framework-guideline requires an imission-based river-basin-management and a good quality for all river-basins in the EU. The following will present the technology that is currently used in WWTP in Germany and the developing trends.

Wastewater Treatment in Germany

Table 1 presents the current minimum requirements for effluents from municipal WWTPs which have to be met as the yearly mean values. Germany adopted the EU Directive, however the effluent levels must be met in the qualified peak sample (ABWV, 2004) – a considerable stronger requirement.

Table 1: Minimum effluent requirements from municipal WWTP in Germany and the EU. (*) denotes “sensitive areas”,(**) “normal areas”

Minimum requirements FRG in (mg/L)					
Size [1000 PE]	COD	BOD	NH_4-N	TN	TP
< 1	150	40	-	-	-
1 - 5	110	25	-	-	-
5 - 10	90	20	10	-	-
10 - 100	90	20	10	18	2
> 100	75	15	10	13	1
EU requirements in (mg/L) or as minimum (%) Removal					
Size [1000 PE]	COD (**)	BOD (**)	NH_4-N	TN (*)	TP (*)
10 - 100	125 or 75 %	25 or 70 -90 %	-	15 or 70 - 80 %	2 or 80 %
> 100	125 or 75 %	25 or 70 - 90 %	-	10 or 70 - 80 %	1 or 80 %

Typical process configuration

The most commonly used BNR processes in Germany are pre-denitrification and simultaneous nitrification-denitrification (SND). Plants practicing enhanced biological phosphorous removal (EBPR) typically employ Johannesburg, ISAH or Phoredox type configuration. Other plants use the cascade-denitrification and the alternating denitrification process.

An example of technology development is provided by Hildesheim WWTP which employs SND and EBPR. Designed in 1982/1983 the plant was commissioned in 1987. In contrast to the warm and concentrated (BOD of 300-400 mg/L) South African wastewater, where BNR processes originated, the Hildesheim WWTP at times may have BOD_5 as low as 100 mg/L due to infiltration and combined sewers. The plant is operated using the ISAH process, where the return sludge (RAS) is denitrified in a separate pre-anoxic zone to offset any impact on phosphorus release in the subsequent anaerobic zone. If necessary, additional substrate can be fed from the anaerobic primary sludge fermentation tank to the pre-anoxic zone. Initially operated as two parallel lines, the plant had all four passes commissioned in 1997 (Figure 1).

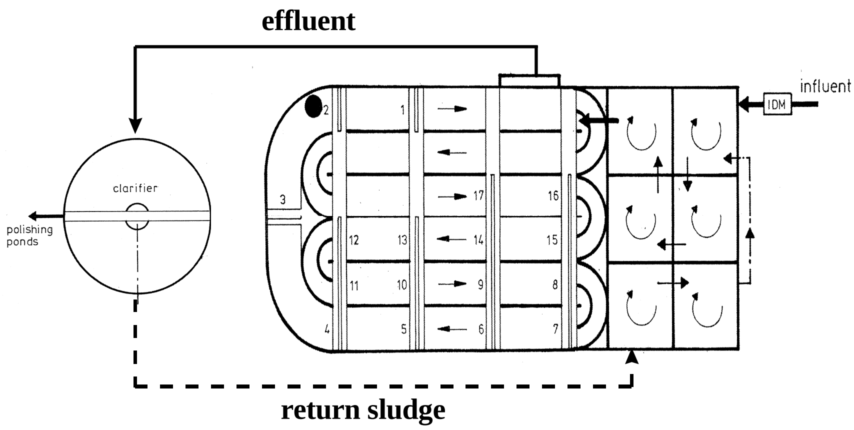


Figure 1: Flow sheet of the Hildesheim WWTP (with digester and EBPR in a fullstream)

The average effluent concentrations in 2001 were 0.12 mg TP/L and 4.0 mg TN_{min}/L (80% cumulative frequency concentrations: 0.26 mg TP/L and 6 mg TN_{min}/L), well below the permit requirements of TN<10 mg/L and TP<1 mg/L (Figure 2). Although chemical precipitation was available the low effluent TP values were almost entirely the result of the biological phosphorus removal. Plants in Germany benefit from significant financial savings in mandatory wastewater charges when treatment effects exceed the permit requirements.

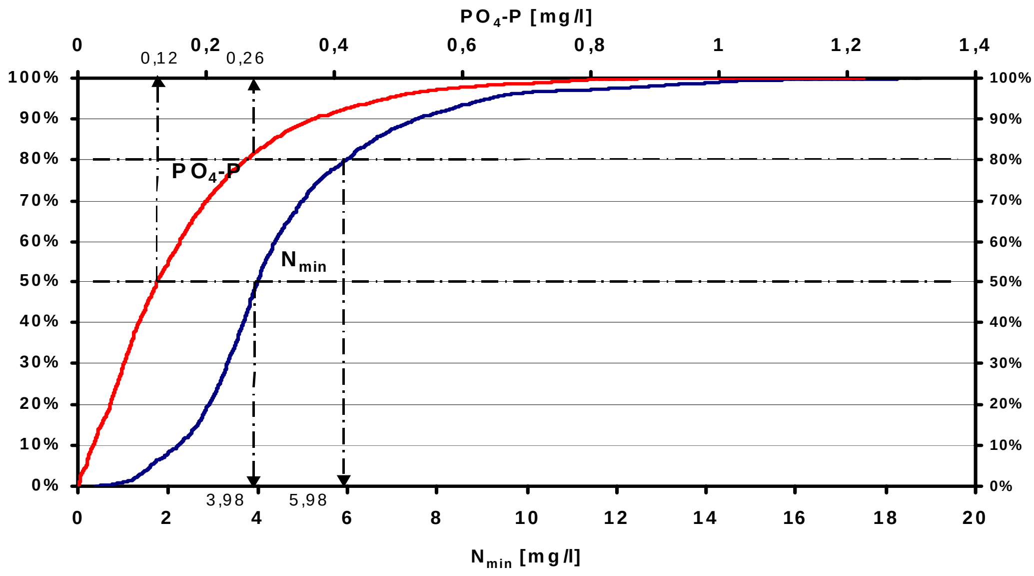


Figure 2: Cumulative frequency for the parameters $N_{mineral}$ (NH_4-N + NO_3-N) and P_{tot} in the effluent of the secondary clarifiers at the Hildesheim WWTP as daily average 2001

The WWTP Husum is an example of a process with SND and biological phosphorous-removal in a sidestream. The side-stream process called the CISAH-Process, consists of anaerobic tanks, stripper and an optional lime precipitation. The flowsheet of the WWTP Husum is represented in Figure 3.

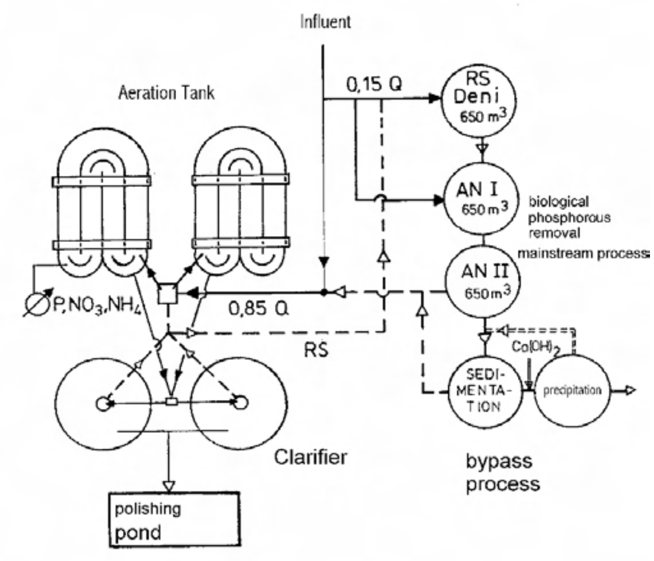


Figure 3: Flow diagram of Husum WWTP without digester and employing SND and side stream biological-chemical phosphorus removal

The effluent concentrations in 2004 were TP (80%)= 0.17 mg/L without precipitation, and TN_{min} (80%) = 2 mg/L, averaging (50% data) 0.12 mg TP/L and 1.7 mg TN_{min}/L. The extremely low nitrogen concentrations were due to the high COD/N ratio (Table 2). At Husum the SRT is 15.1

days in 2004 and the ratio COD/N is 16.2, at the WWTP Hildesheim the SRT is 16 d and the COD/N ratio is 15. The influent-concentrations of the WWTP Husum are much higher than that of the WWTP Hildesheim due to industrial influences. In comparison, for another WWTP Hannover-Gümmervald (approx. 750,000 PE) with a COD/N ratio of only 11.5, the effluent-data of 2001/2002 for the 50% cumulative frequency are 6.6 mg TN_{min}/L and 0.5 mg TP/L (MAKINIA ET AL 2005). These figures show the important influence of the COD/N ratio to the nitrogen-effluent quality, in special for nitrate. Table 2 shows the N-effluent concentrations for the three WWTPs named before, in relation to the COD/N-ratio and the sludge age.

Table 2: Impact of COD/N in three German plants on effluent total nitrogen concentrations

	Capacity	**SRT**	**COD/N**	**TN_{min} effluent concentrations**	
WWTP	[1000 PE]	[d]	[-]	50% [mg/L]	80% [mg/L]
Hildesheim	approx. 240	16.0	15.0	4.0	6.0
Husum	approx. 110	15.1	16.2	1.7	2.0
Hannover-Gümmerwald	approx. 750	16.0	11.5	6.2	8.2

Trends in Germany and EU

Integrated River Basin Management

The emphasis in EU begun to shift from the emission to the imission-based approach to water quality management. This calls for a more integrated, system-wide approach that includes all sources of pollution within a watershed and within an urban jurisdiction, including sewerage, treatment plants and the receiver. Germany was one of the first to establish the river watershed water quality management system such as for the river Ruhr (Ruhrverband). Recently, urban watersheds became targets with attempts to direct as much as possible of the combined sewer overflows into the wastewater treatment plants.

As an example, a case study is presented in which the research in a calibrated model focusses on the influences of different ratios between rain- to dry weather flow on the total emission from the effluent of the treatment-plant and the combined sewage overflow (CSO). In case of a heavy rainfall event high loads are discharged via combined sewer overflows into the receiving waters. Currently, the usual remedy is the construction of stormwater tanks with overflow; however, this method requires large tank volumes and high construction costs. A partial relief from this negative impact could be offered by utilizing the existing capacity of the WWTP to process the CSO and thus reduce total emission from the sewer system and the WWTP. This could be achieved by optimization of the available plant capacity with model-based control strategies. Figure 4 describes the area of interest, with the WWTP, the stormwater overflows and the receiving waters as the focus of attention.

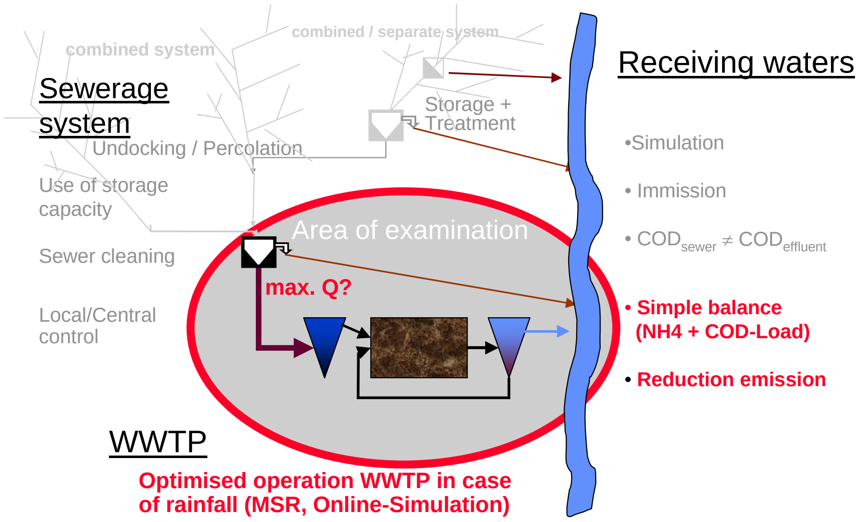


Figure 4: Area of examination in the urban drainage area and the boundaries for total emission from WWTP and CSO

The results of the research show that the increase of use from WWTP capacities will lead to reduction of the total load (e.g. of NH_4-N) to the river (SEGGELKE, 2002). The high and highly-variable WWTP influent loads in case of stormwater necessitate optimisation of control and operation. Apart from conventional control strategies which are adapted to the situation stormwater, observation mechanisms with continuous monitoring of the status of the biological process become necessary. Predictive adaptive control systems, consisting of an on-line coupled model and an implemented prognosis calculation tool could determine the maximum possible loads to the inlet of the WWTP and the optimal utilisation of the capacities while meeting the effluent values.

Following, the results from the theoretical calculations of the total emission of sewer system and WWTP are shown in Table 3 (focus is on COD and KN). Based on scaled-up results (actual effluent concentration, fictitious water quantity) of a pilot plant study for a WWTP (73,500 PE), the emissions are calculated under specification of different inflows to the WWTP with the hydrological sewer model KOSIM (SEGGELKE, 2002). The table presents the load reduction compared to the calculation with the storage volume 8.940 m³ (German ATV A128 design guideline) in case of storm flows as high as twice of the dry weather flow and keeping the limiting values of the EU-guideline in case of higher inflows. For reasons of simplicity the concentration of CSO were assumed to KN = 20 mg/L and COD = 140 mg/L (SEGGELKE AND ROSENWINKEL, 2002).

Table 3: Comparison of the loads from CSO + WWTP and the load reduction for different combined flows to the treatment plant

Influent (%) DWF	**load from total area [kg/a]**		**load reduction**	
	KN	COD	KN	COD
200	12,950	90,600	-	-
300	9,250	64,700	13.8 %	8.4 %
400	6,970	48,800	22.2 %	13.5 %

In the comparison, the reduction of harmful CSO peaks in the receiving waters is neglected. The example shows a reduction of the KN load of 22% to the river in case when the WWTP inflow is four times the dry weather flow i.e. instead of the German standard (2 Q_{dryw}). The most important influence is given for the Ammonia-reduction, this can be reduced effectively only by a biological system.

Plant Wide Modeling

As an important tool for the development, the evaluation of novel control and operation concepts, simulation is widely used. One main focus of the works is the modelling on a plant-wide level including processes for sludge treatment energy consumption/production besides the classical activated sludge process. One main aspect in sustainable operation is the consideration and examination of each relevant emission path. In reference to waste water treatment plants action with the goal of an optimisation of effluent loads also must be analysed on the implicated effects on the sludge digestion and the coupled energy production.

For the expansion of the common models of activated sludge systems for the use in plant wide modelling different additional models are necessary including the mechanical pre-treatment (grids, primary clarification, pre-precipitation etc.), the biological/chemical step with a broad diversity of technologies (activated sludge and biofilm systems, sequencing batch reactors, chemical precipitation, etc.); the sludge treatment (mechanical thickening, anaerobic digestion, drying, incineration) and the energy production and consumption (gas engines, block heating works, aeration devices, etc.) (ROSENWINKEL, SPERING, 2006).

In addition to the integrated consideration of the treatment-plant and the combined sewage overflow (CSO), the several currents have to be eliminated. The co-treatment of waste by kitchen-disrupters together with sewage can be one example (WENDLER, 2005).

New treatment technologies

Overall removal efficiency shows significant decline in effluent concentrations in Germany (Figure 5), mainly due to improved plant design, novel processes and better operation. Significant inroads in activated sludge treatment are being made in EU by the biofilm technologies. Some 40 plants with biological filtration operate in Germany today, treating effluent from 1.5 million PE. The plants use biofiltration for nitrification and also for denitrification. The reactors include aerated submerged-bed upflow filters, downflow filters, and continuously or discontinuously backwashed filtration. The effluent suspended solids concentration of filtration units, following conventional final clarifiers are below 5 mg/L, the nitrogen concentrations in the effluent are covering a wider scale, depending on variations of inlet flow and composition, mode of operation, e.g. dosage of external carbon.

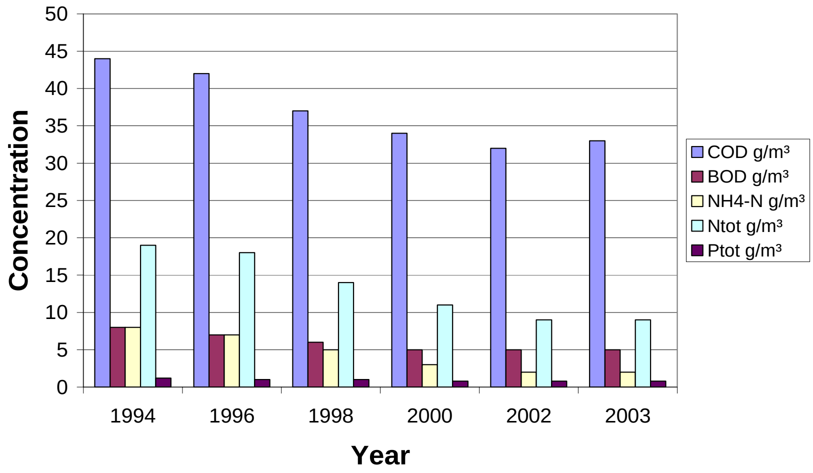


Figure 5: Mean yearly effluent concentrations of German plants (DWA 2003)

Increasingly stringent nitrogen standards call for separate treatment of sludge processing liquors using physical, chemical and biological methods. In a few cases, the nitrogen load is decreased by incineration of raw sludge, e.g. at Vienna or Berlin.

The membrane bioreactor (MBR) technology begins to be implemented more often and for larger facilities. In the MBR the secondary clarifier is replaced by a membrane module yielding high-clarity final effluent. Smaller reactor volumes are typically the result of higher contents of MLSS (up to 15 g/L and above) in comparison to standard activated sludge systems. Today 40 MBR plants operate all over Europe, with 16 of them in Germany. The capacities vary from 150 to 200,000 PE. The technology promises to reduce the suspended solids to zero and to minimise a lot of harmful substances in the effluent (e.g. endocrine disrupters and pharmaceuticals).

Of special importance for the evaluation is the fact, that the membrane is only a physical selection-tool and the reaction is to be done by the biological system. The advantage of the effluent-quality with meeting the high standard of the EU-bathwater-guideline stands in contrast to the higher energy demand and the sensitivity against peak-concentrations like ammonia.

Membrane technology has been used in municipal wastewater treatment involving the application of polymer membranes for more than 10 years now. Polymer membranes have proved themselves, despite exhibiting material dependent disadvantages such as limited chemical stability during cleansing or anti-fouling measures. Ceramic membranes appear to hold significant potential in this area. An extensive implementation of ceramic tubular membranes (cross-flow) for wastewater treatment results in high module and operating costs for the operator. Ceramic flat membranes, which can be implemented in the form of submerged low pressure membranes (TMP <1 bar) are to be tested as alternatives. Their suitability for the treatment of large-volume wastewater streams or types of wastewater that are unsuitable for polymers due to their chemical properties, in combination with a high lifespan of the material involved, facilitates economical deployment (BRINKMEYER ET AL., 2006).

Deammonification process for the treatment of sludge water

By a separate treatment of the sludge water, the biological stage of a municipal wastewater treatment plant may be discharged significantly. For sludge water treatment chemical and physical methods as ammonia-stripping are used as well as biological methods like e.g. nitrification/denitrification. Typically the sludge water is characterized by high ammonia content and low COD/N ratio which makes it unfavourable for conventional biological treatment. Full nitrogen removal by nitrification/denitrification may only succeed by addition of an external carbon source like acetic acid which leads to high operating costs. With the process of Deammonification nitrogen can be biologically removed from wastewater with low COD/N ratio without any additional carbon source.

The Deammonification Process can be described as a process divided into two different steps, which are performed by two groups of organisms. The first step, the aerobic conversion of ammonia to nitrite is done by bacteria of the *nitrosomonas* group, for the following, anoxic conversion of nitrite and ammonia to elementary nitrogen, organisms which are members of the group of *planctomycetales* are hold responsible. Figure 6 shows the application of both steps in a biofilm.

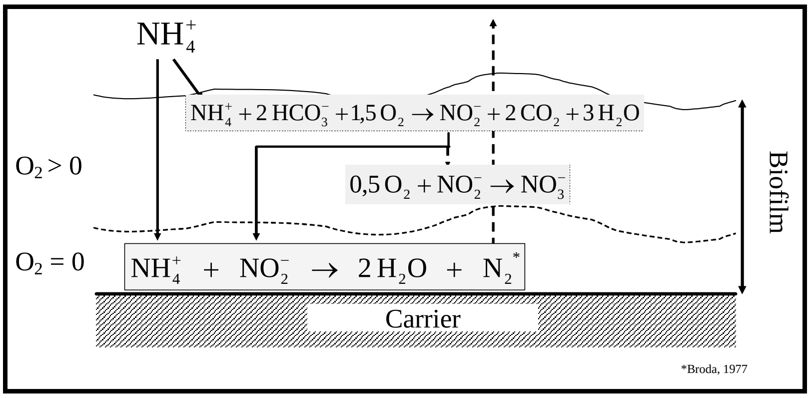


Figure 6: Deammonification in a Biofilm

The members of the *planctomycetales* group seem not to be able to build up an own biofilm structure but need an existing biofilm to enrich in. Thus, the first step of starting up Deammonification is an aerobic operation with high substrate load and adequate aeration which will result in a mixed biocoenosis containing aerobic and anoxic ammonia oxidisers. In a Moving Bed-system the thickness of the biofilm is limited by the shear forces caused by intense mixing, which means build up of anoxic zones for the second step of Deammonification is only possible by ensuring a low oxygen concentration in the reactor. Another possibility is to divide the two process steps ‘time-based’ by an alternating aeration or ‘physically’ by using different reactors.

To ensure Deammonification it is necessary to perform only the first step of nitrification and not oxidise the ammonia to nitrate but nitrite. Therefore the nitrite oxidising *nitrobacter* bacteria have to be inhibited selectively. One possibility to establish nitritation is to completely wash out the *nitrobacter* out of a system of suspended solids by simply adjusting the sludge age appropriately. This can be done, because at higher temperatures the growth rate of *nitrosomonas* is becoming higher than that of *nitrobacter*. The point of washing out *nitrobacter* at e.g. 25°C is at a sludge age of about 1.3 days. The patented SHARON-system is based on this principle and can be used to easily apply a nitritation system (MULDER AND VAN KEMPEN, 1997). SHARON-reactors already are in operation at several WWTPs. Because the washing out of certain bacteria by regulation of the sludge age is not suitable for a biofilm process, different methods for inhibition of nitrite oxidisers must be developed, which do not have a negative influence on aerobic ammonia oxidisers. For example the sensitivity of *nitrosomonas* bacteria on free ammonia (NH_3) is lower than that of *nitrobacter*. Thus, nitritation can be established by adjusting the pH value because the balance between ammonia as NH_4 and free ammonia as NH_3 is based on the ammonia concentration, temperature and the pH value. By rising the pH by addition of a base like NaOH free ammonia will also rise and *nitrobacter* will be inhibited. The ammonia concentration and the pH will have to be observed accurately because, if free ammonia rises too much, *nitrosomonas* also will be inhibited. Another possibility of selective inhibition of aerobic nitrite oxidisers is based on the different conversion rates in relation to the oxygen concentration. At low DO, *nitrosomonas* is growing faster than *nitrobacter* so nitrite will be enriched (HIPPEN, 2001). Also an intermittent aeration of a nitrification reactor will lead to nitrite enrichment if the aeration time is adjusted appropriately, because after switching on aeration again, *nitrobacter* seem to have a „lag-phase“ that is longer than the one of *nitrosomonas* (KATSOGIANNIS ET. AL., 2002). This method of discontinuous aeration is successfully used to ensure nitritation in the full scale plant at Hattingen which is describe in the following chapter.

In the year 2000 a full scale sludge-water treatment plant was built at the WWTP of Hattingen by the Ruhrverband, Germany. Within the scope of a research project, the process of Deammonification should be implemented, using the Kaldnes®-Movig-Bed System. Project partners were the Ruhrverband, the PURAC GmbH, Merseburg, and the Institute for Water Quality and Waste Management Hanover. Figure 7 shows the flowsheet of the full-scale plant in Hattingen.

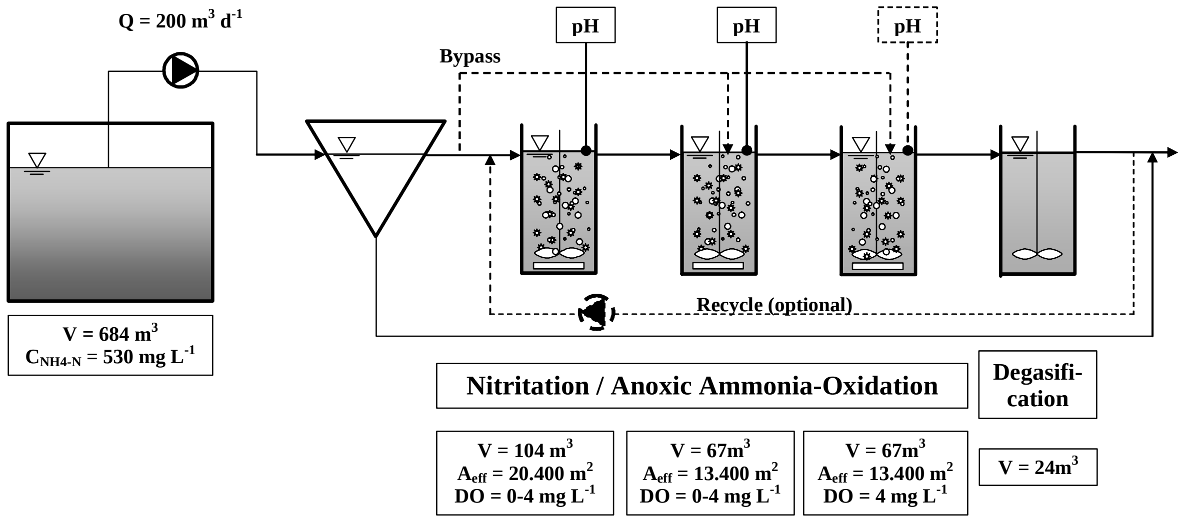


Figure 7: Flowsheet of the full scale Deammonification at Hattingen (ROSENWINKEL ET AL., 2005)

Some results of the Deammonification Phase are shown in Figure 8. In this Figure the nitrogen feed for the plant is shown together with the temperature of the wastewater and the load converted to elementary nitrogen. Maximum performance is at approx. 70-80% converted at a load between 100-160 kg N d^{-1} during normal operation. In the beginning of 2004 a reduced nitrogen elimination of down to 25 kg N d^{-1} was detected, caused by very low wastewater temperature and, following, by biofilm loss. Meanwhile by rising the nitrogen load and oxygen supply, the biofilm thickness has developed again and nitrogen elimination performance has reached a satisfactory level. In winter 2004/2005 plant performance could be ensured, because the water temperature did not drop below 20°C due to the installation of a cover to the sludge water storage tank. Nevertheless the measurement of the biomass cultivated on the Kaldnes®-carriers has become one of the most important factors for running the Deammonification plant.

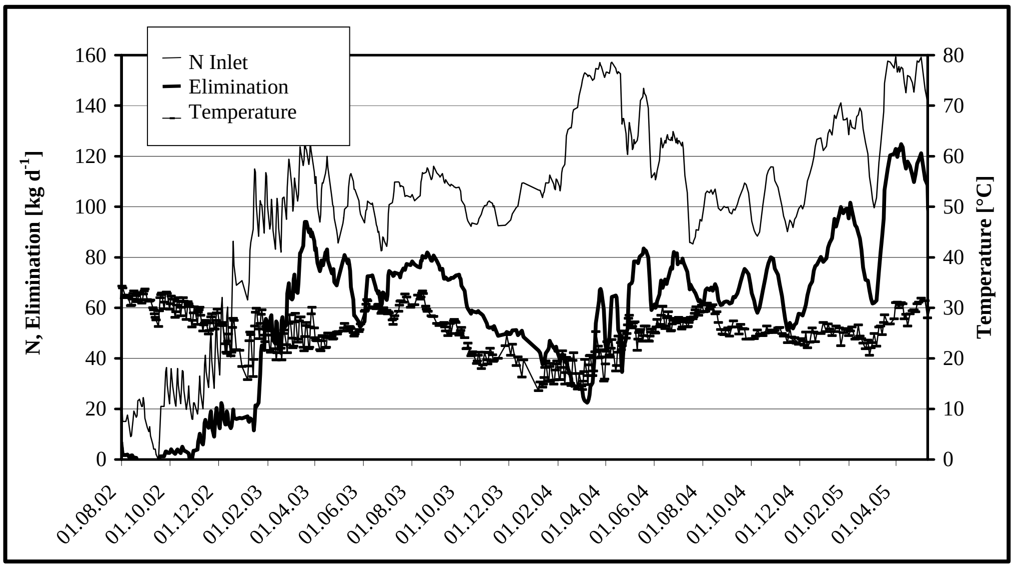


Figure 8: Overall performance of the full scale Deammonification (ROSENWINKEL ET AL., 2005)

Optimisation of Phosphorus Recovery by MAP Precipitation (Magnesium-Ammonium-Phosphate)

Another trend is the development of techniques for phosphorus recovery, which can be done by recovery from the liquid phase, from the sludge or from the ash. The stream used for P recovery is selected based on the recovery potential to be utilised, the acceptable effort for phosphorus redissolution and the desired quality of the precipitation.

Figure 9 shows the phosphorus balance of a WWTP with enhanced biological P-removal (EBPR). Approx. 10 % of the phosphorus remain in the effluent and approx. 11% are incorporated in the primary sludge (Jardin, 2003). The potential of p-recovery from the liquid phase accounts for approximately 37 %, from digested sludge or ash nearly 90 %.

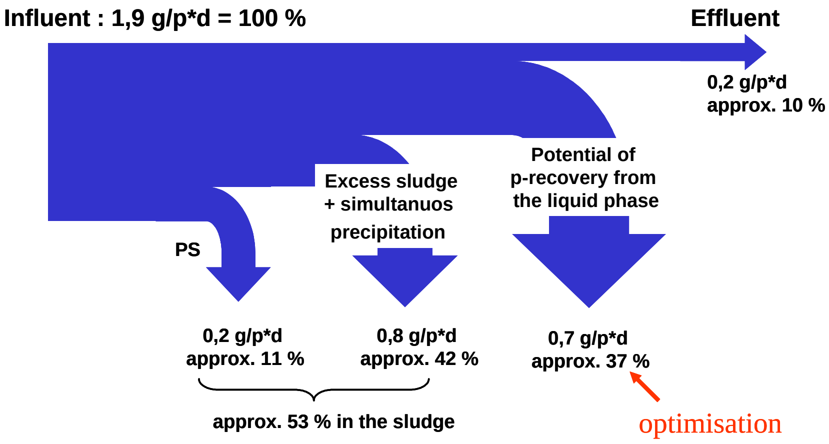


Figure 9: Potential for phosphorus recovery from the liquid phase (ROSENWINKEL ET AL., 2005a)

The recovery from the liquid phase shows in comparison with recovery from digested sludge or ash the slightest potential. However it is relatively easy to apply and to integrate near-term in existing plants. Furthermore, processing of the received phosphorus-products of P-recovery by crystallisation or MAP-precipitation is much easier and without or with only low application of chemicals. It is thus cheaper than a P-recovery from digested sludge or ash.

In case of plants with enhanced biological P-removal, the goal is to re-extract the phosphorus stored in the phosphorus accumulating organisms (PAOs). For this, a reactor is placed in the return activated sludge line. In this reactor an anaerobic phosphorus release is initiated by dosing readily biodegradable carbon. Through subsequent precipitation and separation, the stored phosphorus can be recovered and re-used as e.g. fertiliser.

Among optimisation of precipitation the optimisation of phosphorus-redissolution plays a crucial role regarding to utilise as much as possible potential of phosphor-recovery.

Known measures for optimisation of phosphorus-redissolution are increasing the supply of readily biodegradable substrate, adjusting the optimum of pH-value and temperature as well as an adequate anaerobic contact time. Considering excess sludge, thickened sludge offers an other chance of optimisation. Due to a lower flow, less tank volume is needed. Furthermore by disintegration of the excess sludge by extensive cell disruption more redissolution can be achieved.

The precipitation of phosphate and magnesium respectively as $NH_4MgPO_4 \times 6H_2O$ is known in the analytic chemistry since 1825. In the chemical nomenclature, the hardly soluble salt is named ammonium-magnesium-phosphat-hexahydrat. In wastewater engineering it is applied for precipitation of ammonium or phosphorus and it is called magnesium-ammonium-phosphat (MAP) or struvite.

The technical reaction equation of MAP-precipitation results with regard of the chemically combined water:

$$Mg^{2+} + NH_4^{+} + PO_4^{3-} + H_2O \leftrightarrow MgNH_4PO_4 \cdot 6\,H_2O$$

MAP-precipitation is influenced by temperature, supersaturation degree achieved in the reactor related to pH, Mg^{2+}, NH_4^+ and PO_4^{3-} concentrations, and the presence of other ions such as Ca^{2+}.

Uncontrolled precipitation of MAP can produce pipe blockages and problems in the succeeding aggregates of the dewatering process. However, MAP can be crystallised under controlled conditions. Figure 10 shows an example for a MAP-precipitation unit on a WWTP with EBPR.

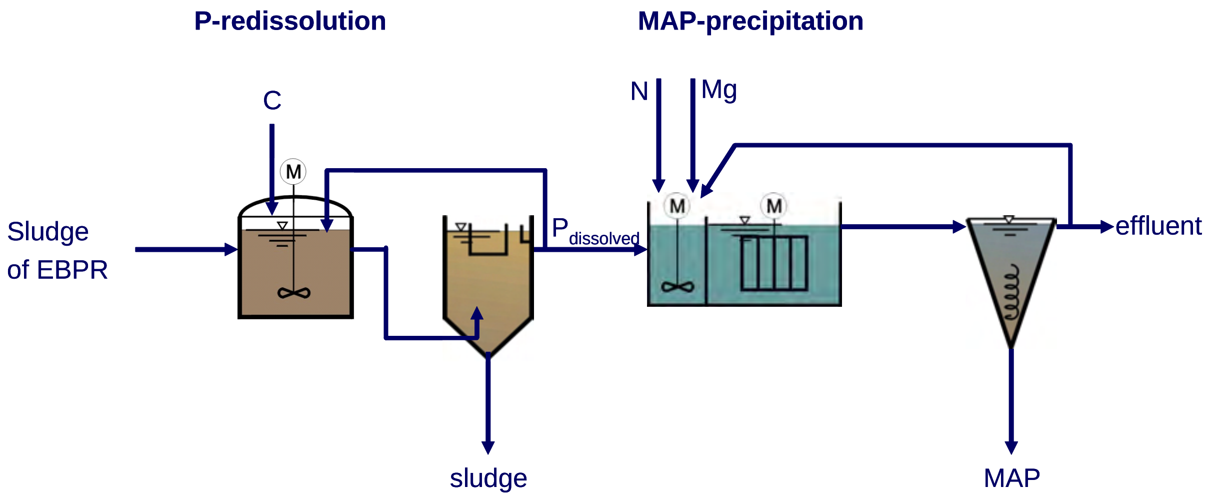


Figure 10: Flowsheet of a potential implementation of a MAP-precipitation unit on a WWTP with EBPR

Readily biodegradable substrate, required for P-redissolution, can be obtained from the supernatant of the acidification of primary sludge. Sludge liquor from plants with sludge digestion can be used as nitrogen source.

WWTP with anaerobic sludge stabilisation have a higher sludge age and different sludge balance than plants without sludge stabilisation. It would be interesting to analyse the influence of this differences on the phosphorus recovery.

Anyway, the controlled MAP-precipitation enables EBPR plants to achieve very low levels of effluent phosphorus concentrations and to recover phosphorus as a product that can be used as a fertiliser.

Conclusions

EU has introduced minimum effluent (emission) standards in 1991 which led to implementation of biological nutrient removal. The trends in EU and Germany also point towards lowering the effluent nutrient levels to below those required by EU Directive, leading to lower discharge fees and protection of eutrophic receivers.

In spite of local preferences for a particular BNR configuration, similar tendencies were observed in Germany with the most common process employing anaerobic/anoxic/aerobic configuration with pre-denitrification, with many plants capitalizing on the simultaneous nitrification and denitrification (SND) and with practicing enhanced biological phosphorus removal (EBPR) in fullstream or sidestream.

The main new trends in EU and Germany include the integrated river basin management, the deammonification process for the treatment of sludge water, the optimisation of phosphorus recovery by MAP and the membrane technology (MBR and ceramic membranes) especially for the elimination of endocrine disrupters and pharmaceuticals.

References

AbwV (2004): *Verordnung über das Einleiten von Abwasser in Gewässer, Bekanntmachung der Neufassung der Abwasserverordnung vom 17.Juni 2004*. BGBl. I S. 1108

Brinkmeyer, J.; Rosenwinkel, K-H.; Binkle, O.; Braun, G.; Gabriel, K.; Nonninger, R. (2006): *Development of a submerged ceramic plate module within the scope of a DBU project,* Vortrag auf der Industrial Water 2006, Dechema, 06.02.2006 in Frankfurt

Broda, E. (1977): *Two kinds of lithotrophs missing in nature*, Zeitung Allg. Mikrobiol. Vol. 17, No. 6, pp. 491-493

EU (1991) *Rat der Europäischen Gemeinschaften: Richtlinie des Rates vom 21.05.1991 über die Behandlung von kommunalem Abwasser (91/271/EWG)*; Amtsblatt der Europäischen Gemeinschaften Nr. L 135, 1991

Hippen, A. (2001): *Einsatz der Deammonifikation zur Behandlung hoch stickstoffhaltiger Abwässer*, Publications of the Institute of Water Quality and Waste Management, University of Hanover Vol. 116

Jardin, N. (2003): *Phosphorbilanz bei der Abwasser- und Klärschlammbehandlung In: Rückgewinnung von Phosphor in der Landwirtschaft und aus Abwasser und Abfall,* Tagungsband zum Symposium am 6./7. Februar 2003 in Berlin

Katsogiannis, A. N.; Kornaros, M.; Lyberatos, G. (2002): *Enhanced Nitrogen Removal in SBRs Bypassing Nitrate Generation Accomplished by Multiple Aerobic/Anoxic Phase Pairs*, e21344a, IWA 3rd World Water Congress, Melbourne, Australia, 7.-12. April 2002

Makinia, J., Rosenwinkel, K. H., Spering, V. (2005) *Long Term Simulation of the Activated Sludge Process at the Hannover Gümmerwald Pilot WWTP.* Water Research 39, 1489-1502

Mulder, J.W.; van Kempen, R. (1997): *N-removal by SHARON*, Water Quality international, IAWQ (Edit.), March/April 1997, pp. 30-31

Obenaus, F., Rosenwinkel, K.-H., Alex, J., Tschepetzki, R. und Jumar, U. (1999): *Components of a model-based operation system for wastewater treatment plants.* Water Science and Technology, 39 (4), 103-111

Rosenwinkel, K.-H., Cornelius, A., Thöle, D. (2005): *Full Scale Application of the Deammonification Process for the treatment of Sludge Water.* IWA Specialized Conference, Krakow, Poland, 19.-21. September 2005

Rosenwinkel, K.-H., Beier, M., Pabst, M. (2005a): *Optimierung der Phosphorrückgewinnung aus der wässrigen Phase mittels MAP*, Tagungsband zum 75. Darmstädter Seminar Rückgewinnung von Phosphor aus Abwasser und Klärschlamm, Schriftenreihe WAR, Band 167

Rosenwinkel, K.-H., Spering, V. (2006): *Plant Wide Modeling als Instrument medienübergreifender Emissionsbetrachtung*; 13. Simba Anwendertreffen; 18. bis 19. Mai 2006, Wernigerode

Seggelke, K. (2002): *Integrierte Bewirtschaftung von Kanalnetz und Kläranlage zur Reduzierung der Gesamtemissionen.* Dissertation am Institut für Siedlungswasserwirtschaft und Abfalltechnik der Universität Hannover, Veröffentlichungen des Institutes für Siedlungswasserwirtschaft und Abfalltechnik der Universität Hannover, Heft 124

Seggelke, K., Rosenwinkel, K.-H. (2002): *Online-Simulation of the WWTP to minimise the total emission of WWTP and sewer system* Water Science and Technology, 45 (3), 101-108

Spering, V. (2006): *Plant Wide Modeling von Abwasserbehandlungsanlagen als Teil einer Gesamtbetrachtung von Stoffeinträgen*, Vortrag 18. Norddeutsche Tagung für Abwasserwirtschaft und Gewässerentwicklung; 2006

Wendler, D. (2005): *Erfassung und Behandlung ausgewählter Stoffströme in der Siedlungswasserwirtschaft*, Veröffentlichungen des Institutes für Siedlungswasserwirtschaft und Abfalltechnik der Universität Hannover, Heft 131, 2005

Municipal wastewater treatment in Germany - state of the art -

Prof. Dr.-Ing. K.-H. Rosenwinkel
Institute for Water Quality and Waste Management
Leibniz University Hannover

Content

- Effluent requirements
- Typical process configurations
- Trends in Technology and Management:

  Management:
  - Integrated River Basin Management

  Technology:
  - Membrane Technology
  - Biofilm Technology

  Sidestream Elimination and Recovery:
  - Deammonification
  - P-Recovery / Energyrecovery

Effluent requirements

EU Effluent requirements

Requirements EU-Standards					
Size [inhab. equiv.]	COD [mg/l] (**)	BOD [mg/l] (**)	NH_4-N [mg/l]	$N_{tot.}$ [mg/l] (*)	$P_{tot.}$ [mg/l] (*)
10.000 - 100.000	125 or 75 %	25 or 70 -90 %	-	15 or 70 - 80 %	2 or 80 %
> 100.000	125 or 75 %	25 or 70 - 90 %	-	10 or 70 - 80 %	1 or 80 %

FRG Effluent requirements

Minimum requirement FRG					
Size [inhab. equiv.]	COD [mg/l]	BOD [mg/l]	NH_4-N [mg/l]	TN_{min} [mg/l]	$P_{tot.}$ [mg/l]
5.000 – 10.000	90	20	10	-	-
10.000 - 100.000	90	20	10	18	2
> 100.000	75	15	10	13	1

TN_{min} = TN mineral (without organic) (*) for „sensitive areas", (**) „normal areas"

Typical process configurations

Activated Sludge Systems

N – Elimination

- simultaneous denitrification
- Cascade denitrification
- Preliminary denitrification
- Intermittent denitrification
- Alternating denitrification
- Sludge stabilisation
- SBR-Technology
- Membrane bioreactors
- A-B Technology / 2 stage

P removal

- EBPR (combines with any activated sludge system)
- Johannesburg System
- ISAH System
- Phoredox System/Phostrip

Biofilm Systems

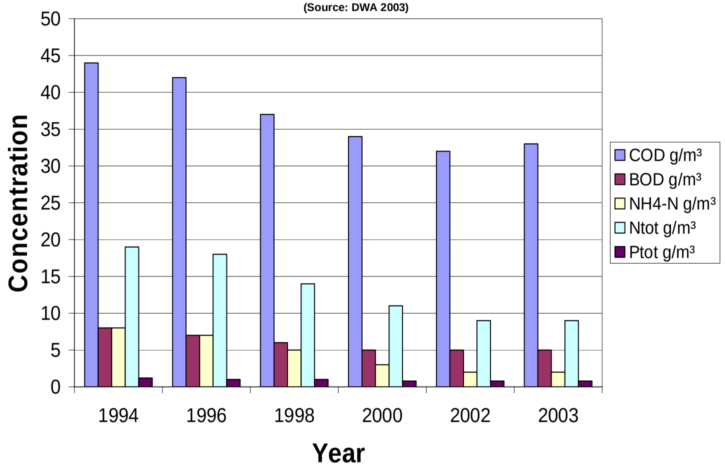
- Biofilter (Nitrification and Nitrification / Denitrification)
- Moving bed systems

Total number of municipal WWTP's in FRG: 6110

Full Scale Experiences

Mean yearly effluent concentrations of german WWTP's

(Source: DWA 2003)

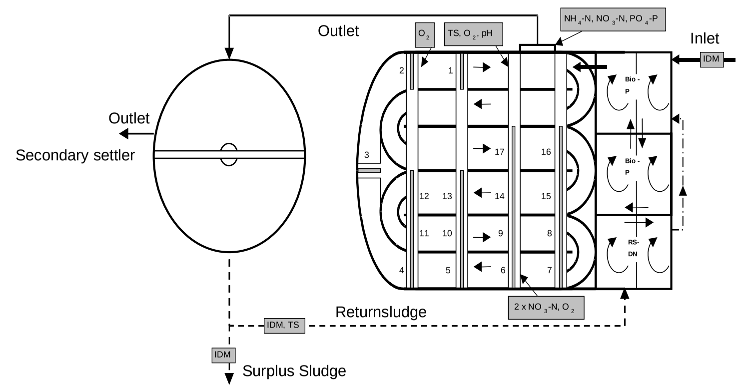


Institut für Siedlungswasserwirtschaft und Abfalltechnik
Leibniz Universität Hannover

WWTP Hildesheim

6

Simultaneous N – Elimination and EBPR in a fullstream



Institut für Siedlungswasserwirtschaft und Abfalltechnik
Leibniz Universität Hannover

Integrated River Basin Management

7

Aim

European Water Framework Directive:

⇨ imission based approach

⇨ river water quality management

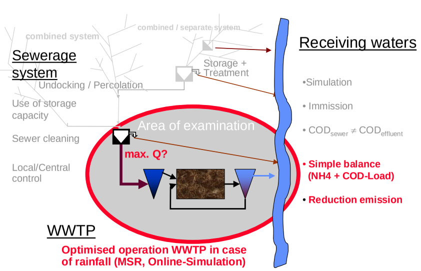
⇨ integrated systemwide approach

Case Study

⇨ inflow WWTP > 2 $Q_{dryweather}$

⇨ significant reduction of the emission

⇨ but: exceeding of the limiting values can't be excluded in case of rainfall



Research approach

⇨ optimisation of the control strategies

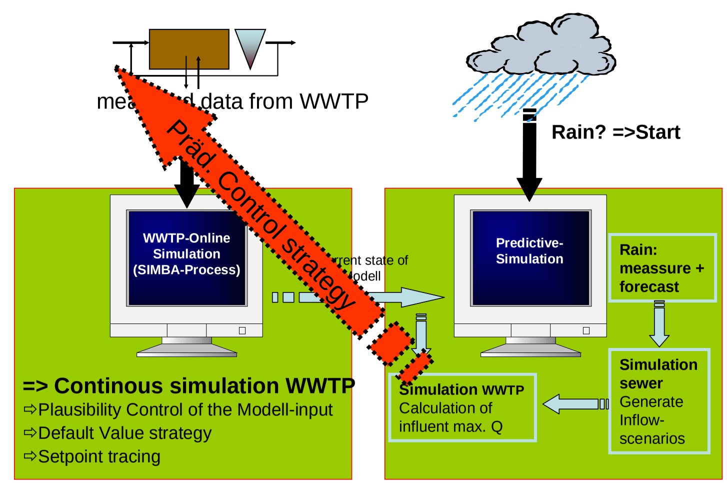
⇨ continuous observation of the state + prognosis

⟹ **Predictive, adaptive control system with an online coupled model** prediction and regulation

Institut für Siedlungswasserwirtschaft und Abfalltechnik
Leibniz Universität Hannover

Predictive Control Strategy using simulation

8



Institut für Siedlungswasserwirtschaft und Abfalltechnik
Leibniz Universität Hannover

Research project ISAH (founded BMBF)

9

Phase 1: „pilot-scale plant“ (Hannover-Gümmerwald)

1) Influence of increasing Q, optimal MSR-strategy etc.

2) Test of Online-simulation

results:

⇨ Capacity up to 4 Q_t (critical: Nitri + final clarifier)

⇨ MSR-concepts for rainwether conditions developed

⇨ Very good results for longtime simulation (ASM 2d)

Phase 2: fullscale plant (KA Hildesheim)

1) Online-simulation WWTP + prognose-simulation plant + sewer

2) Integrated view: influence on river (Optimisationpotential)

⇨Control by measurements sewer, WWTP, river

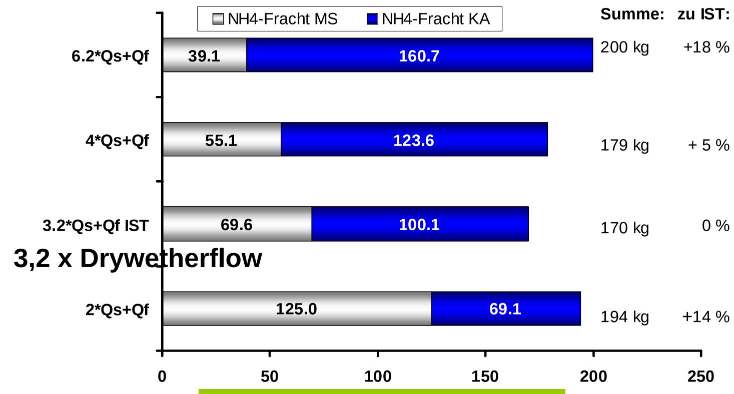
⇨Casestudies-simulation with calibrated models

Institut für Siedlungswasserwirtschaft und Abfalltechnik — Leibniz Universität Hannover

Trends: Integrated River Basin Management

10

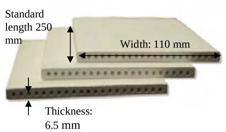
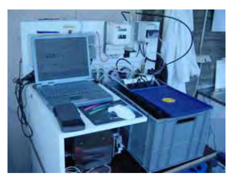
NH_4-N-load from Sewer and WWTP (Simulation results)



Institut für Siedlungswasserwirtschaft und Abfalltechnik — Leibniz Universität Hannover

Laboratory Tests

11

Nanopore® -Model F 21/30/1100	Laboratory module	Laboratory system
		

- Internal channel 21 units, ∅ 3 mm
- Pore size 800/300/200/80/ 50 nm
- Membrane material α-Al_2O_3
- Pressure resistance > 10 bar

- 0.172 m² active filtering surface
- 3 x 25 cm plates
- 3 aerator tubes for cross flow

- 45 l activated sludge tank
- Fully automatic process management & data recording
- Capacity of 0.11 to 1 m² of filtering surface

Institut für Siedlungswasserwirtschaft und Abfalltechnik — Leibniz Universität Hannover

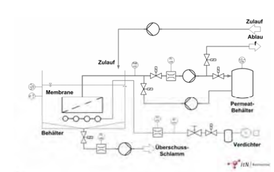
Municipal wastewater pilot system

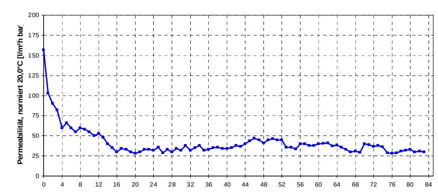
12

From laboratory to pilot system at the municipal wastewater treatment plant

- 4 m² filtering surface
- TS= 2-5 g/l
- TMP= 300 mbar
- Permeability after 80 days: 30 l/m²hbar

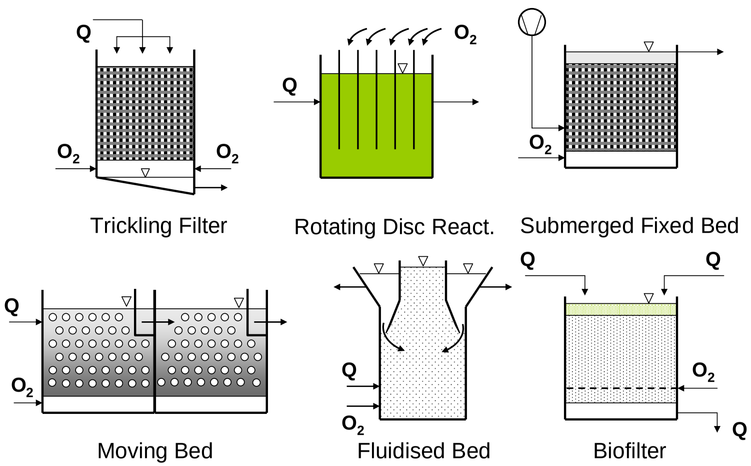
➡ Good comparability of laboratory values





Institut für Siedlungswasserwirtschaft und Abfalltechnik — Leibniz Universität Hannover

Biofilm Technologies
13



ISAH Institut für Siedlungswasserwirtschaft und Abfalltechnik — Leibniz Universität Hannover

Deammonification
14

Biological Nitrogen Removal via Nitrite

Nitritation	Nitratation	Denitrification
$NH_4 + O_2 \rightarrow NO_2$	$NO_2 + O_2 \rightarrow NO_3$	$NO_3 + org.\ C \rightarrow N_2$

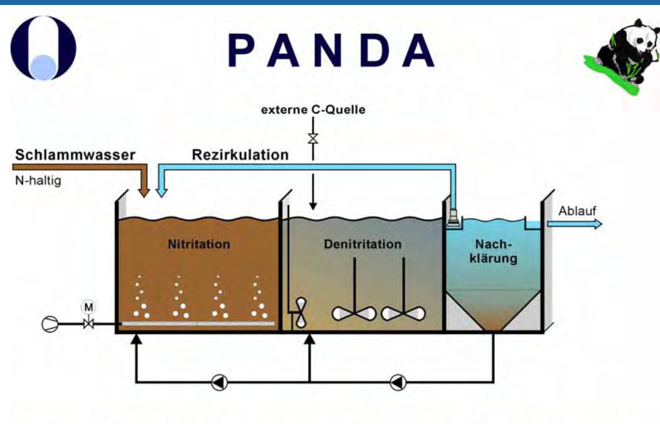
Nitritation	Denitritation
$NH_4 + O_2 \rightarrow NO_2$	$NO_2 + org.\ C \rightarrow N_2$

Deammonification

$NH_4 + O_2 \rightarrow NO_2 \longrightarrow NH_4 + NO_2 \rightarrow N_2 + 2H_2O$

ISAH Institut für Siedlungswasserwirtschaft und Abfalltechnik — Leibniz Universität Hannover

15

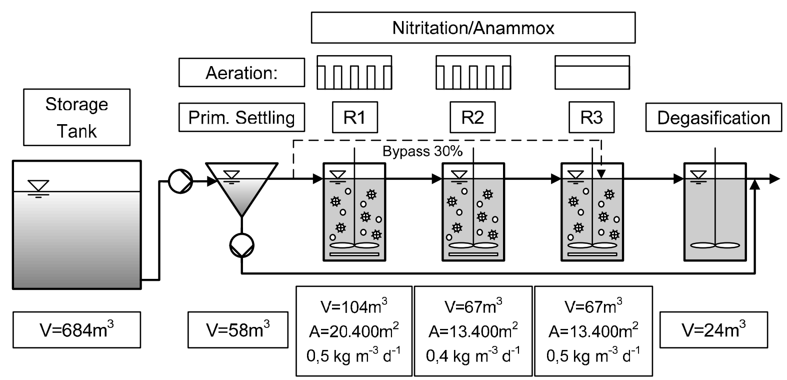


Partial Augmented Nitritation Denitritation Alkalinityrecovery

Developed and copyright by aqua consult Ingenieur GmbH / ISAH, Universität Hannover

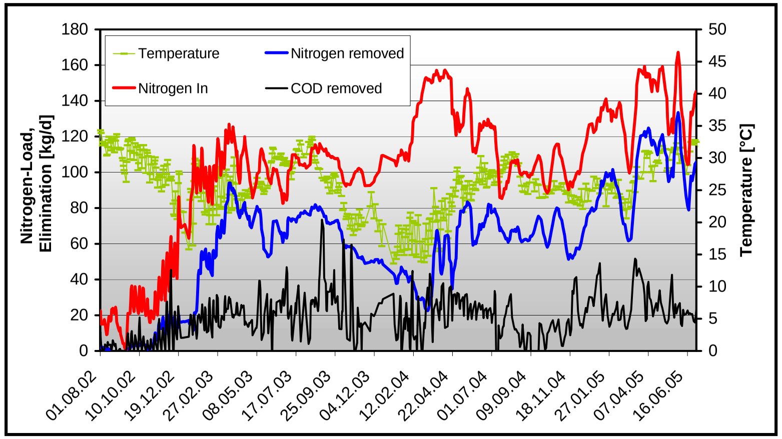
ISAH Institut für Siedlungswasserwirtschaft und Abfalltechnik — Leibniz Universität Hannover

Full scale plant at Hattingen
16



ISAH Institut für Siedlungswasserwirtschaft und Abfalltechnik — Leibniz Universität Hannover

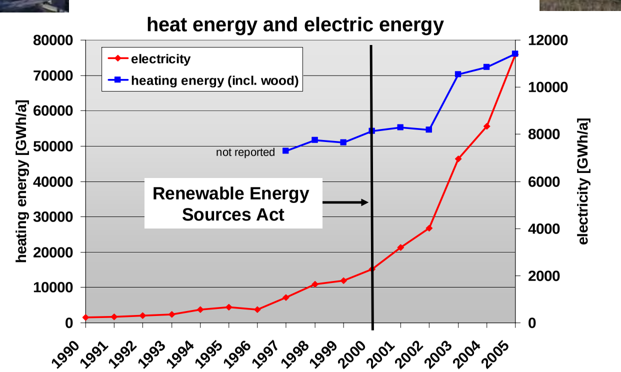
Nitrogen-, COD-Elimination over the full scale Plant



Design of the Mixing Facilities R1 & R3

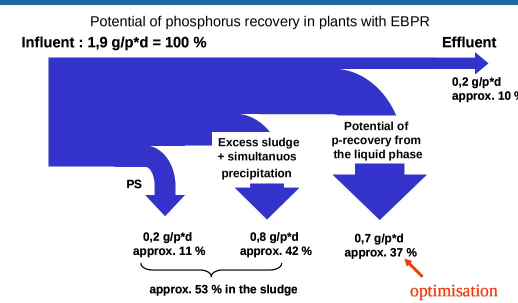
Anaerobic Digestion of Wastes and Energy crops

Real production of biomass energy in Germany



[BMU, Mai 2006]

Phosphorus Recovery



- **Recovery from Surplus-sludge PRISA Process (MAP precipitation)**
- **Recovery from anaerobic digested sludge**
- **SEABORN process**
- **PHOSTRIP process**
- **Aqua Reci process**
- **KREPRO bzw. Kemicond process**

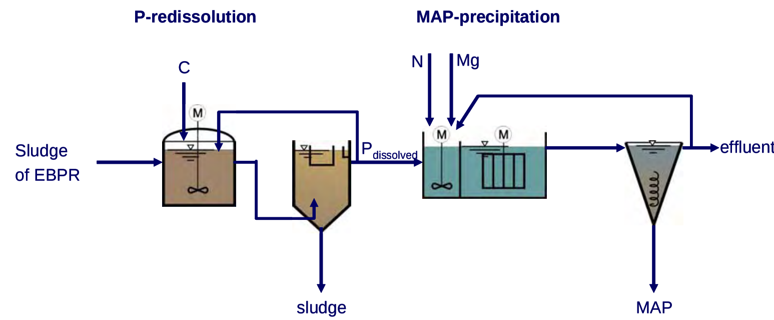
MAP precipitation in digested sludge pipes

21

Institut für Siedlungswasserwirtschaft und Abfalltechnik — Leibniz Universität Hannover

Optimising MAP precipitation

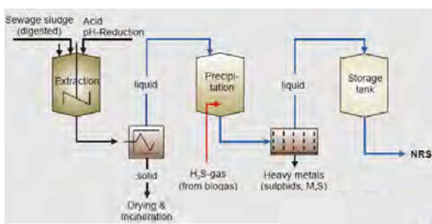
22



Institut für Siedlungswasserwirtschaft und Abfalltechnik — Leibniz Universität Hannover

SEABORN process

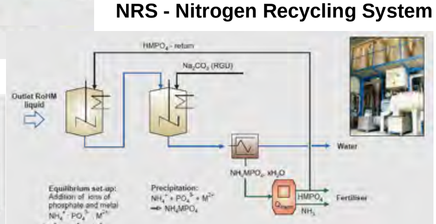
23

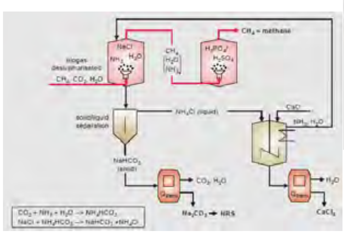


RoHM - Removal of Heavy Metal

Pilotplant Owschlag SLH
Fullscale plant Gifhorn NDS

NRS - Nitrogen Recycling System





RGU – Regenerative Gas Upgrading

www.seaborne-erl.de, 2006

Institut für Siedlungswasserwirtschaft und Abfalltechnik — Leibniz Universität Hannover

Conclusions and final remarks

24

- Minimum Requirements for C/N/P are fullfilled in germany
- Applications of different Technologies for N and P-removal are in operation, most activated sludge, but also biofilmtechnologies
- Integrated Management of sewer and WWTP is nessecary for optimisation costs and efficiency
- Membranetechnology gives chances to improve the hygienic aspects in the riverquality
- Sidestreamtechnology for deammonification is a efficient application of biofilmtechnology
- Energyrecovery from waste and sludge is efficient, energyproduction from crops must be validated, the competition to the food production in agricultural area must be very carefully observed
- Future technology must consider harmful substances, endocrine disrupters and personal careproducts

Institut für Siedlungswasserwirtschaft und Abfalltechnik — Leibniz Universität Hannover

THANK YOU FOR YOUR ATTENTION