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REPORT

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Comparative study of small wastewater treatment technologies under special operation conditions

COMPAS

by

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Abstract

In rural areas, small wastewater treatment plants (SWWTP) are a cost-efficient solution to sewage disposal issues. In Europe, small WWTPs are defined as plants for treating domestic wastewater up 50 PE. In Germany, about 2.2 million SWWTPs are in operation or are being installed. In France about 10 to 12 million people are served by decentralised systems.

There are many different technical solutions on the market, ranging from artificial wetlands, reed bed filters to activated sludge systems. All systems available on the European market have to meet the EU-Certification EN 12566-3, which regulates a minimum standard of operation reliability and purification limits. Furthermore, additional guidelines have to be considered, depending on national and regional specifications. There is still a lack of information about performance, operation reliability and maintainability of the different types of SWWTP under real operating conditions. These parameters are however, of particular importance to both customers and service providers. To fill this gap, during a duration time of 14 month in this study 12 different treatment systems were simultaneously compared and evaluated under real operating conditions. The study delivers now detailed information about the performances of different plant models with regard to purification capacity, effluent values, operating expenditures, sludge treatment etc. The results will be published in a user guide.

The study was performed at the Training and Demonstration Centre for Decentralised Sewage Treatment (BDZ) in Leipzig with a special range of small wastewater treatment plant, already installed at BDZ for training purposes as well as two additional plants, which has been installed there especially for the compass study.

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Chapter 1

Motivation and Objectives

All small wastewater treatment systems sold on the European market must be certified to European standard EN 12566, Part 3 (EN 12566-3). As such, they all meet uniform minimum requirements for operating safety and treatment efficiency. In addition, each system must meet any national or regional standards that may apply. However, these minimum requirements say little about the treatment efficiency, stability, ease of maintenance and wide range of different technological features of SWWTPs under realistic operating conditions, although this information would be of particular interest, not only to consumers but also to wastewater service providers.

Therefore, it was an explicit objective of the COMPAS study to test a wide range of SWWTPs under as real as possible operation conditions for more stringent than those defined in design approval procedures and EU certification throughout a test period of one year. In particular, operating conditions were to be simulated, that the principal "Veolia" had determined as representative for one-family-households in France, meaning comparably high specific water consumption and high temporal fluctuation of usage within a year.

The test took place on the Demonstration field of the BDZ with 10 already installed plants, that are provided by the manufacturers organised in the BDZ for demonstration and training purposes. In addition, two Canadian SWWTPs were to be installed for the COMPAS study, to be able to compare the results of this study with an almost contemporaneously carried out study in France (CSTB, Nantes). The operation conditions of this French study consisting of a test field with 8 SWWTPs, mainly soil filter systems, were identical.

The test program was to be carried out in accordance with EN 12566-3 (daily schedule, etc.) with additional load charges. Throughout the year of testing, the following process variables were to be assessed:

- Treatment efficiency,
- Technical and maintenance requirements,
- Operational stability,
- Power consumption,
- Consumables
- Sludge accumulation, etc.

To facilitate interpretation of the results in regard to the effluent values not only the German limiting values but the French limiting values were taken into account as references as well.

Chapter 2

Definitions and Explanations

2.1 Abbreviations and translations

For better comprehension at the international level, all data concerning the target parameters are written and/or abbreviated in English throughout this report. Legends to tables and figures are also presented in English as far as possible.

German and English equivalents of important terms and abbreviations are listed on the following page (Table 1).

Table 1: German and English equivalents of important terms and abbreviations

English		German	
NH_4-N	Ammonia nitrogen	NH_4-N	Ammoniumstickstoff
BOD_5	Biochemical oxygen demand in five days	BSB_5	biochemischer Sauerstoffbedarf in fünf Tagen
COD	Chemical oxygen demand	CSB	chemische Sauerstoffbedarf
	Conductivity		Leitfähigkeit
	Degradation rate		Abbaugrad
	Class	GK	Größenklasse
	Limiting value (maximum limit)		Überwachungswert (Grenzwert)
	Mean		Mittelwert
	Median		Median-Wert
max.	Maximum	Max	Maximum
min.	Minimum	Min	Minimum
N_{tot}	Total nitrogen	N_{ges}	Stickstoff, gesamt
N_{inorg}	Inorganic nitrogen	N_{inorg}	Stickstoff, inorganisch
N	Number of samples	N	Anzahl
P_{tot}	Total phosphorus	P_{ges}	Phosphor, gesamt
PLC	Programmable logic controller	SPS	Speicherprogrammierbare Steuerung
	Treatment efficiency		Reinigungsleistung
SD	Standard deviation	SA	Standardabweichung
	Compliance rate, "stay below probability"		Unterschreitungshäufigkeit
SS	Suspended solids	AFS	abfiltrierbare Stoffe
PE	Population equivalent	EW	Einwohnerwert
VC	Variation coefficient	VK	Variationskoeffizient

2.2 Definitions

2.2.1 Statutory requirements

2.2.1.1 German statutory requirements (maximum limits)

In Germany, maximum limits for the following effluent parameters are prescribed in the German Waste Water Ordinance (AbwV); they apply to Class 1 wastewater treatment plants with capacities of up to 60 kg/d BOD_5 in raw sewage (< 1000 PE) and thus to small wastewater treatment plants and are to be determined in a "qualified random sample" or 2-hour composite sample:

COD: 150 mg/L
BOD_5: 40 mg/L

For WWTPs with small discharges as defined in Section 8 of the Waste Water Ordinance in connection with Section 9 (2) sentence 2 of the Wastewater Levies Law, the requirements are said to be satisfied when a wastewater treatment system approved by General Technical Approval, European Technical Approval according to the provisions of the Building Products Act or state law is installed and operated in conformity with the provisions of the specific authorization. The installation, operation and maintenance requirements for proper function of the system in accordance with the requirements in Section 1 must be specified in the specific authorization.

2.2.1.2 French statutory requirements (maximum limits)

Based on the French statutory limits for small wastewater treatment systems having a biochemical oxygen demand of ≥ 120 kg BOD_5/d (ARRÊTÉ DU 22/6/2007), effluent requirements (maximum limits) were set so as to ensure the comparability of results with those of larger WWTPs. These values are referred to as the "French statutory limits" throughout this report.

COD: 125 mg/L
BOD_5: 25 mg/L
SS: 35 mg/L

2.2.1.3 Minimum requirements of the Deutsches Institut für Bautechnik (DIBt, 2006)

The requirements of the Deutsches Institut für Bautechnik (DIBt) for assessment of treatment performance in the scope of General Technical Approval of small wastewater treatment systems according to effluent class are outlined in Table 2. Wastewater treatment systems meeting the minimum requirements of the Waste Water Ordinance are assigned Class C approval. To have a system approved for a higher class, the manufacturer can submit an application once the necessary tests have been performed. Small wastewater systems are defined by effluent class as follows:

1. Systems with carbon removal: Class C
2. Systems with carbon removal and nitrification Class N
3. Systems with carbon removal, nitrification and denitrification Class D
4. Systems with additional phosphorus elimination: Class C / N / D / +P*
5. Systems with additional hygienisation: Class C / N / D / +H*

* Features "+P" and "+H" are added to Class C, N and D designations where applicable.

Table 2: Minimum requirements for wastewater discharges into surface waters (DIBt, 2006)

Class	**COD** [mg/L]	**BOD_5** [mg/L]	**NH_4-N** [mg/L]	**$N_{inorg.}$** [mg/L]	**P** [mg/L]	**Faecal coliform bacteria** [1/L]	**SS** [mg/L]
C	150^{*} / $\mathbf{100}^{**}$	40^{*} / $\mathbf{25}^{**}$					75^{*}
N	90^{*} / $\mathbf{75}^{**}$	20^{*} / $\mathbf{15}^{**}$	$\mathbf{10}^{**}$				50^{*}
D	90^{*} / $\mathbf{75}^{**}$	20^{*} / $\mathbf{15}^{**}$	$\mathbf{10}^{**}$	$\mathbf{25}^{**}$			50^{*}
+ P					$\mathbf{2}^{**}$		
+ H						100*	

The minimum requirements are said to be satisfied when concentrations in 4 out of 5 consecutive measurements obtained under design load conditions do not exceed the specified concentration limit and if one result does not exceed the limit by more than 100%.

2.2.2 Additional parameters monitored

Apart from the organic parameters BOD_5 and COD, for which there are statutory limits, the following effluent parameters for which no statutory limits exist in Germany were additionally assessed in the scope of this comparative study.

- Suspended solids (SS): provides useful information for sludge overflow analysis.
- Ammonia (NH_4-N): The course of NH_4-N reflects the course of nitrification, which is a more sensitive indicator than the degradation of organic compounds (COD, BOD_5). Therefore, NH_4-N was analysed in all SWWTPs studied even though some were not equipped for nitrification.
- Inorganic nitrogen (N_{inorg}): Provides information about potential denitrification.

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[*] Determined in a qualified random sample or, for faecal coliform bacteria, single random sample

- Phosphorus (P): As the only route by which phosphorus can leave the system is via sludge, increased P concentrations are suggestive of sludge overflow.

2.3 Microbiological parameters

The effluent of each SWWTP was also tested for "faecal indicator bacteria" specified in the EU guidelines for bathing water quality, including pathogenic bacteria (Salmonella) and eggs of nematodes (roundworms). The presence of Escherichia coli in the effluent is a sign of faecal contamination as they are always present in the intestines of humans and warm-blooded animals in significantly higher numbers than other microorganisms that might be pathogenic. Although these microorganisms themselves generally cause no impairment of human health, their presence increases the risk of occurrence of pathogenic microorganisms.

The following bacterial groups or species were classified as faecal indicator bacteria:

- Total coliform bacteria
- Faecal coliform bacteria (Escherichia coli)
- Faecal enterococci (faecal streptococci).

Total coliform bacteria detection only indicates the presence of faecal contamination because these bacteria may originate from sources other than the intestines of warm-blooded animals. Detection of faecal coliform bacteria (Escherichia coli), on the other hand, provides proof of faecal contamination because the intestines of warm-blooded animals are the only source of these microorganisms. Faecal enterococci likewise originate exclusively from the intestines of warm-blooded animals. Because they can survive in water longer than faecal coliform bacteria, their presence can also indicate faecal contamination from further in the past. Tests for pathogenic bacteria (Salmonella) are required under certain conditions (POPP, 2000).

Nematodes or roundworms are some of the most common infectious agents around the world. The name "nematodes" (*nema*—thread) describes the external appearance of the thread-like organisms of this group. Certain nematodes (e.g., *Enterobius, Ascaris* and *Trichiuris*) cause infections in humans after ingestion of the eggs of the parasites. In other cases, the nematode may either actively infiltrate the skin of the host (*Ancylostoma, Necator, Strongyloides*) or be passively transmitted by way of fleas ingested with water (*Dracunculus*) or by biting insects (filarids) (HAHN ET AL. 2009).

[**] Determined in 24h composite samples; NH_4-N and inorganic nitrogen at water temperatures ≥12°C

2.4 Small wastewater treatment plants

Small wastewater treatment plants (SWWTPs) are small-scale wastewater treatment systems designed to handle of domestic wastewater loads of up to 8 m^3/d, corresponding to a connected load of approximately 50 population equivalents (PE). Industrial or agricultural wastewater may also be treated in an SWWTP provided that the wastewater to be clarified is comparable to domestic wastewater.

2.5 Population equivalent

A population equivalent (PE) is the organic load placed on a wastewater system by one individual. The following definitions were used in the study:

- The design load was defined as the design population equivalent specified for a given wastewater treatment system by the manufacturer.
- The real load was calculated based on the actual population equivalent measured during testing.

The following definition specified in the Official Journal of the European Communities (91/271/EEC) served as the basis of both definitions: "1 PE (population equivalent) means the organic biodegradable load having a five-day biochemical oxygen demand (BOD_5) of 60 g of oxygen per day."

The parameters were used for load analyses as follows:

- The *real load* was determined the actual influent load per population equivalent throughout a given sampling period.
- Weekly averages of daily influent loads in L/(PE·d), including bath water discharges on 5 days a week, were used when mean values were required, e.g., for calculation of power consumption per population equivalent (Section 6.2), or specific sludge volume (Section 6.3). These values were then used to determine the corresponding BOD_5 concentration (in mg/L) to yield the *calculated load*.

2.6 Residence time

The mean residence time (t) is a factor of the combined volume (V) of individual tanks and the mean influent load (Q_{mean}). Based on the sum of volumes of the individual tanks (primary clarifier + reactor + secondary clarifier, if present), it is calculated as follows:

$$t = \frac{V}{Q_{mean}} \; [d]$$

t = Residence time, in days
V = Volume of individual tanks (primary and secondary clarifiers, etc.) in m^3
Q_{mean} = mean influent load, in m^3 / d

2.7 Volume load

Volume load (VL) is calculated as the quotient of the organic load and reactor volume. It is therefore related to the organic load and serves as an important variable for system design and comparison. Volume load describes the volumetric "stress" on a wastewater treatment system.

$$VL = \frac{DL_x}{V_{\mathrm{Re}actor}} \left[{}^{kg}\!\big/\!_{(m^3 \cdot d)} \right]$$

VL = Volume load in kg / (m^3·d)
DL_x = Daily load of substance X in kg / d
$V_{Reactor}$ = Reactor volume in m^3

2.8 Volumetric degradation rate

The volumetric degradation rate (VDR) describes the degraded portion of the volume load. Volume load is equal to volumetric degradation when the degradation rate is 100%.

$$VDR = \frac{B_{BOD,\,Inf\,/\,d} - B_{BOD,\,Eff\,/\,d}}{V_{\mathrm{Re}actor}} \left[{}^{kg}\!\big/\!_{(m^3 \cdot d)} \right]$$

VDR = Volumetric degradation rate in kg / (m^3·d)
$B_{BOD,Inf/d}$ = Daily influent BOD_5 load in kg/d
$B_{BOD,Eff/d}$ = Daily effluent BOD_5 load in kg/d
$V_{Reactor}$ = Reactor volume in m^3

2.9 Degradation rate

The degradation rate was determined as a measure of biological or chemical degradation of compounds as specified in EN 12566-3. The degradation rate can be calculated for various compounds individually or as a sum parameter (e.g., TOC, BOD_5 or COD). The following general formula is used to calculate the degradation rate in a wastewater treatment plant:

$$\eta = \frac{C_{Inf} - C_{Eff}}{C_{Inf}}$$

η = Degradation rate

C_{Inf} = Concentration in influent

C_{Eff} = Concentration in effluent

Consequently, the result must be a value between 0 and 1, corresponding to a degradation rate of 0% to 100%. The degradation rate is a measure of a WWTP's treatment efficiency. Because volume flow is present in both the numerator and the denominator, its effect is cancelled, i.e., nullified.

2.10 Statistical parameters

2.10.1 Sample size

The sample size (n) indicates the number of measurements obtained for a given parameter and system.

2.10.2 Mean

The arithmetic means for the statistical analyses were calculated using the following formula:

$$\bar{x}_{\mathbf{arithm}} = \frac{1}{n}\sum_{i=1}^{n} x_i = \frac{x_1 + x_2 + \cdots + x_n}{n}$$

n = Number of samples
x_i = Measured value

2.10.3 Median

The median (x_M) is the line dividing two halves. In statistics, the median is the line dividing a group of measured values in half. One half of the measured values lie below the median, and the other half above the median. As shown in the equation below, the median is particularly useful for assessing an average overall result:

$$xM = \begin{cases} x_{\frac{n+1}{2}} & n \ odd \\ \frac{1}{2}\left(x_{\frac{n}{2}} + x_{\frac{n}{2}+1}\right) & n \ even \end{cases}$$

n = Number of samples
x_i = Measured value

2.10.4 Minimum / Maximum

The minimum and maximum are, respectively, the smallest and largest value measured in a data set.~

2.10.5 Variance

Variance describes the variation or "scatter" of a given variable from the mean. Variance is calculated by dividing the sum of the squares of the deviations by the sample size (number of measured values).

2.10.6 Standard deviation

Standard deviation is a measure of the dispersion of values of a random variable around its mean. Standard deviation is the square of the variance of a random variable.

2.10.7 Coefficient of variation

The coefficient of variation is a statistical parameter used in stochastics and mathematical statistics. It is defined as the relative standard deviation, that is, as the standard deviation divided by the mean.

2.10.8 85th percentile

The 85th percentile, defined as the value which 85% of all measured values were less than, was used to assess the stability of each SWWTP in terms of a target parameter (85% of measured values below the 85th percentile). This is approximately equivalent to the "4 out of 5 rule" described in the German Waste Water Ordinance, which states that 4 out of 5 measured values must be within the maximum limits specified for a given parameter.

2.10.9 Compliance rate ("stay below probability")

The compliance rate, or "stay-below probability", indicates which percentage of measured values was below a specified level. The number of compliant values for a specific percentage (e.g. 85%) can also be determined. This is useful for assessment of process stability, etc. Steep curves indicate good process stability and flat curves poor process stability.

Chapter 3

Description of the Test Site

3.1 Test site (BDZ facility in Leipzig-Leutzsch) and catchment area

The BDZ Training and Demonstration Centre for Decentralised Sewage Treatment is situated along the edge of an alluvial forest in Leutzsch, a district in the western part of the city of Leipzig, Germany. It is located on the premises of the former municipal sewage plant "KA Leutzsch" and is bordered by sports fields and allotment gardening fields. The BDZ facility belongs to the municipal waterworks company "Kommunale Wasserwerke Leipzig GmbH". "KA Leutzsch" was in operation until the year 2000. Wastewater from the Leutzsch catchment area was treated there (see Appendix A for a map of the catchment area). KA Leutzsch had a capacity of 10,000 PE.

Figure 1: BDZ Training and Demonstration Centre in Leipzig-Leutzsch

The old sewage plant, built in 1914, was a biological trickling filter facility that became obsolete due to the passage of increasingly demanding municipal wastewater treatment requirements. Therefore, it was taken out of operation after a new pumping station was connected to the main sewage plant, KA Rosental. In the scope of a project sponsored by the German Environmental Foundation (DBU), the site was modified for used by the BDZ in 2006.

One of the advantages it had from the beginning was the availability of all necessary media. Thanks to the wastewater supply directly from the Leutzsch catchment area, it is possible to investigate SWWTPs there under realistic operating conditions.

The urban drainage network in the Leutzsch watershed is a mixed sewer system with combined wastewater and stormwater channels. The sewer system in the direction of flow upstream of Leutzsch (sum) has a total length of approximately 35,780 m.

The longest distance (path of flow) to the pumping station is roughly 3030 m (pipe length).

Because of the decline in industry in Leutzsch, nearly all of the water in the region is domestic wastewater and sanitary wastewater from industrial enterprises.

3.2 Demonstration field

Each of the small wastewater treatment systems investigated in this study was installed in the rear section of the demonstration field in a container called a "Demo Box" (demonstration box). Due to financial constraints, only a first group of 12 Demo Boxes has been constructed so far. Each Demo Box is 5 x 7 m in size and fully connected to all media required. The base size of the Demo Boxes is variable insofar as the boxes can be connected by taking out removable partitions as needed to adjust the size to fit the measurements of any SWWTP desired.

Figure 2: Demonstration boxes

To achieve high resistance to buoyancy due to potentially high groundwater levels and to achieve a high level of accident safety in case of leakage, an impervious concrete basin was built as the supporting base of each unit. The inner and outer wall components of the Demo Boxes were then erected over the supporting base. A staircase leads to an inspection walkway providing direct access to each of the individual SWWTP units. The walkway is located directly over the operating aisle.

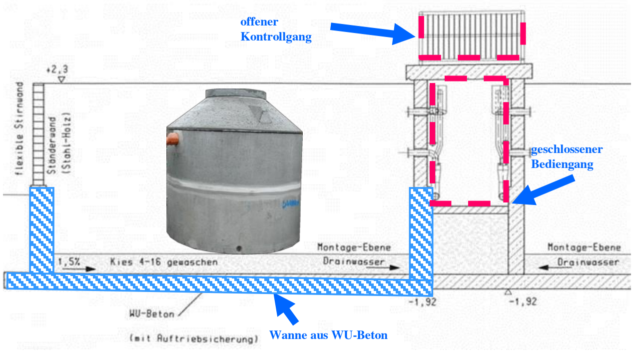


Figure 3: Cross-section through a Demo Box

The demonstration site, measuring 32 × 17 m, is divided into two rows of six Demo Boxes each, which are separated by a closed central operating aisle.

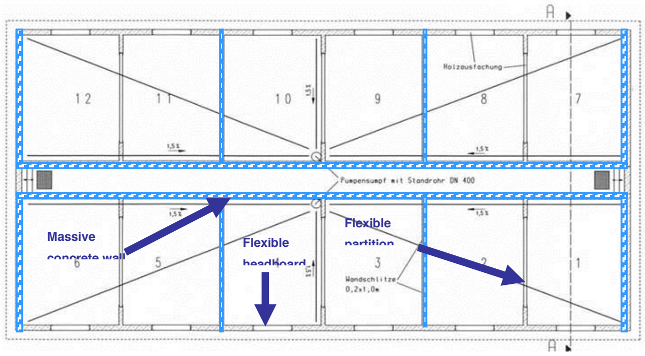


Figure 4: Layout of the demonstration site

A circular flow system was built to ensure a constant supply of fresh wastewater. Essentially, the circular pipeline consists of a master submersible motor pump (capacity: 30 l/s) integrated in the receiver tank at Leutzsch Pumping Station, two pressurized wastewater pipelines (nominal diameter: 90 mm) conducting water to the from the Demo Boxes, and a double pump consisting of two submersible motor pumps with capacities of 30 l/s and 7 l/s, respectively, ensuring the return of wastewater to the receiver tank shaft.

Wastewater is removed from the receiver tank at Leutzsch Pumping Station without pretreatment or comminution and is fed into the pressurized circulation pipe. The influent load of wastewater is divided into two pool lines in the operating aisle. To maintain the pressure required to fill the receiver tank, each line was fitted with an integrated sluice gate and influent pump of appropriate size (see above). The spherical passage of the influent pump is large enough (80 mm) to ensure that materials contained in the wastewater (e.g. screened material) arrive at the SWWTPs in unchanged form.

Defined quantities of wastewater can be removed from the pool line as required. Excess wastewater from the circulatory system is collected together with the fraction of sewer throughput in the receiver tank located behind the building and returned.

Thus, the combined sewage problem leads to a certain amount of wastewater dilution but not to overloading of the SWWTP units during rain events.

Dosing systems for each Demo Box are located in the operating aisle, protected from inclement weather. Essentially, each consists of a 30-litre receiver tank and two pneumatic slide valves driven by a programmable logic controller (PLC).

Figure 5: Equipment in operating aisle of a Demo Box at the BDZ

Figure 6: Dosing system

The feed system makes it possible to supply each individual SWWTP unit with wastewater according to a freely selectable daily flow curve in order to run the units under realistic operating conditions.

Because of the expandable capacity of the programmable logic controller, it is currently possible to programme and assign three flow curves (feed groups) per unit.

The feed system works by timed firing of the different slide valves. The necessary air pressure is generated by means of a compressor/air pressure tank located outside the Demo Box building. A Siemens S7-200 PLC, installed in a control cabinet outside the Demo Box building, is used to activate the slide valves in freely programmable cycles following the following basic activation sequence:

- The slide valve on the influent side of the receiver tank opens for 18 seconds.

- The receiver tank is fed wastewater from the pool line until full.
- Excess wastewater spills over via the emergency overflow of the receiver tank into a control tank discharging into the drain pipe leading to the double pump.
- The slide valve on the influent side of the tank then closes.
- There is a two-second pause.
- The remaining wastewater overflows and the volume in the tank levels off to about 30 litres.
- The slide valve on the effluent side of the receiver tank opens for about 10 seconds.
- Wastewater is emptied from the tank and fed into the target SWWTP unit.
- Treated wastewater from the SWWTP is returned to the control tank, from which it passes into the drain pipe.

Figure 7: Siemens S7-200 PLC outside the Demo Box building

The total influent load is calculated by multiplying the number of cycles by the volume of the receiver tank.

The number of cycles for the three possible daily flow curves can be changed by entering the changes in the software on a laptop computer or by entering the changes on the touch panel located directly in the operating aisle.

All water drained, including that from the Demo Box, is conducted via a line connected to the Pumping Station to KA Rosental, the main sewage plant, for further treatment.

In addition to the dosing system, the control aisle also contains an electric meter and sampling chamber for each Demo Box i.e. SWWTP. The electric meters were used for calculation of power consumption and the sampling chambers for sample collection.

Chapter 4

Description of the Small Wastewater Systems

4.1 Overview of the 12 small wastewater systems investigated

Under the guidance of the Steering Committee and in collaboration with the BDZ, we selected a group of small wastewater treatment systems representing the most commonly used procedures on the German and European market for testing in the scope of the COMPAS project. The selected SWWTPs included systems using sessile biomass, different types of soil filters and membrane bioreactors with suspended biomass, sequencing batch reactors and combined technologies. The type of technology determined the sequence of the presentation of results. In the majority of cases, the SWWTPs tested in the scope of this study had already been installed previously for demonstration purposes. Therefore, possibilities to modify the systems to meet the more stringent test conditions of the study were generally very limited. Two systems were replaced with the Ecofix and Ecoflex systems manufactured by PREMIER TECH. The 12 small wastewater systems studied are described in Table 3. Detailed descriptions of the individual systems, based on information obtained from the manufacturers and in the approvals, are provided in Sections 4.3 to 4.14.

Table 3: Names and types of the 12 small wastewater systems investigated

No.	Manufacturer	System	Process	Biological reactor	Design PE
1	Aquamatic GmbH & Co. KG	STM 5	Combined (RBC + activated sludge)	Sessile and suspended biomass	4[1] (5[2])
2	Martin Bergmann Umwelttechnik	BIO- WSB®-N	Aerated fluidized bed reactor	Sessile biomass	4
3	Klargester Environmental Ltd.	BioDisc BA	Rotating biological contactor (RBC)	Sessile biomass	6 (5[1])
4	Nordbeton GmbH	KP253 PAL	Trickling filter	Sessile biomass	9
5	PREMIER TECH Ltee	Ecoflex™	Textile biofilter	Sessile biomass	6 / 4 (5[1])
6	HUBER DeWaTec GmbH	3K PLUS®	Submerged fixed bed reactor	Sessile biomass	4
7	Lauterbach-Kießling GmbH	BKF 4 DN2000 Z1	Trickling filter	Biofilter	4
8	UFZ	UFZ C+H 4 E	Constructed wetland	Biofilter	4
9	PREMIER TECH Ltee	Ecofix ®STB-500	Filter / coconut fibre material	Biofilter	6
10	BUSSE IS GmbH	MF-HKA4	Membrane bioreactor	Suspended biomass	4
11	ATB Umwelttechnologien GmbH	AQUAmax BASIC	Sequencing batch reactor	Suspended biomass	9 / 4 (8[1])
12	Mall Umweltsysteme GmbH	SanoClean XL 4 EW H20	Sequencing batch reactor	Suspended biomass	4

---

[1] According to manufacturer's specification

[2] According to National Technical Approval

4.2 Configuration of the test site and design load conditions

The test site consists of two rows of six containers (Demo Boxes) of equal size in which the respective small wastewater treatment systems were installed. A separate additional container was provided by Busse GmbH. Because the test site could only accommodate three different load levels, the SWWTPs were divided into three size groups according to design population equivalent size (Figure 8):

- Group 1: 4 PE
- Group 2: 6 PE
- Group 3: 9 PE

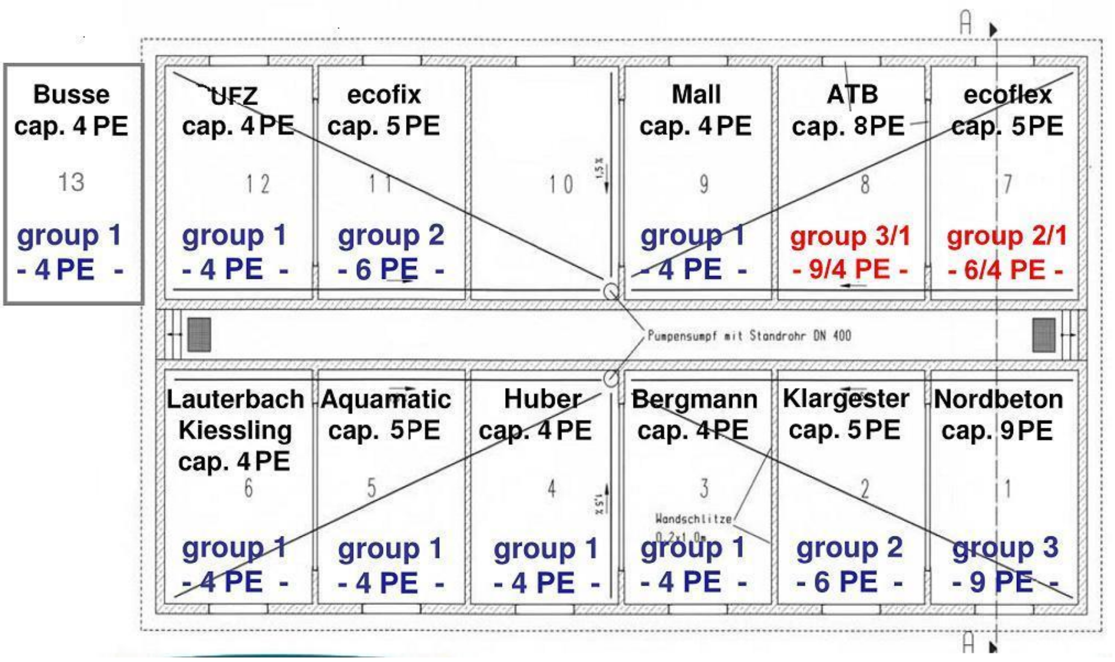


Figure 8: Division of the test site and SWWTPs into groups according to design population equivalent

4.3 Technical Informations

Table 4: Technical Informations of the 12 small wastewater systems investigated

System	Weight / heaviest module	floor space required	Difference between inflow and outflow level
	[kg]	[m^2]	[cm]
Aquamatic – STM 5	180	4,5	21
Bergmann – BIO-WSB®-N	11.100 / 3.400	4,91	20
Klargester – BioDisk BA	325	3,14	7
Nordbeton – Biofilter KP253 PAL	12.232 incl. Lava / 3.000 basement	4,91	26
PREMIER TECH – EcoflexTM*) **)			
HUBER - 3K PLUS®	2.200	4,91	10
Lauterbach-Kießling – BKF 4	15.007 / 2.110 basement	7,46 without pump shaft	164
UFZ - PKA Typ UFZ C+H 4 E	2420	35	0-20 (pumps)
PREMIER TECH – Ecofix Typ STB 500			
Busse – MF Typ MF-HKA4	85 kg	ca. 3 m²	not relevant
ATB – AQUA max BASIC		4,91	not relevant
Mall – SanoClean XL	6.000 / 4.529	3,14	not relevant

4.4 Aquamatic – STM 5

4.4.1 Manufacturer

Aquamatic GmbH & Co. KG
Bischofsweg 33
D-04779 Wermsdorf
Contact person: Mr. Stähler

4.4.2 System name

STM 5

4.4.3 Design capacity

4 PE

4.4.4 Licenses and patents

- National Technical Approval No. Z-55.5-24 from the German approval body, the *Deutsches Institut für Bautechnik* (DIBt)

4.4.5 Technology description and diagrams/photographs

System description

- Mechanical pre-treatment consisting of a multi-chamber septic tank with consolidated mixed sludge storage
- STÄHLERMATIC combination basin consisting of a primary (biological) and secondary clarifier. Settled sludge from the secondary clarifier returns to the primary clarifier by gravity, and excess sludge is removed by means of the capture cups.

The biological contactor is installed in the primary clarifier. An external drive motor rotates the media around the axis of the shaft.

Technical description:

Aquamatic STM5 is a combined biological wastewater treatment system consisting of rotating biological contactor and an activated sludge process. Like conventional activated sludge tanks, this system has a high-performance activated sludge component with a return sludge function to concentrate the activated sludge suspension. The increased activated sludge concentration and sessile biomass help to significantly increase the system's overall treatment efficiency.

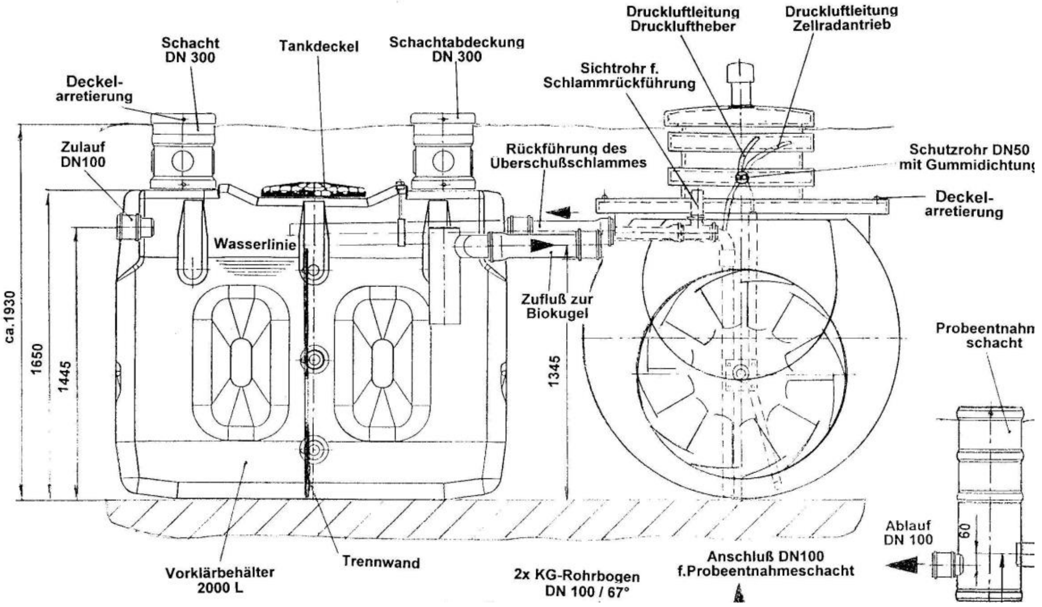
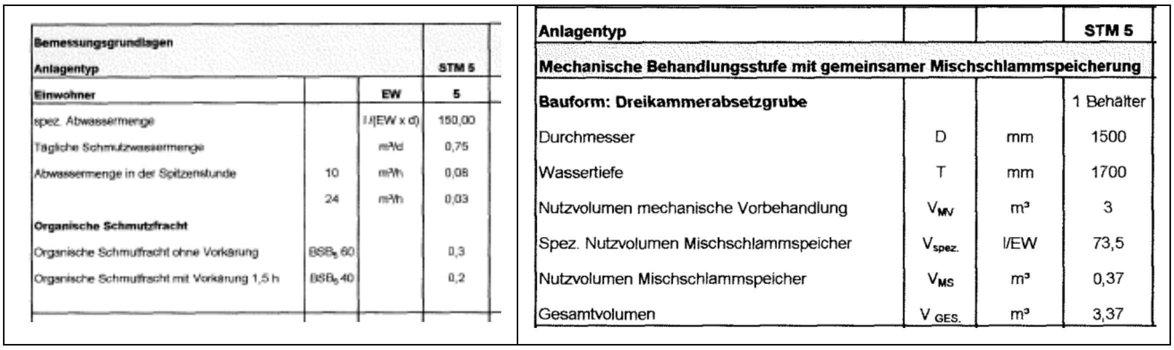


Figure 9: Operating principle of the biological contactor (http://www.aquamatic-klaeranlagen.de)

Figure 10: Photograph of the system in operation (BDZ Leipzig)

4.4.6 Design data

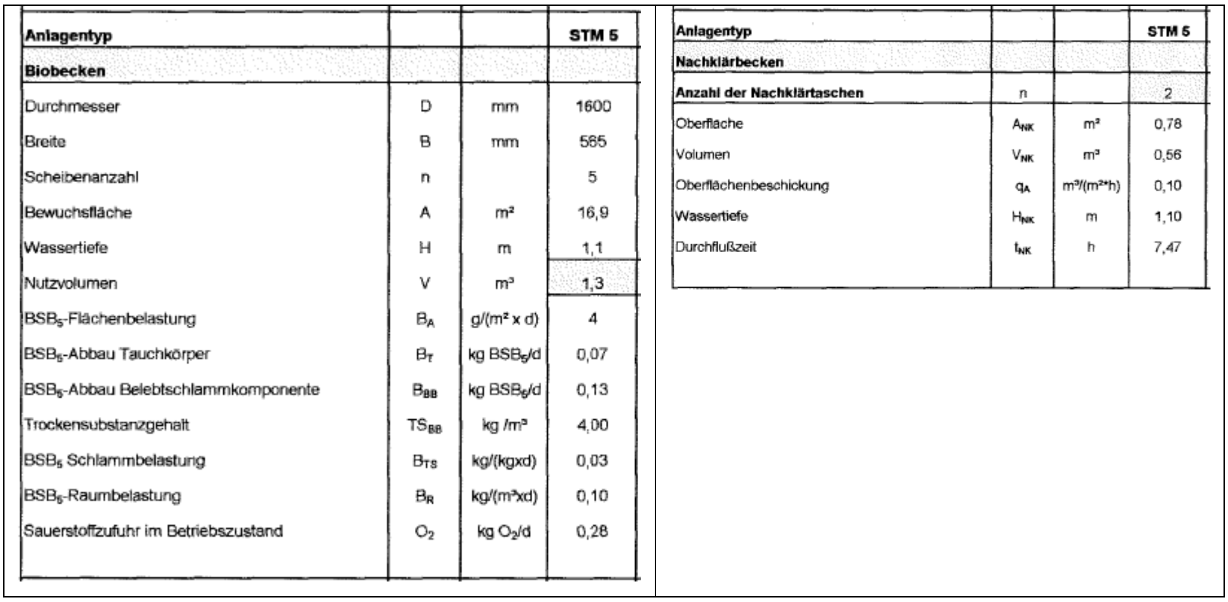
Table 5: Design bases (left); dimensions of primary treatment (right)



Bemessungsgrundlagen Anlagentyp			STM 5
Einwohner		EW	5
spez. Abwassermenge		l/(EW x d)	150,00
Tägliche Schmutzwassermenge		m³/d	0,75
Abwassermenge in der Spitzenstunde	10	m³/h	0,08
	24	m³/h	0,03
Organische Schmutzfracht			
Organische Schmutfracht ohne Vorkärung	BSB_5 60		0,3
Organische Schmutfracht mit Vorkärung 1,5 h	BSB_5 40		0,2

Anlagentyp			**STM 5**
Mechanische Behandlungsstufe mit gemeinsamer Mischschlammspeicherung			
Bauform: Dreikammerabsetzgrube			1 Behälter
Durchmesser	D	mm	1500
Wassertiefe	T	mm	1700
Nutzvolumen mechanische Vorbehandlung	V_{MV}	m³	3
Spez. Nutzvolumen Mischschlammspeicher	$V_{spez.}$	l/EW	73,5
Nutzvolumen Mischschlammspeicher	V_{MS}	m³	0,37
Gesamtvolumen	$V_{GES.}$	m³	3,37

Table 6: Dimensions of biological waste water treatment (approval data)



Anlagentyp			**STM 5**
Biobecken			
Durchmesser	D	mm	1600
Breite	B	mm	585
Scheibenanzahl	n		5
Bewuchsfläche	A	m²	16,9
Wassertiefe	H	m	1,1
Nutzvolumen	V	m³	1,3
BSB_5-Flächenbelastung	B_A	g/(m² x d)	4
BSB_5-Abbau Tauchkörper	B_T	kg BSB_5/d	0,07
BSB_5-Abbau Belebtschlammkomponente	B_{BB}	kg BSB_5/d	0,13
Trockensubstanzgehalt	TS_{BB}	kg /m³	4,00
BSB_5 Schlammbelastung	B_{TS}	kg/(kgxd)	0,03
BSB_5-Raumbelastung	B_R	kg/(m³xd)	0,10
Sauerstoffzufuhr im Betriebszustand	O_2	kg O_2/d	0,28

Anlagentyp			**STM 5**
Nachklärbecken			
Anzahl der Nachklärtaschen	n		2
Oberflache	A_{NK}	m²	0,78
Volumen	V_{NK}	m³	0,56
Oberflächenbeschickung	q_A	m³/(m²*h)	0,10
Wassertiefe	H_{NK}	m	1,10
Durchflußzeit	t_{NK}	h	7,47

4.4.7 Power units

Compressor, 50 W, for rotation of star feeder and additional oxygenation

4.4.8 Nominal power consumption

1.0 kWh/d (compare test certificate PIA, 2008)

4.4.9 Operation parameters

Cleaning capacity (nominal phases):

COD	87.1 %
BOD_5	93.7 %
SS	93.3 %

(compare test certificate PIA, 2008)

4.4.10 Maintenance

The sludge volume should be kept at 300-350 ml/l.

Regular maintenance and inspection (biyearly) of the system and operating conditions is imperative when the system is in operation (compare approval data).

4.5 Bergmann – BIO- WSB®-N

4.5.1 Manufacturer

Martin Bergmann Umwelttechnik
Am Zeisig Nr. 8
D-09322 Penig OT Wernsdorf
Internet: www.wsb-clean.com
E-Mail: kontakt@wsb-clean.com

4.5.2 System name

BIO-WSB®-N

Small-scale wastewater system consisting of an aerated fluidised bed reactor with a concrete aeration tank

Model: WSB®–clean Basic

4.5.3 Design capacity

4 PE

4.5.4 Licenses and patents

National German General Approval in accordance with DIN EN 12566-3

Current National Technical Approvals:

SWWTP with aerated fluidised bed reactor. WSB®: Z-55.6-64 Class N

Patent application: No. DE 101 27 554 A1 Process for biological treatment of wastewater.

4.5.5 Technology description and diagrams/photographs

Primary treatment:

Domestic wastewater enters the first chamber, which mainly serves as the pretreatment/ settling tank for coarse material, but also as a sludge storage tank. The mechanically pretreated wastewater is then fed into the bioreactor. This system requires periodic sludge removal. Therefore, the sludge level should be checked during maintenance inspections so that sludge removal can be ordered as needed. Due to the slow rate of sludge accumulation (primary and secondary sludge), sludge can accumulate for up to about 2 years before removal is needed.

Biological treatment stage:

The fully biological treatment stage is based on the patented WSB® - technique (aerated fluidised bed reactor/biofilm process, which does not require the return of activated sludge from the secondary clarifier to the biofilm reactor).

The plastic carrier material has a specific surface area of ≥ 300 m²/m³. The carrier elements are colonised by micro-organisms, which utilise the available nutrients in the wastewater and the fine air bubbles produced by the membrane diffuser to fuel their biosynthetic and metabolic processes. In addition, the bioreactor's fine bubble diffuser produces shearing forces high enough to reliably prevent overgrowth from covering the carrier elements. This eliminates the problem of carrier overgrowth. A thin and highly active biofilm forms on the carrier elements.

Oxygen input through aeration is intermittent. Aerobic processes (mainly carbon removal and nitrification) take place during the aeration process (in the fluidised bed). During non-oxygenation periods, the carrier elements float as dense packets below the water surface. This principle results in alternating states (aerobic/anaerobic) in the fluidised bed reactor.

As the system is filled to only 55% of its capacity, solids loadings are low and intermittent overloads can be easily managed.

A special retainer (patented design) is used to hold the carrier material in the biology. Its streamlined design prevents clogging.

Secondary treatment:

The bottom of the secondary clarifier is shaped like a ¼ truncated cone. Secondary sludge collects on the bottom of the tank and is conveyed to the primary clarifier by a lift pump or submersible motor pump.

To ensure reliable sludge removal, the lift pump or secondary sludge pump is positioned in a way that sludge always settles in the area of suction.

The biologically treated wastewater from the secondary clarifier is transported via a revision shaft or sampling chamber (integrated sampling – INPN – optional feature) to the receiving waters or irrigation site.

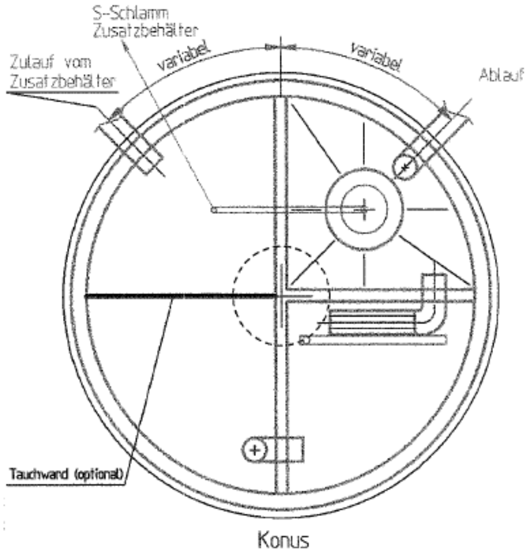


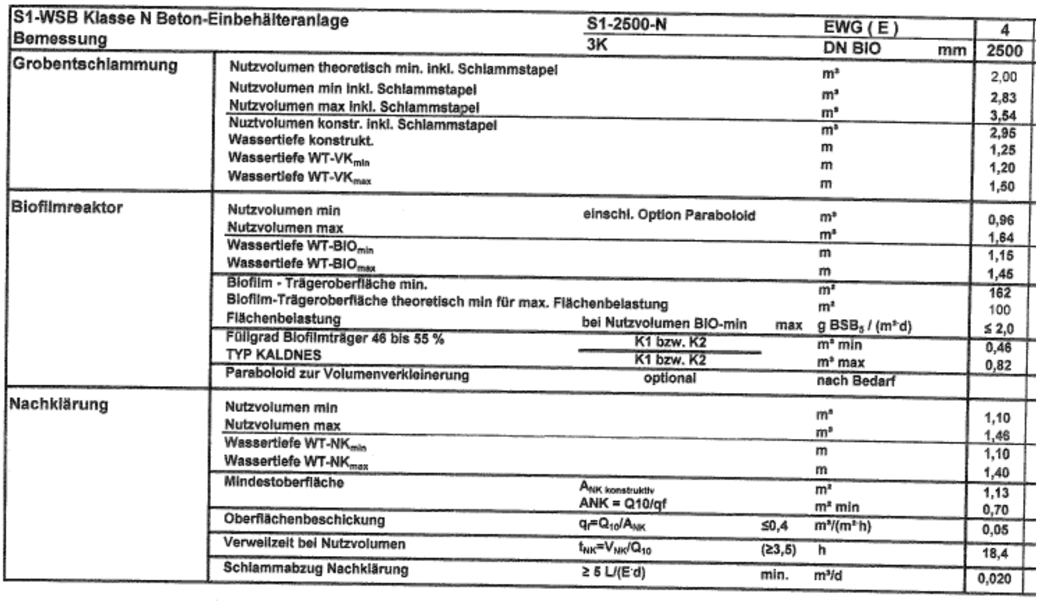
Figure 11: System draft (approval data)

Figure 12: Carrier material (BDZ Leipzig)

4.5.6 Design data

The system is constructed pursuant to DIN EN 12566-3 and DIBt authorisation principles.

Table 7: Dimensions according to approval data



S1-WSB Klasse N Beton-Einbehälteranlage		S1-2500-N		EWG (E)	4
Bemessung		3K		DN BIO mm	2500
Grobentschlammung	Nutzvolumen theoretisch min. inkl. Schlammstapel			m^3	2,00
	Nutzvolumen min inkl. Schlammstapel			m^3	2,83
	Nutzvolumen max inkl. Schlammstapel			m^3	3,54
	Nuztvolumen konstr. inkl. Schlammstapel			m^3	2,95
	Wassertiefe konstrukt.			m	1,25
	Wassertiefe WT-VK$_{min}$			m	1,20
	Wassertiefe WT-VK$_{max}$			m	1,50
Biofilmreaktor	Nutzvolumen min	einschl. Option Paraboloid		m^3	0,96
	Nutzvolumen max			m^3	1,64
	Wassertiefe WT-BIO$_{min}$			m	1,15
	Wassertiefe WT-BIO$_{max}$			m	1,46
	Biofilm - Trägeroberfläche min.			m^2	162
	Biofilm-Trägeroberfläche theoretisch min für max. Flächenbelastung			m^2	100
	Flächenbelastung	bei Nutzvolumen BIO-min	max	g BSB$_5$ / (m^{3}d)	≤ 2,0
	Füllgrad Biofilmträger 46 bis 55 %	K1 bzw. K2		m^3 min	0,46
	TYP KALDNES	K1 bzw. K2		m^3 max	0,82
	Paraboloid zur Volumenverkleinerung	optional		nach Bedarf	
Nachklärung	Nutzvolumen min			m^3	1,10
	Nutzvolumen max			m^3	1,46
	Wassertiefe WT-NK$_{min}$			m	1,10
	Wassertiefe WT-NK$_{max}$			m	1,40
	Mindestoberfläche	A$_{NK\ konstruktiv}$		m^2	1,13
		ANK = Q10/qf		m^2 min	0,70
	Oberflächenbeschickung	$q_f=Q_{10}/A_{NK}$	≤0,4	m^3/(m^{2}h)	0,05
	Verweilzeit bei Nutzvolumen	$t_{NK}=V_{NK}/Q_{10}$	(≥3,5)	h	18,4
	Schlammabzug Nachklärung	≥ 5 L/(E·d)	min.	m^3/d	0,020

4.5.7 Power units

- Compressor (membrane compressor or submersible compressor)
- Solenoid-operated lift pump (mammoth pump) or submersible motor pump for sludge removal
- Programmable logic controller (PLC) with user-friendly software and USB interface / optional GSM module for remote monitoring
- Control cabinet for indoor or outdoor installation

(compare approval documents and manufacturer information)

4.5.8 Nominal power consumption

About 55 kWh per year and inhabitant for a 4 PE unit, Class C

(according to manufacturer information)

4.5.9 Operation parameters

BOD$_5$: ≤ 15 mg/l in homogenized 24-hour composite samples

≤ 20 mg/l in homogenized random samples

COD: ≤ 75 mg/l in homogenized 24-hour composite samples

≤ 90 mg/l in homogenized random samples

NH_4-N: ≤ 10 mg/l in filtered 24-hour composite samples

SS: ≤ 50 mg/l in random samples

4.5.10 Maintenance

Maintenance should be performed by the Applicant or a qualified service firm at least twice a year (at intervals of 6 months). Maintenance consists of the following tasks:

- Review the operating log, check the operating hours counter and compare the target and actual performance.
- Ensure that the controller, compressor, sludge pump and air distribution system are working properly.
- Perform compressor maintenance.
- Adjust the cycle times of the compressor (after measuring the O2 concentration in the bioreactor) and secondary sludge pump as needed.
- Measure the sludge level in primary clarifier and order sludge removal if necessary.
- Perform cleaning tasks (integrated sampling, removal of scum and deposits).
- Check the physical state of the system and assess for corrosion, accessibility and aeration.
- Take random samples from the effluent (test for temperature, pH, NH_4-N, settled solids and COD).

All maintenance tasks performed should be recorded in the operating and maintenance logs.

A written maintenance report is to be completed and sent to the system operator. The operator should file the maintenance report in the operating manual and keep it available for submission to the responsible building or wastewater authorities on demand.

4.5.11 References

- 25,000 WSB®-clean units have been installed worldwide.

4.6 Klargester – Bio-Disk BA

4.6.1 Manufacturer

Kingspan Environmental GmbH,
Am Schornacker 2;
D-46485 Wesel
Klargester is trademark of Kingspan
Telephon: +49 (0) 0281 - 95 250 45
Telefax: +49 (0) 0281 - 95 250 50
E-mail: verkauf@klargester.de

4.6.2 System name

Klargester BioDisc BA

4.6.3 Design capacity

5 PE (6 PE)

4.6.4 Licenses and patents

Klargester BioDisc® small-scale sewage treatment systems are based on rotating biological contactor (RBC) technology. BioDisc® systems are industrially manufactured in different sizes (up to 50 PE) for domestic wastewater applications in accordance with DIN 4261 Part 2 under German National Technical Approval No. Z 55.5-22.

4.6.5 Technology description and diagrams/photographs

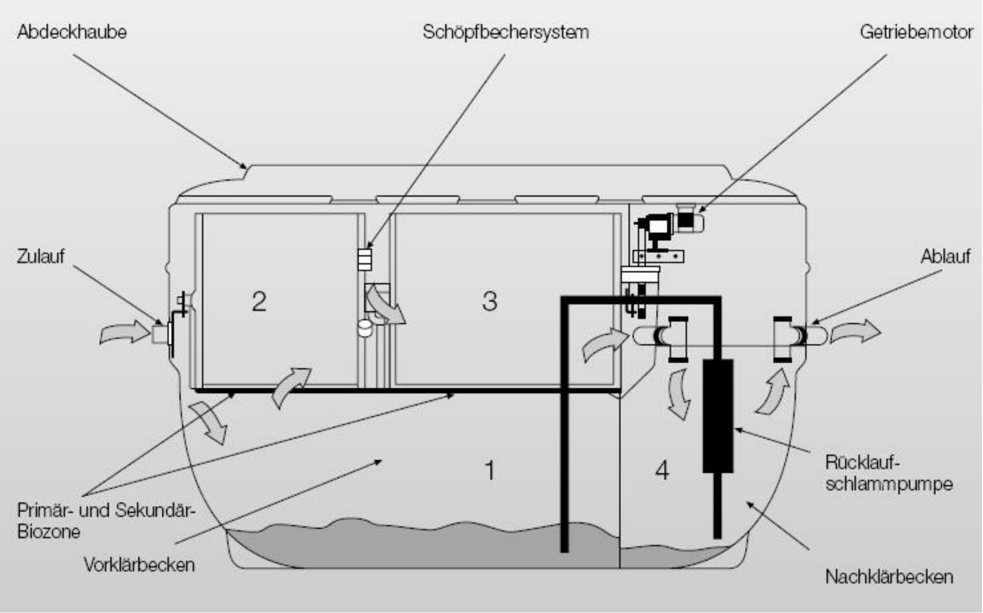


Figure 13: Sectional drawing of the Klagester unit

The basic elements of the BioDisc® system are a primary settlement tank, a Biozone consisting of two stages including the rotating biological contactor, a Managed Flow System, and a final settlement tank equipped with a sludge return pump. The Managed Flow System is located between the first and second stage rotor. The BioDisc® unit is driven by a small gear motor. Each system comes complete with a control panel.

Primary settlement tank (1):

Incoming sewage first passes into the primary settlement zone, where suspended solids are retained and settleable solids settle to the bottom of the tank to form primary sludge, which must be periodically removed. The partly clarified sewage containing suspended solids passes from the primary settlement tank into the first stage of the Biozone.

First and second stage rotor (2 and 3)

The Biozone housing the two-stage rotating biological contactor is located above the primary settlement tank. The Managed Flow System buffers and equalizes strong and variable hydraulic and organic load surges of the influent. The first stage of the Biozone receives continuous feed from the primary settlement tank, and the second stage of the Biozone receives controlled flow from the Managed Flow System. The rotating biological contactor consists of a series of closely spaced, round, perforated, drive-shaft-mounted rotating discs, or "*biodiscs*". The biodiscs are partially immersed in sewage. Within a few days, a biologically active film of micro-organisms and microbes (biomass) forms on the surface of the biodiscs.

While immersed, the biofilm absorbs dissolved organic solids. In the aerobic zone at the top of the disc, the biomass receives the air exposure needed for metabolism. Organic impurities are oxidised or converted into new biomass. Excess biological growth falls off the biodiscs and remains in the tank as biologically active biomass. In the final settlement tank, it is separated from clarified wastewater. A submersible pump is used to return part of the excess sludge to the primary settlement tank to stabilize the treatment process and to ensure load equalisation.

Managed flow system (patented):

The Managed Flow System is specially designed to remove cleaning solvents and household pollutants found in domestic and industrial wastewater. The Klargester Managed Flow System regulates flow through the system to avoid surges during peak flow periods. This fully biological system can therefore achieve effluent quality that satisfies the highest standards. The Klargester BioDisc® and Managed Flow System are therefore able to handle higher organic loads. The Managed Flow System improves the quality of the wastewater by producing higher quantities of settleable solids. Flow to the final settlement tank is also controlled by this system.

Final settlement tank (4):

The biologically clarified liquor passes from the second stage of the Biozone though a baffle into the final settlement tank, where suspended solids settle to the bottom of the tank or form a scum on the surface. The scum is drawn off and returned to the primary settlement tank at regular intervals by a return sludge pump (manufacturer information, brochure).

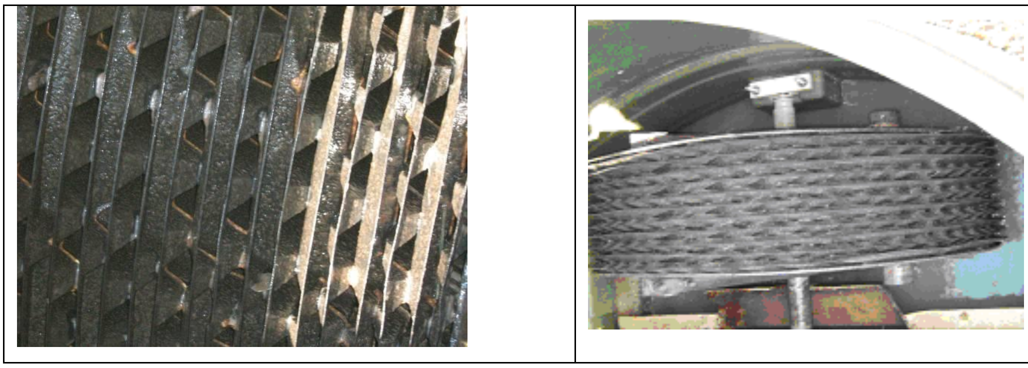


Figure 14: Rotating biological contactor Klargester BioDisk BA (BDZ Leipzig)

4.6.6 Design data

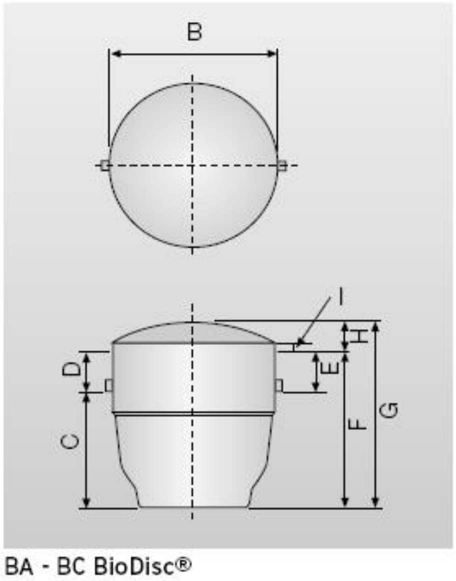


Figure 15: Drawing of dimensioning (manufacturer brochure)

Table 8: Dimensions (manufacturer information, brochure)

BioDisc®	Einheit	BA
Anschlussgröße		5 EW
Tägliche Abwassermenge	m^3/d	0,75
Tägliche Schmutzfracht	kg BSB_5/d	0,3
Abwasserspitze Q_{10}	m^3/h	0,075
Einbaumaße		
A-Länge	mm	-
B-Durchmesser/Breite	mm	1995
C-Tiefe unter Zulauf	mm	1400
D-Zulauftiefe	mm	450/750/1250
E-Ablauftiefe	mm	520/820/1320
F-Einbautiefe	mm	1850/2150/2650
G-Gesamthöhe	mm	2160/2460/2960
H-Höhe über GOK	mm	310
I-Höhe GOK-Deckel	mm	95
J-Zwischenmaß Zu-/Ablauf	mm	-
K-Zulaufposition	mm	-
L-Ablaufposition	mm	-
Zu-/Ablaufdurchmesser	mm	DN 150
Massen		
Gesamtmasse, leer	kg	310/325/380

4.6.7 Power units

Motor/pump:

Motor rating: 0.050 kW

Pump rating: 0.480 kW

(manufacturer information, brochure)

4.6.8 Operation parameters

BOD_5: 25 mg/l 24 hours, mixed samples

COD: 110 mg/l 24 hours, mixed samples

SS: 30 mg/l 24 hours, mixed samples

(manufacturer information, brochure)

4.6.9 Maintenance

Because most of its components are made of glass fibre-reinforced polyester (GRP) and corrosion-resistant materials, the Klargester BioDisc® is a low-maintenance system. Biomass is a biological system component that should neither be cleaned nor removed. Like all electrical and mechanical equipment, regular maintenance is required. The maintenance requirements are specified in the operating manual. For proper performance, we recommend signing a maintenance contract with a local Klargester service partner (manufacturer information, brochure). Maintenance intervals are not specified.

4.7 Nordbeton – KP253 PAL

4.7.1 Manufacturer

Nordbeton GmbH
Industriestr. 2
D-26169 Friesoythe
Contact person: Mr. Uphoff
Tel.: 04497 / 9241-13
Fax: 04497 / 9241-70
E-mail: juphoff@nordbeton.com

4.7.2 System name

KP253 PAL (trickling filter system with lava rock, particle size 40/90)

Small-scale trickling filter system with concrete aeration tank: NORDBETON KLÄRPOTT; effluent class C.

4.7.3 Design capacity

9 PE

4.7.4 Licenses and patents

German National Technical Approval
No. Z-55.2-13 in accordance with
DIN 4261

4.7.5 Technology description and diagrams/photographs

Primary treatment

NORDBETON KLÄRPOTT is a two-chamber SWWTP with primary sedimentation; biological treatment and secondary sedimentation are integrated in one tank. Sewage first enters the primary sedimentation compartment for settling. Undissolved and floating solids in the wastewater are retained in the primary sedimentation tank, where they settle as sludge on the bottom of the tank.

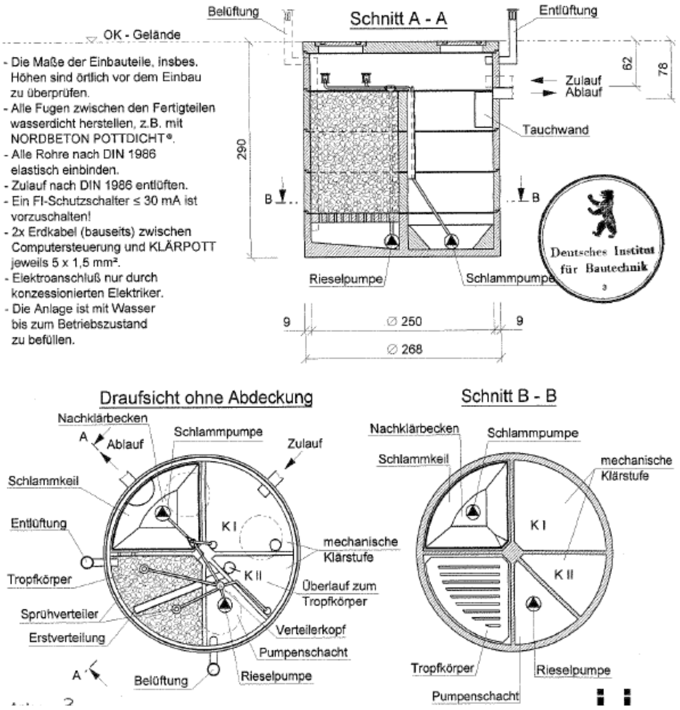
Trickling filter unit

The mechanically treated (primary treatment) and hereby partially clarified wastewater is distributed over the trickling filter by a rotary distributor (primary distributor). At the same time, air is blown through the filter filler material from the opposite direction. A film of biomass forms within a few weeks. Water that has trickled through the filler material collects in the pump shaft, where two floating switches are installed. If water is present in the pump shaft, the dry run protection switch activates the pump (sprinkler pump) at programmed intervals. If the water rises to a certain level, the high water alarm (level switch) activates the sprinkler pump, which switches to a continuous operation mode. If the pump is unable to handle the water, the high level alarm switch is activated. When the pump is in operation, water is pumped to a distributor head located above the trickling filter. The distributor head splits the water it receives into three parts:

- A portion is sent to the spray distributor to be distributed over the trickling filter again.
- A second portion is pumped back to the primary sedimentation tank for partial clarification purposes.
- A third portion is sent to the secondary sedimentation tank.

Secondary sedimentation tank

The brought in clarified water is let to settle in the secondary sedimenation tank. The settled sludge is pumped back into the primary sedimentation tank. The purified water is discharged into the receiving waters (compare approval data).



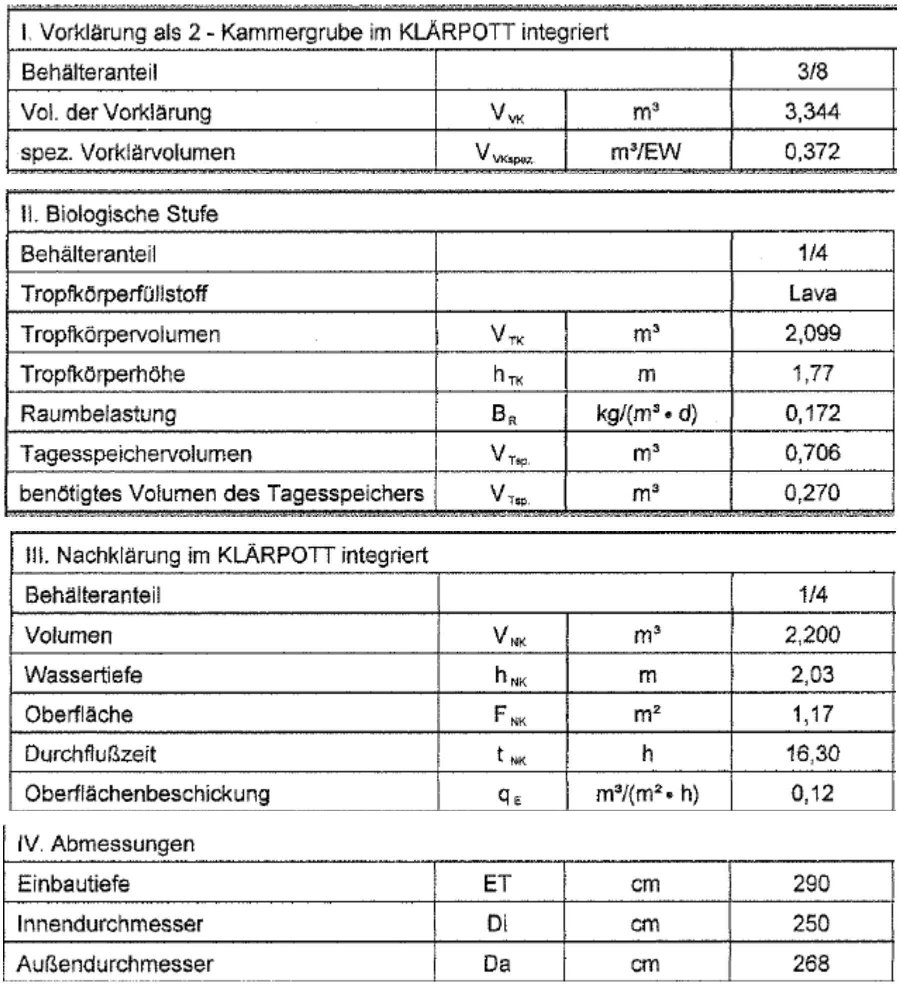
- Die Maße der Einbauteile, insbes. Höhen sind örtlich vor dem Einbau zu überprüfen.
- Alle Fugen zwischen den Fertigteilen wasserdicht herstellen, z.B. mit NORDBETON POTTDICHT®.
- Alle Rohre nach DIN 1986 elastisch einbinden.
- Zulauf nach DIN 1986 entlüften.
- Ein FI-Schutzschalter ≤ 30 mA ist vorzuschalten!
- 2x Erdkabel (bauseits) zwischen Computersteuerung und KLÄRPOTT jeweils 5 x 1,5 mm².
- Elektroanschluß nur durch konzessionierten Elektriker.
- Die Anlage ist mit Wasser bis zum Betriebszustand zu befüllen.

Figure 16: Drawing of trickling filter KP253 PAL (approval data)

Figure 17: Trickling filter KP253 PAL and primary treatment (BDZ Leipzig)

4.7.6 Design data

Table 9: Dimensions of trickling filter KP253 PAL (approval data)



I. Vorklärung als 2 - Kammergrube im KLÄRPOTT integriert			
Behälteranteil			3/8
Vol. der Vorklärung	V_{VK}	m³	3,344
spez. Vorklärvolumen	$V_{VKspez.}$	m³/EW	0,372
II. Biologische Stufe			
Behälteranteil			1/4
Tropfkörperfüllstoff			Lava
Tropfkörpervolumen	V_{TK}	m³	2,099
Tropfkörperhöhe	h_{TK}	m	1,77
Raumbelastung	B_R	kg/(m³ • d)	0,172
Tagesspeichervolumen	$V_{Tsp.}$	m³	0,706
benötigtes Volumen des Tagesspeichers	$V_{Tsp.}$	m³	0,270
III. Nachklärung im KLÄRPOTT integriert			
Behälteranteil			1/4
Volumen	V_{NK}	m³	2,200
Wassertiefe	h_{NK}	m	2,03
Oberfläche	F_{NK}	m²	1,17
Durchflußzeit	t_{NK}	h	16,30
Oberflächenbeschickung	q_E	m³/(m² • h)	0,12
IV. Abmessungen			
Einbautiefe	ET	cm	290
Innendurchmesser	Di	cm	250
Außendurchmesser	Da	cm	268

4.7.7 Power units

Sprinkler pump	DAB NOVA 203, power rating 0.22 kW
Sludge pump	DAB NOVA 180, power rating 0.20 kW
Control unit	Microprocessor control unit, power rating 10 W

4.7.8 Nominal power consumption

Maximum daily power consumption: 0.9 kW

4.7.9 Treatment efficiency

BOD_5: ≤ 25 mg/l in homogenized 24-hour composite samples
≤ 40 mg/l in homogenized random samples
COD: ≤ 100 mg/l in homogenized 24-hour composite samples
≤ 150 mg/l in homogenized random samples
SS: ≤ 75 mg/l in random samples

(Approval data)

4.7.10 Maintenance

Maintenance should be performed by the Applicant or a qualified service firm at least twice a year (at intervalls of 6 months).

Maintenance consists of the following tasks (approval data):

- Review the operating log.
- Check all important mechanical, electronic and other components and perform maintenance of these components according to the manufacturer's instructions.
- Ensure that the controller and alarms are working properly.
- Adjust and optimise the operating parameters, particularly the return sludge ratio.
- Clean the distributor if necessary.
- Check the sludge level in the primary sedimentation tank and order sludge removal if necessary.
- Check secondary sedimentation tank for scum and sludge.
- Perform general cleaning tasks.
- Check the physical state of the unit.
- Check ventilation and air supply.
- Record maintenance activities performed in operating log.
- Take random samples from the effluent (test for temperature, pH, settled solids and COD).

Complete a written maintenance report and send to the system operator. The operator should file the maintenance report in the operating manual and keep it available for submission to the responsible building or wastewater authorities on demand.

4.8 PREMIER TECH - Ecoflex^{TM}

4.8.1 Manufacturer

PREMIER TECH LTEE

4.8.2 System name

Textile Biofilter Ecoflex^{TM} model EFX-300

4.8.3 Design capacity

Model EFX-300 corresponding to 5 PE

4.8.4 Licenses and patents

European patent 1301441

USA patent 6602407

Canadian patent 2410541

4.8.5 Technology description and diagrams/photographs

The Ecoflex^{TM} Wastewater Treatment Technology (WTT) consists of a primary reactor (septic tank), a dosing chamber and the Ecoflex^{TM}Textile Biofilter (see Figure 18)

The Ecoflex^{TM} Textile Biofilter is a packed bed filter composed of vertical layers of attached growth filtering media composites that utilize a combination of geotextile and peat material prepared in rolls (US patent 6602407, European patent 1301441, Canadian patent 240541), where septic tank effluent is sprayed under low pressure.

The Ecoflex^{TM} WTT uses physical, biochemical and biological processes to treat septic tank effluent. The septic tank effluent trickles through the highly porous media which provides a high surface area to volume ratio for microbial attachment and the design feature provides for naturally aerated conditions.
The flow is split into three channels equally, and then the filtrate is collected for discharge or recirculation. Each roll is 600 mm high and has an effective surface area of 0.5 square meters. The system is available in different versions: as an individual polyethylene container (3 rolls for 5PE, 4 rolls for 6PE, 6 rolls for 10 PE, etc.), a concrete tank and a fiberglass container with 4-10 rolls.

The Ecoflex^{TM} WTT is equipped to recirculate flows back to the primary tank (septic tank) to promote denitrification where denitrification to reduce nitrate discharges is required. If denitrification is not required, a part of the treated effluent is recirculated to the dosing chamber.

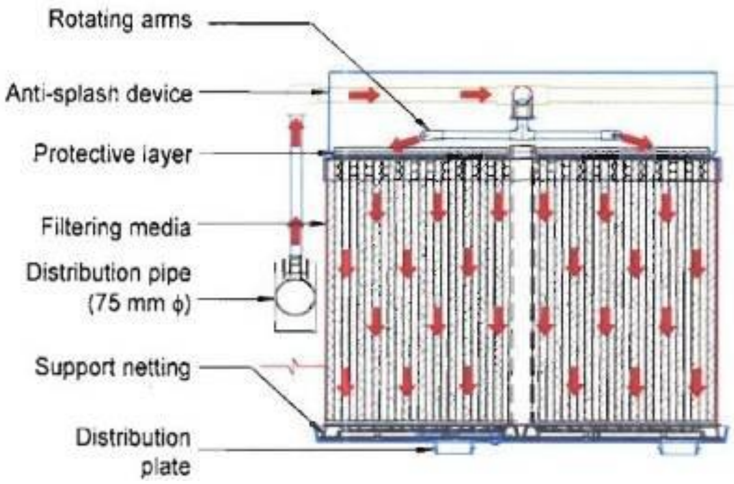


Figure 18: Ecoflex^{TM} filter modules

Figure 19: Ecoflex^{TM} patented textile filter

The flow scheme is following (see also Figure 20)

1. Primary treatment usually consisting of a septic tank equipped with an effluent filter with a minimal hydraulic retention time (HRT) of 36 hours at average daily flow rate. A grease trap has to be provided in front of the septic tank for some commercial projects (e.g. restaurants).
2. Equalization and dosing tank providing 12-hour HRT in case of the commercial performance and 8.5-hour HRT in case of the municipal performance. The equalization and dosing tank is operated under anoxic conditions, which allows transforming the nitrates in a recirculated flow to the nitrogen gas (denitrification).
3. The Ecoflex^{TM} Textile Biofilter combining physical treatment by filtration and biological treatment by fixed micro organisms.
4. Partial flow recirculation to optimize nitrogen removal (2/3 of the treated water).
5. Effluent disposal towards surface (subsurface) discharge or disinfection by UV.

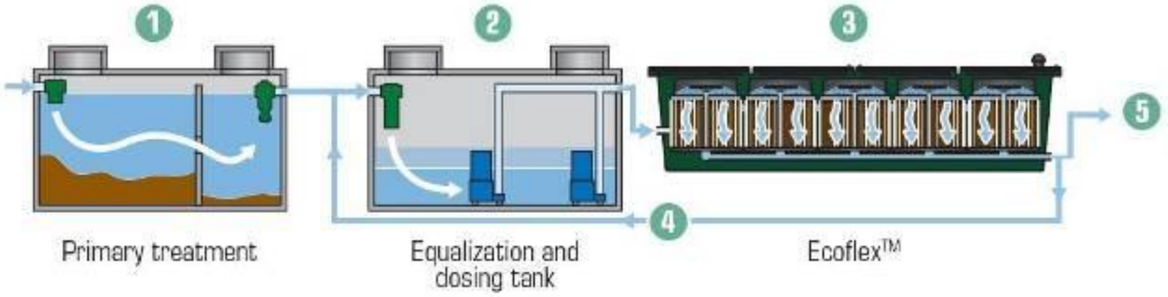


Figure 20: Design of Ecoflex^{TM}- small sewage treatment plant

4.8.6 Design data

Ecoflex^{TM} system of 3 filter modules (rolls) for 5 PE: 0.75 m³/d

Hydraulic loading on the filter (excluding recirculation): 0.50 m³/(m²·d)

Total Filter surface area: 1.5 m²

Volume of septic tank: 4.0 m³

Volume of equalization and dosing tank: 0.50 m³

Biology: fixed micro organisms

4.8.7 Power units

Dosing pump to apply septic tank effluent on filtering media (0.3 kW)

4.8.8 Power consumption nominal

The nominal power consumption corresponds to 0.80 kWh/d

4.8.9 Treatment efficiency

Based on 150 l per 1 PE and hydraulic loading 50 cm/d, the decrease of the main pollutions (TSS, COD, BOD_5, and NH4) comes to the following values.

Rate of the pollution removal measured between the septic tank influent and the Ecoflex^{TM} Textile biofilter effluent:

Table 10: Treatment efficiency of Ecoflex^{TM} Textile-Biofilter, including primary treatment

Parameter	TSS	BOD_5	COD	NH_4
Rate of removal, %	≥ 96	≥ 97	≥ 92	≥ 82

4.8.10 Maintenance

An annual follow up which consists of an inspection and maintenance of the system is performed on the Ecoflex^{TM} Biofilter. The lifespan of the filtering media is 8 to 10 years (under normal utilization conditions) and its replacement is carried out with a portable lift. The filtering media can also be subject to revalorization in landfill site.

4.8.11 References

More than 1,000 Ecoflex^{TM} rolls have been installed in the world till the end of 2005.

4.9 HUBER - 3K PLUS®

4.9.1 Manufacturer

HUBER DeWaTec GmbH
Brassertstrasse 251
D-45768 Marl
Contact person: Jens Köhler Ferreira
Tel.: +49 (0)2365 / 696 578
E-Mail: jens.koehler-ferreira@huber.de

4.9.2 System name

HUBER 3K PLUS®

4.9.3 Design capacity

4 PE

4.9.4 Licenses and patents

In accordance with DIN EN 12566 Part 3 and with German National Technical Approval No. Z-55.6-2, Effluent Class C issued for Huber

4.9.5 Technology description and diagrams/photographs

The small scale sewage treatment plants from “HUBER DeWaTec” operate with a plunged packed bed, which can be, in case of re-fitting or of new construction, built into the second chamber of a three-chamber-pit or of a multicompartment system. This packed bed consists of synthetic tubes with a specific grid structure and provides the micobiological habitat. The first of the three chambers takes over the mechanical (primary) treatment. After this, the sewage is conducted to the second chamber for biological treatment. Here, with aerators installed on the floor, the sewage is aerated in regular intervals with a defined air quantity. The plunged packed bed is fitted above the aerators. Excessive microorganisms are regularly scaled off of the packed bed by the up-flow of the air, and then flushed with the biologically purified water into the third chamber for secondary sedimentation. In this last step, the excessive microorganisms settle to the ground as so called ecxess sludge which is then transported back into the first chamber (primary treatment) before the purified water leaves the unit (compare manufacturers information).

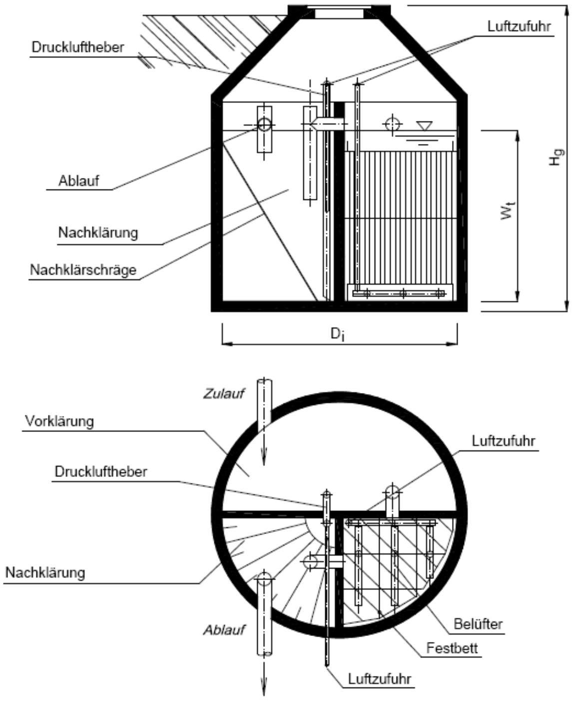
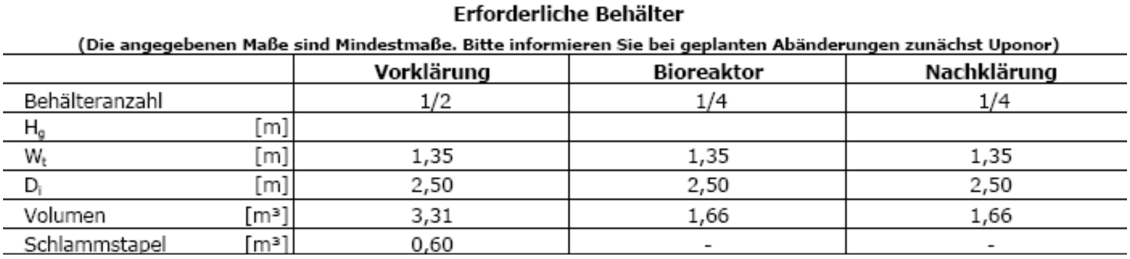


Figure 21: Drawing of system (approval data)

4.9.6 Design data

Table 11: Dimensions of single plant components (approval data)



Erforderliche Behälter

(Die angegebenen Maße sind Mindestmaße. Bitte informieren Sie bei geplanten Abänderungen zunächst Uponor)

		Vorklärung	**Bioreaktor**	**Nachklärung**
Behälteranzahl		1/2	1/4	1/4
H_g	[m]			
W_t	[m]	1,35	1,35	1,35
D_i	[m]	2,50	2,50	2,50
Volumen	[m³]	3,31	1,66	1,66
Schlammstapel	[m³]	0,60	-	-

4.9.7 Power units

Air compressor type:	Nitto LA 120
Motor rating:	0.13 kW
Daily run time:	11.50 hours (approximately)

4.9.8 Nominal power consumption

1.50 kWh/d; 0.37 kWh/(PE·d)

4.9.9 Treatment efficiency

BOD_5: 98.7%
COD: 92.9%
SS: 97.1%
$N_{tot,inorg}$.: 67.1%
NH_4-N: 97.9%
TP: 48.6%

4.9.10 Maintenance

Maintenance is performed every six months.

4.9.11 References

More than 30,000 units installed.

4.10 Lauterbach-Kießling – BKF 4 DN2000 Z1

4.10.1 Manufacturer

Lauterbach-Kießling GmbH
Industriestr. 2-4
D-95517 Seybothenreuth
Contact person: Johann Schmidschneider, VWA, Managing Director
Tel.: (09275) 981-51
Fax: (09275) 981-11
E-Mail: schmidschneider@lauterbach-kiessling.de

4.10.2 System name

Lauterbach BKF 4 DN2000 Z1

4.10.3 Design capacity

4 PE

4.10.4 Licenses and patents

German National Technical Approval
No. Z-55.4-44 in accordance with
DIN 4261/1.

4.10.5 Technology description and diagrams/photographs

Biological wastewater treatment in trickling filter chambers is accomplished by microorganisms, which form a biofilm on the packing material and pervious concrete (lightweight concrete manufactured according to DIN 1045) in the filtering devices. The biological treatment process proceeds from the top to the bottom of the trickling filter chamber. The composition of the biological community varies from one treatment zone to another.

The following conditions must be met to ensure adequate performance of trickling filters:

- Uniform and proportional distribution of wastewater across the total surface area of the filtering device.
- Adequate ventilation, which, in most cases, is achieved via the drainage pipe of the trickling filter system or ventilation holes in the cover.

- To permit air passage, it is to be ensured that the drainage pipe below the last layer of packing material is only partly filled and constructed with centrally positioned support posts.

Pretreatment

Trickling filters should be preceded by a primary sedimentation tank of adequate size. The minimum volume of the primary sedimentation tank should comply with the German Standard ATV-A 262.

The last chamber contains a throttle that slows down bathtub flows to ensure uniform and continuous dosing to the trickling filter chamber to prevent overloading during peak flows.

Fixed film media

The fixed film media consist of the concrete basins, the basin floors made of pervious concrete (lightweight concrete manufactured according to DIN 1045), and the packing materials.

If multiple trickling filtering devices are stacked on top of each other, the column should taper to allow for wastewater overflow into the trickling filtering device below.

A 1 to 3 mm layer of plastic granules with a large specific surface area is poured on the floor of the basin. This bottom layer is covered with a close-meshed, non-decaying textile divider.

A 90 mm layer of fine crushed rock (Diabas Edelsplitt 2/5) filter media is then added to the basins.

Washed gravel or a similar material is poured on the floor of the trickling filter chamber and filled to the upper edge of the drainage pipe; the further composition is analogous to that of the trickling filter devices.

Required surface area

A filter surface area of 2m² per population equivalent is required. The filter surface area is calculated as the sum of the area of the circles of the stacked trickling filters (ring diameter) and of the bottom filter layer (on the floor of the container).

In trickling filter systems with capacities exceeding 20 population equivalents, a two-arm distributor uniformly distributes wastewater from a dual compartment septic tank to two serially connected trickling filter units.

Sampling chamber and aeration system

Aeration of the trickling filter is accomplished by permitting a free flow of air from the exterior via the outlet. If this is not possible, a sampling chamber must be used in connection with a perforated cover to selectively suck air into the trickling filter chamber to create a draft by means of a chimney effect.

Operational particulars

The filtering devices should be aligned horizontally.

It is important to ensure that the holes in the cover provide sufficient aeration.

It is to be ensured that the wastewater is evenly distributed over the top of the trickling filter.

Unobstructed discharge of effluent is to be ensured.

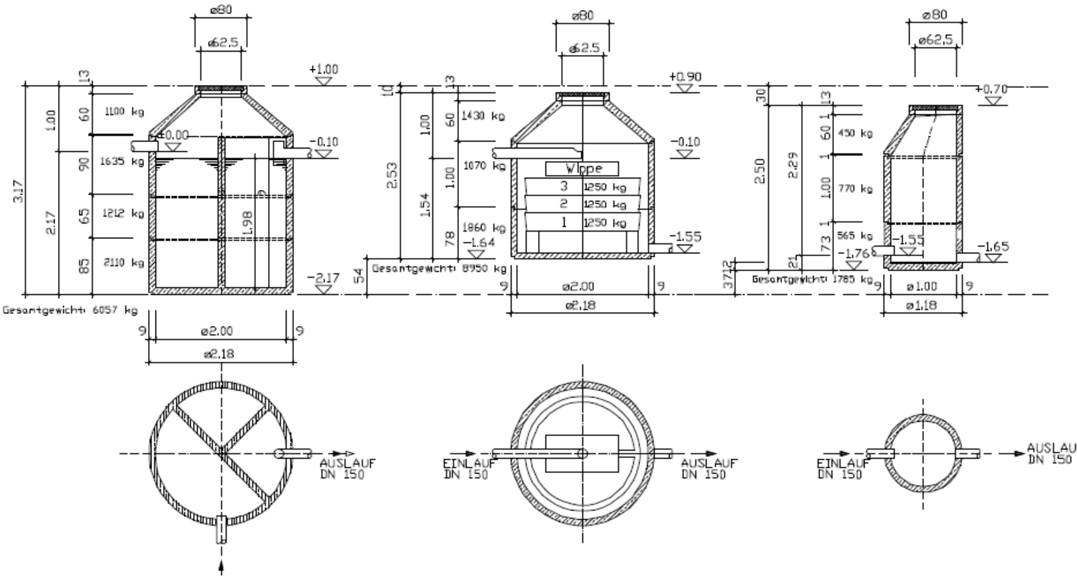


Figure 22: Design of the Lauterbach BKF 4 DN2000 Z1 system

4.10.6 Design data

Small wastewater treatment plant:

Volume: 6.00 m³. Diameter: 2.00 m. Total height: approx. 3.17 m

Trickling filter chamber:

Diameter: 2.00 m. Total height: approx. 2.53 m.

Three trickling filters, one distribution unit and filter media.

Sampling chamber:

Diameter: 1.00 m. Total height: approx. 2.50 m.

4.10.7 Power units

Power units are generally not necessary.

4.10.8 Nominal power consumption

./.

4.10.9 Treatment efficiency

Small wastewater treatment systems of this type are able to satisfy the following effluent quality requirements in on-the-site operations:

Effluent quality requirements:

BOD_5: ≤ 15 mg/l in homogenized 24-hour composite samples
≤ 20 mg/l in homogenized, qualified random samples
COD: ≤ 75 mg/l in homogenized 24-hour composite samples
≤ 90 mg/l in homogenized, qualified random samples
NH_4-N ≤ 10 mg/l in filtered 24-hour composite samples
SS ≤ 50 mg/l in qualified random samples

(German National Technical Approval)

4.11 UFZ – PKA Type UFZ C+H 4 E

4.11.1 Manufacturer

UFZ

This system manufactured by ÖKOTEC GmbH is a specially designed two-stage constructed wetland combining the know-how of the UFZ (Helmholtz Centre for Environmental Development) and the ÖKOTEC Company. The UFZ was responsible for the dimensioning and functional design of the facility. ÖKOTEC GmbH was responsible for its technical design and construction.

Helmholtz-Zentrum für Umweltforschung GmbH – UFZ
Helmholtz Centre for Environmental Research – UFZ
Head of Environmental and Biotechnology Centre (UBZ)
Dr. Roland A. Müller
Permoserstr. 15
04318 Leipzig

Tel.: (+49 341) 235-3000
Fax.: (+49 341) 235-2885
E-Mail: roland.mueller@ufz.de
http://www.ufz.de

ÖKOTEC GmbH (Zentrale)
Ingenieurbüro für Wassertechnologie,
Ingenieurbiologie und Umweltmanagement

Rosa-Luxemburg-Straße 89
D-14806 Belzig

Tel.: +49 (0) 33841-3889-0
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ÖKOTEC GmbH - Büro Sachsen
Manfred Gröner
Reichenberger Str. 44
02763 Zittau

Tel.: +49 (0) 3583-795598
Fax: +49 (0) 3583-696828
E-Mail: groener@oekotec-gmbh.com
http://www.mangro.net/

4.11.2 System name

Constructed Wetland Type UFZ C + H 4 E

The 3 or 4 in the system name indicates whether the constructed wetland is designed for 3 or 4 population equivalents:

- Constructed Wetland Type UFZ C+H 3 E (according to DIBt approval criteria)
- **Constructed Wetland Type UFZ C+H 4 E (according to practical results)**

The "C" in the name stands for compliance with effluent class C of the DIBt authorisation criteria.

The "H" stands for "Hygienisation" (UV unit for extensive hygienisation), the principle objective of which is compliance with the DIBt effluent class C+H criteria.

"3 E" refers to the fact that the first stage of the system is designed for 3 population equivalents (3 PE * 4 m² / PE = 12 m²) following the generally recognized rules of technology and DIBt approval criteria for small wastewater treatment systems. Both standards are based on Standard ATV-A 262 [1], which prescribes a minimum surface area of 4 m²/PE for constructed wetlands for wastewater treatment. Any unit having a surface area of only 3 m²/PE deviates from this standard and is not eligible for DIBt approval as a constructed wetland for wastewater treatment, regardless of which filter material is used. Therefore, Constructed Wetland Type UFZ C+H 3 E will be discussed but is not eligible for DIBt approval.

Based on its treatment performance and the practical results of the comparison of small wastewater treatment systems, Constructed Wetland Type UFZ C+H 4 E can be included in the analysis.

The suffix "4 E" refers to the surface area calculation by the manufacturer, which deviates from the generally recognized surface area calculation principles. The manufacturer is of the opinion that a surface area of 3 m²/PE * 4 PE = 12 m² is sufficient for the first soil filter (vertical soil filter). In addition, the primary treatment capacity is 900 L/PE. This deviates from the specifications of German Standard DWA-A 262 [1], which strictly specifies 1500 L/PE for soil filters with sand used for wetlands of this size. The small wastewater treatment system comparison study in Leutzsch demonstrated that 3 m²/PE is feasible for 4 population equivalents with this system and that the system reliably meets the treatment performance requirements for small wastewater treatment systems of Effluent Class C.

4.11.3 Design capacity

Design population: 4 PE

Dimensioning:

Maximum population size: 4 PE (manufacturer)

3 PE/DIBt: Permissible only for 3 PE according to ATV-A 262 and rules of general practice.

According to the manufacturer, the system is designed for four population equivalents (4 PE).

In the unanimous opinion of the experts of the German Association for Water, Wastewater and Waste (DWA), the three-chamber pit and vertical soil filter are permissible only for three population equivalents (3 PE) according to its standards for constructed wetlands using vertical sand filters as the soil filters.

1. - Mechanical stage (mechanical pretreatment):

Type: Three-chamber pit
Volume: 3.7 m³
Surface area: 925 L/PE (1500 L/PE for soil filters required by ATV-A 262)
Design capacity: 4 PE (3 PE according to ATV -A 262 standards)

2. - Biological stage (carbon elimination):

Type: Vertical soil filter (expanded clay)
Area: 12 m²
Surface area: 3.0 m² / PE (4.0 m²/PE according to ATV-A 262 standards)
Design capacity: 4 PE (3 PE according to ATV-A 262 standards)

3. - Biological stage (hygienisation):

Type: Horizontal soil filter (sand):
Area: 6 m²
Surface area: 1.5 m²/PE (no normative data available)
Design capacity: 4 PE

4. - Physical stage (hygienisation):

Type: UV unit, 253.7 Nm (conforms to VDI 6022)
Power: 16 W
Surface area: -
Design capacity:

4.11.4 CE and/or DIBt certification

The system has no certification mark.

This system is a two-stage constructed wetland, the design of which deviates from recognized standards but is based on similar principles and is now in the DIN-EN 12566-3 practical testing phase at a test field certified by the *Deutsches Institut für Bautechnik Berlin* (DIBt).

4.11.5 Technology description and diagrams/photographs

Near-natural process

The system is a two-stage constructed wetland for wastewater treatment designed by the UFZ Leipzig and constructed by ÖKOTEC GmbH. Itconsists of the following four wastewater treatment stages:

1. Three-chamber pit (mechanical treatment stage)
2. Planted vertical soil filter (first biological treatment stage)
3. Planted horizontal soil filter (second biological treatment stage)
4. UV unit (further physical treatment stage)

Figure 23: Constructed wetland Type UFZ C+H 4 E: photo of the Demobox BDZ in Leutzsch

System design

- Three-chamber pit (MKG)
- Pump shaft 1 (PS1)
- Plant bed 1 (Bed 1) – Planted vertical soil filter of expanded clay
- Pump shaft 2 (PS2)
- Plant bed 2 (Bed 2) – Planted horizontal soil filter made of sand
- UV shaft (UVS) with UV unit
- Outlet shaft/sampling chamber (AS)

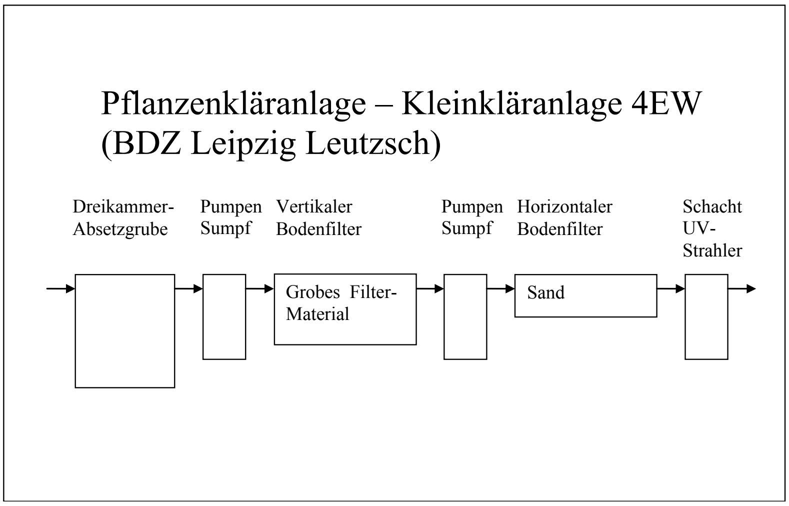


Figure 24: Process diagram of Constructed Wetland Type UFZ C + H 4E E

Wastewater pathway through the constructed wetland

First treatment stage: Mechanical pretreatment

The water passes through the feed line and flows freely down through the three-chamber septic tank or multi-compartment tank and in the free outlet into pump shaft PS1.

Second treatment stage: Biological treatment

A submersible pump (feed pump) in Pump Shaft 1 (PS1) feeds the wastewater in surges through the distribution pipe system into Bed 1. The water flows through the vertical soil filter (filter layer made of expanded clay) from top to bottom and undergoes biological treatment in the process. The wastewater passes through a drainage layer with a drain pipe on the bottom of the filter into Pump Shaft 2 (PS2).

Third treatment stage: Biological treatment

A submersible feed pump in Pump Shaft 2 (PS2) feeds wastewater in surges to Bed 1 via a drainage pipe. The water flows through the horizontal soil filter layer made of sand, where it undergoes extensive biological treatment. Water from the gravel layer near the outlet flows freely down through a drainage pipe to the UV shaft (UVS).

Fourth treatment stage: Physical treatment

In the UV shaft (UVS), the water flows through a pipe though the UV unit, where it receives a defined dose of UV irradiation. This deactivates most of the active micro-organisms still present in the wastewater, which then passes into the outlet shaft (AS).

Outlet shaft/sampling chamber (AS)

The pipes in the outlet shaft/sampling chamber are designed to allow for collection of random samples or 24-hour composite samples for water quality monitoring before the extensively clarified effluent is discharged or removed for other uses.

Alarm system

Floating switches in pump shafts 1 and 2 generate optic and acoustic alarm signals in the event of feed pump failure or other hydraulic problems.

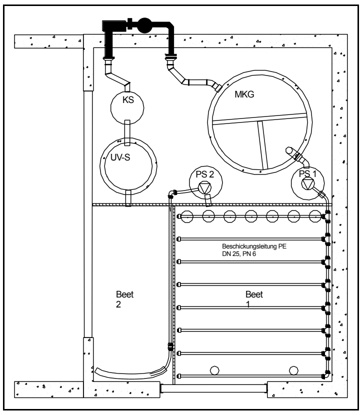


Figure 25: Layout of constructed wetland Type UFZ C+H 4E E in the Demobox in Leutzsch

4.11.6 Design data

Three-chamber septic tank: 4 PE * 0.925 m³ = 3.7 m³ (approx. 900 l/PE)

Vertical soil filter composition (from bottom to top)

- Geotextile RK 4
- Polyethylene sheet, 1 mm

- Geotextile RK 4
- Drainage layer: gravel 2/8, with drainage lines
- Filter layer: Expanded clay, 2/5
- Cover layer: Gravel, 2/8

Planted vertical soil filter: 4 PE * 3.0 m² / PE = 12 m²

Horizontal soil filter composition (from bottom to top)

- Geotextile RK 4
- Polyethylene sheet, 1 mm
- Geotextile RK 4
- Drainage layer: Gravel, 2/8
- Filter layer: Sand, 0/2

Planted horizontal soil filter: 4 PE * 1.5 m² / PE = 6 m²

4.11.7 Power units

Three-chamber septic tank made of concrete

BBW Beton- und Bausteinwerk GmbH, Altdorfer Weg 13, D-14823 Niemegk, Germany,

Tel.: +49 (0)3384351-222 Fax: +49 (0)3384351-229

Pumps in pump shafts 1 and 2

KSB Amar-Drainer 301.2

KSB S.A.S., 128, rue Carnot, F-59320 Sequedin/Lille, France

Fig. 1

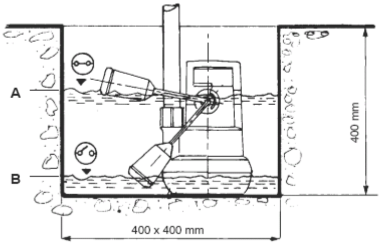


Figure 26: KSB Amar-Drainer 301.2 pump

UV system

Table 12: UVC - 1.2 // UVC - 2.4 (Last updated 06.03.2008)

Dimensions (Ø x Length): 100 mm x 560 mm

Maximum disinfection capacity for E. coli, Legionella, etc.: 2400 l / h

Maximum water volume for disinfection in circulatory systems

(At 20 °C): ≤ 60,000 L (ponds, water circulation tanks, etc.)

Quartz glass lamp: 20 mm x 380 mm

Maximum water pressure: 6 bar

Seal (UV-proof): O-ring

Inlet size: 1.5"

Number of lamps: 1 - 2

Power of lamps: 2 x 16 W maximum

Power supply: 120 - 260 VAC or 12 / 24 VDC

Lamp life: 9000 hours

Electronic ballast: Electronic control gear (ECG)

4.11.8 Nominal power consumption

Based on the sample calculation below, the maximum annual power consumption is about 90 kWh when the wastewater volume increases by 100 % in the target period. The annual power costs for a four-person household is therefore around 10 to 20 EUR/year without UV treatment (hygienisation) and approximately 35 EUR per year more with UV treatment (140 kWh/y x 0.25 EUR/kWh = 35 EUR per year).

Time [d]	kWh
28 Mar 2008 14:00	33,350
31 Mar 2008 11:20	33,700
2.89	0.35
0.121	kWh/d
44	kWh/y
0.016	kW for UV
24	hours
0.384	kWh/d
140.16	kWh/y
184.16	kWh/a in total

4.11.9 Operating parameters

The soil filters are aerated passively by means of surge feeding in intervals. The surge volume is determined by floating switches on the pumps, which automatically switch on and off the feeding when the water level reaches the upper or lower threshold. There are no other operating parameters requiring control or adjustment.

4.11.10 Maintenance

Maintenance procedures can be described as very low.

- 2/a control of sludge level (max. removal 1/a)
- Maintenance/control of pumps for correct position
- Cutting and tailoring of reeds in spring
- Only for disinfection: changing of 16 W lamp (1/a)
- Only for disinfection: controlling of 16 W lamp (2/a)

4.11.11 References

[1] DWA – German Association for Water, Wastewater and Waste**:** Standard DWA-A 262: Principles for the Dimensioning, Construction and Operation of Plant Beds for Communal Wastewater with Capacities up to 1000 Total Number of Inhabitants and Population Equivalents, 1st Edition, 21 Mar 2006, Bad Hennef, March 2006

4.12 PREMIER TECH – Ecofix® Typ STB 500

4.12.1 Manufacturer

PREMIER TECH LTEE

4.12.2 System name

Ecofix® Biofilter type STB 500?

4.12.3 Design capacity

6 PE

4.12.4 Licenses and patents

European patents 0 836 585 and 1 539 325, ASTM?

USA patents 5 618 414 and 7 097 768

Canadian patent 2 149 202

4.12.5 Technology description and diagrams/photographs

The Ecofix® Biofilter (see Figs.1, 2) provides biological domestic wastewater treatment (after the bloc of primary treatment) till the water quality allows effluent disposal towards surface or subsurface discharge. The proposed treatment procedure is based on the 0,8m deep filtering media consisting of coco shavings. The filtering media of coco shavings permit to combine filtration, adsorption, absorption and biofiltration properties.

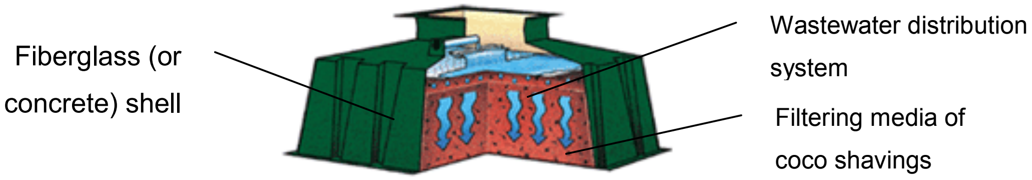


Figure 27: Operating principle of the Ecofix® biofilter

Figure 28: Distribution plate assembly – Ecofix® biofilter

To be treated, the wastewater first goes into the septic tank where it is submitted to a primary treatment. The septic tank has to be equipped with a prefilter. A grease trap has to be provided in front of the septic tank for some commercial projects (e.g. restaurants, kitchens etc.). The septic tank effluent enters the Ecofix® Biofilter after the primary treatment. Once inside the Ecofix® Biofilter, the water is directed into the tipping bucket in order to be split equally over the distribution plates located on both sides of the central support plate. These plates include channels with orifices to distribute the effluent evenly on top of the filtering media. Afterwards, wastewater trickles down into the filtering media where its organic content is consumed by bacteria. The treated effluent is collected in the bottom bed and evacuated by gravity (filters marked as ST) or with an integrated pump (filters marked as STB, see also Figure 29)

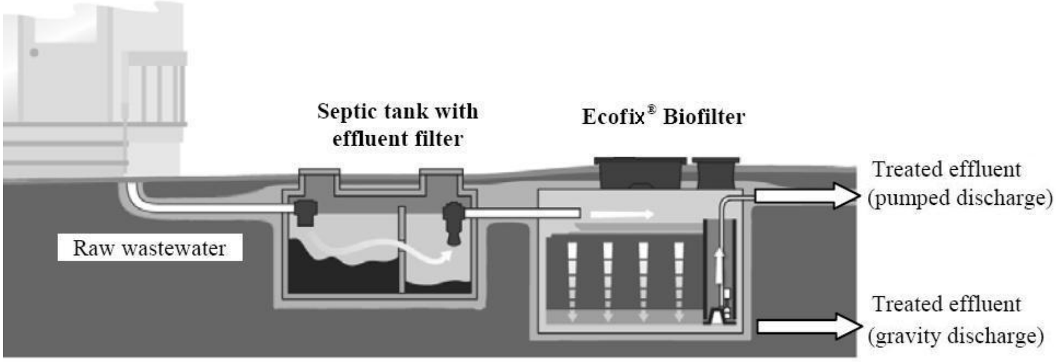


Figure 29: Flow chart of Ecofix® Biofilter process

To be efficient, the system requires enough oxygen so that the filtering media's bacteria do their work. In order to achieve this goal, the filtering media is fed oxygen by air flowing both at the top and at the bottom of the filtering media. Air comes into the system by the intake located on the main access lid, flows to the extremities of the filter bed via the air ducts on top of the filtering media underneath the distribution plates, and enters the filtering media via the water infiltration that takes it to the bottom. Moreover, a gas exchange occurs at the top and bottom of the filtering media promoting its oxygenation. The air coming out of the bottom of the filtering media is taken back towards the water supply line through the opening located in the access funnel and is directed by convection to the home air vent via the septic tank (Fig.4).

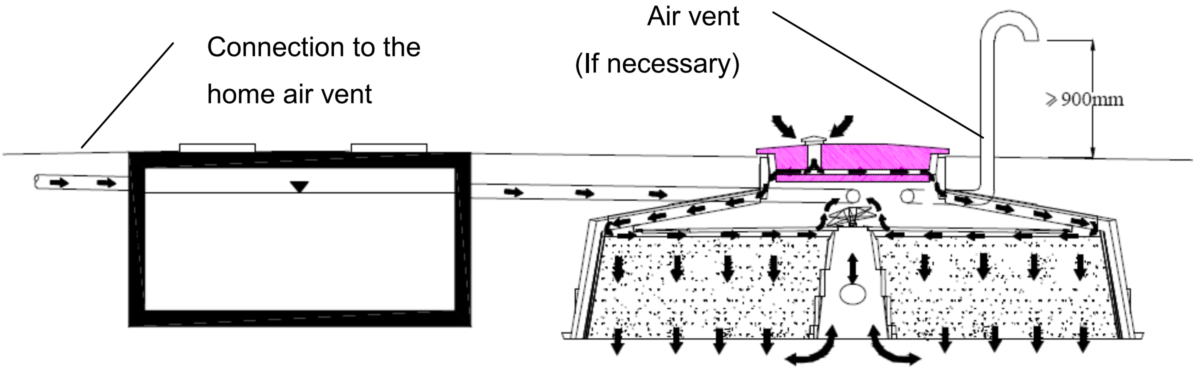


Figure 30: Air circulation diagram

4.12.6 Design data

Average flow rate for 6 PE: 0.9 m^3/d

Usable filtration area: 4.9 m^2 for 6 PE

Depth of filtration layer: 0.8 m

Number of distribution plates: 4

Coco volume: 3.9 m^3

Average size of filtering elements:

- Ordinary elements: 3 mm (no elements < 2 mm)
- Filter bottom (for STB type): 4.7 mm (no elements < 4 mm)
- Reinforcing and top layers: 4.7 mm (no elements < 4 mm)

Filter dimensions (mm):

Table 13: Design data

Parameter	ST500	STB500
Total height	1320	1700
Water depth	965	1350
Minimal width	2320	2320
Length	3345	3360

4.12.7 Power units

4.12.8 Nominal power consumption

4.12.9 Operation parameters

Based on 150 l per 1 PE and hydraulic loading of 18.4 cm/d, the decrease of the main pollutions (TSS, COD, BOD_5 and NH4) comes to the following values.

Rate of the pollution removal measured between the septic tank effluent and the Ecofix® biofilter effluent:

Table 14: Treatment efficiency of the Ecofix® Biofilter

Parameter	TSS	COD	NH4
Rate of removal (%)	≥ 86	≥ 82	≥ 59

Rate of the pollution removal measured between the septic tank influent and the Ecofix® biofilter effluent:

Table 15: Treatment efficiency of the Ecofix® Biofilter, including pretreatment

Parameter	TSS	BOD_5	COD	NH4
Rate of removal (%)	≥ 96	≥ 97	≥ 91	≥ 74

4.12.10 Maintenance

An annual follow up which consists of an inspection and maintenance of the system is performed on the Ecofix® Biofilter. The lifespan of the filtering media is 10 years (under normal utilization conditions) and its replacement is carried out with the same type of truck to empty septic tanks. This particularity allows easy access to the lid of Ecofix® and therefore the owner avoids excavating works and keeps the landscaping intact. The filtering media can also be subject to revalorization.

4.12.11 References

More than 5,000 Ecofix® Biofilter systems were installed worldwide by the end of 2007.

4.13 Busse – Typ MF-HKA4

4.13.1 Manufacturer

BUSSE IS GmbH
Zaucheweg 6
D-04316 Leipzig
Telefon: 0341-65984-25
Telefax: 0341-65984-26

4.13.2 System name

Type MF-HKA4

4.13.3 Design Capacity

Table 16: Companion dimensions

companion dimensions	one to four	population
max. daily waste water amount	0.6	m^3/d
max. daily pollutant load	0.24	kg BOD_5/d

4.13.4 Licenses and patents

4.13.5 Technology description and diagrams/photographs

Busse MF-HKA4 is a small-scale MBR system constructed using double-walled safety tanks designed for indoor installation in frost-proof locations (e.g. basement or attached building such as a garage or shed).

Figure 31: Dual tank system

The BUSSE-MF small wastewater system is designed in accordance with DIN 4261 Part 2 with a two-stage treatment process consist of a primary treatment tank (1) and an aeration tank (2). In the primary treatment tank, which also serves as a wastewater storage tank, an aerated sieve (3) separates biologically degradable coarse matter (e.g. faeces and toilet paper) and non-dissolvable substances from the wastewater. A pump (4) then conveys the separated wastewater into the aeration tank, where organic matter in the wastewater is biologically degraded by micro-organisms. An aeration system (5) provides the oxygen needed for this process. The treated wastewater then passes through microfiltration membranes (6) with a pore size of 0.4 µm for additional mechanical separation. The pores of the microfiltration membranes are so small that they eliminate not only suspended solids, but also bacteria and other micro-organisms. Therefore, the effluent discharged from the system is an absolutely clear, odourless, sanitary and safe liquid.

The BUSSE-MF system was tested by the University of Hannover and the Technical University of Berlin, which found that it significantly outperforms the minimum quality criteria of the DIBt Berlin* (Z-55.3-60) and the statutory requirements. The use of submerged microfiltration membranes in combination with a process-related high biomass concentration makes it possible to achieve effluent COD concentrations less than 30 mg/l* and BOD_5concentrations less than 5 mg/l*.

(Source: http://www.busse-is.de/de/busse-mf/funktionsprinzip.asp)

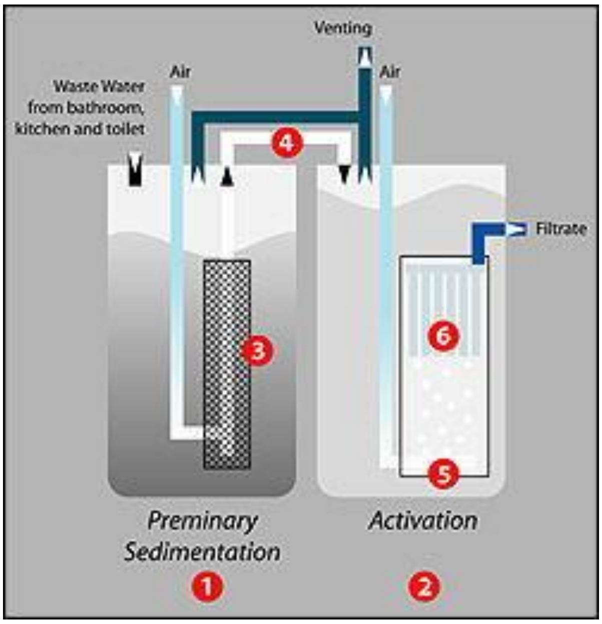


Figure 32: Process diagram of BUSSE MF

4.13.6 Design capacity

Table 17: Dimensions

Width	0.75	m
Depth	1.15	m
Height		
Minimum height	2	m
Number of containers	2	pieces

Installation options

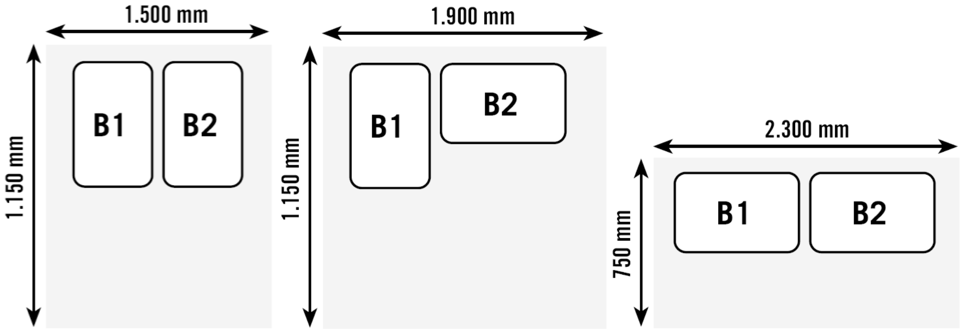


Figure 33: Installation options

4.13.7 Power units

Mammoth pump (sewage lifting unit from the primary treatment to the activation)

2 compressors

4.13.8 Nominal power consumption

4.13.9 Operation parameters

Effluent quality requirements:

BOD_5:	≤ 15 mg/l in homogenized 24-hour composite samples
	≤ 20 mg/l in homogenized, qualified random samples
COD:	≤ 75 mg/l in homogenized 24-hour composite samples
	≤ 90 mg/l in homogenized, qualified random samples
NH_4-N	≤ 10 mg/l in filtered 24-hour composite samples
SS	≤ 50 mg/l in qualified random samples

(German National Technical Approval)

4.13.10 Maintenance

Maintenance is to be performed three times a year. During the usual maintenance the membrane is not allowed to be cleaned chemically in its installed position.The membrane has to be exchanged once per annum.

4.13.11 References

4.14 ATB – AQUA max BASIC

4.14.1 Manufacturer

ATB Umwelttechnologien GmbH
Mr. Mirco Koppmann
Suedstr. 2
D – 32457 Porta Westfalica
E-Mail: m.koppmann@aquamax.net

4.14.2 System name

AQUAmax® BASIC

4.14.3 Design capacity

2 to 8 PE;

9 to 16 PE

(0.3 to 1.2 m^3/d; 1.35 to 2.4 m^3/d)

Flexible capacity depending on water depth and tank geometry

4.14.4 Licenses and patents

National German General Approval (DIBt)

No. Z-55.3-53, Z-55.3-106, Z-55.3-139, Z-55.3-144, Z-55.3-151, Z-55.3-182, Z-55.3-200, Z-55.3-210, in accordance with DIN 4261 and EN 12566-3.

CE-Mark? Yes, self-evident

International, European and German patents. The most important patents regarding the AQUAmax® BASIC are:

EP 1 650 169

EP 1 213 265

4.14.5 Technology description and diagrams/photographs

The AQUAmax® (Figure 34) from ATB Umwelttechnologien GmbH is based on the SBR technology (sequential batch reactor) which basically carries out every step of the depuration treatment taking place in municipal wastewater treatment plants. The only difference is that the AQUAmax® uses one tank alone to fulfil all phases of the process in a temporal sequence. This saves so much space that it can be installed on your property. A preliminary tank is necessary to separate the solids. The wastewater is treated biologically in the reactor, where it is aerated which allows the micro organisms to degrade the organic load using oxygen. The purified water can be evacuated without causing problems to the environment, letting it flow to a stream or seep into a suitable ground, with the permission of the respective authorities. The essential micro organisms are retained in the reactor. The remaining sludge of the preliminary tank must be extracted approximately once a year and can then be brought to a nearby central wastewater treatment plant or it is transformed into manure.

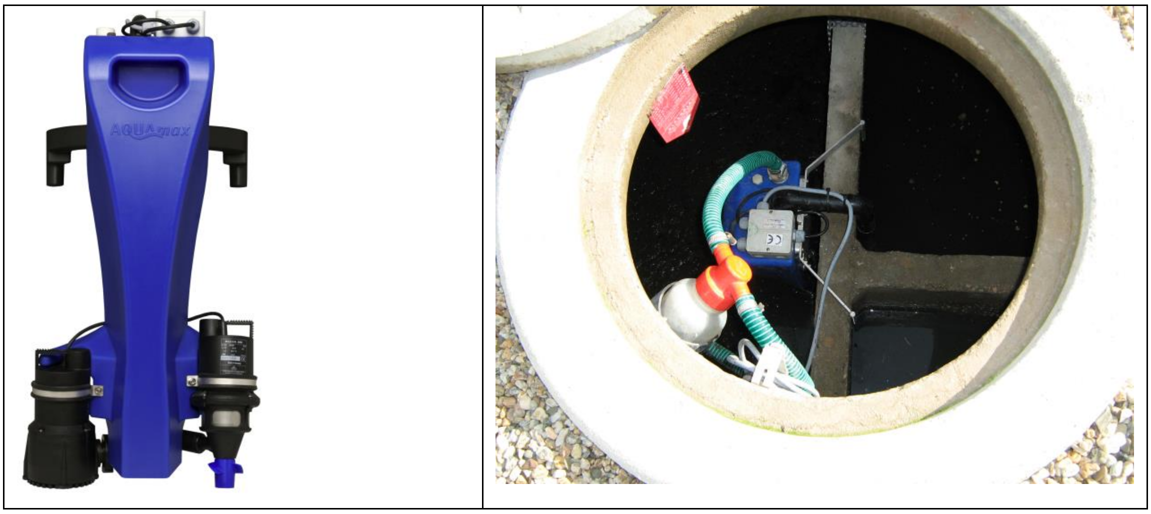


Figure 34: AQUAmax® BASIC

The wastewater treatment plant is operated with a cycle time of 8 hours. The sedimentation takes two hours. The clear water removal may take up to 20 minutes. A submerged aerator brings oxygen into the system during 6 hours of the aeration period.
An accumulating zone has to be provided in front of the main working zone to accumulate primary and secondary sludge as well as an influent. The accumulation zone has to store the maximal influent during at least 4 hours. 4 hours is a maximal time when no wastewater can enter the SBR (2 hours of primary clarification and 2 hours of secondary clarification).

The wastewater goes into the aeration zone from the accumulation zone through the communicating pipes. These pipes are filled by the excess sludge pump every 2 hours during the aeration phase. Finally the water level in the accumulating zone has to be equal to the water level in the aeration zone.

The tank is filled the last time 2 hours prior to the sedimentation phase. Excess sludge is pumped to the accumulating zone once per cycle.

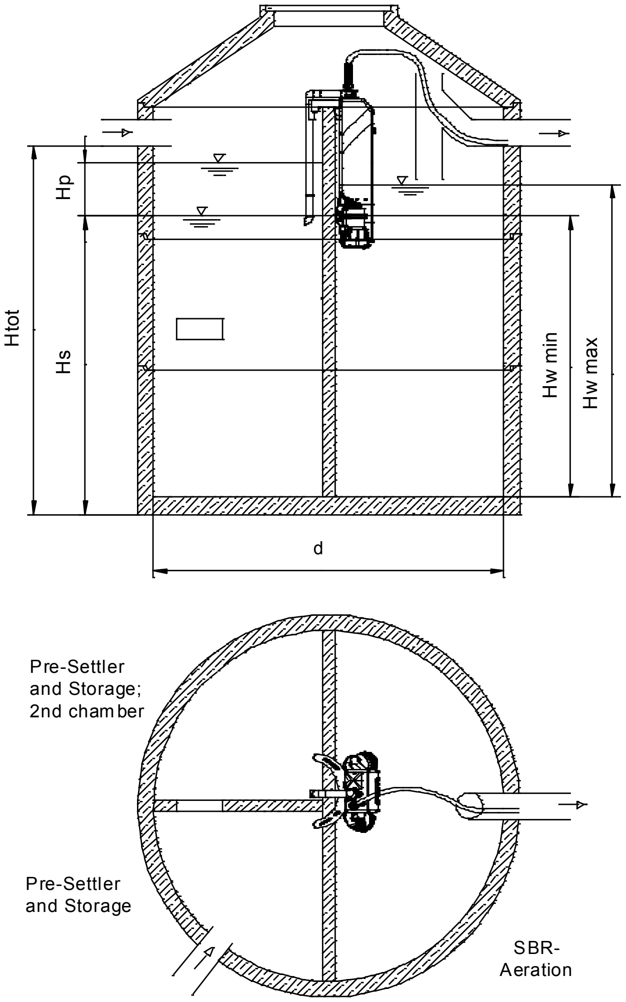


Figure 35 Design of the AQUAmax BASIC system

4.14.6 Design data (example for 4 PE in reinforced concrete tank)

Surface area of the SBR reactor: 2.02 m^2

Surface area of the accumulating zone: 1.96 m^2

Htot: 1.68 m

Organic loading: 0.24 g BOD_5/d

Diameter: 2.30 m

Design population: 4 PE

Maximal water level in the SBR reactor: HW max = 1.23 m

Minimal water level in the SBR reactor: HW min = 1.13 m

Minimal water level in the accumulating zone: HS = 1.13 m

Water depth in the accumulating zone: HP =0.22 m

Minimal water depth between the bottom edge of the inlet and the water level of the tank (HS+HP): = 1.35 m

Flow rate of waste water: Q_d =0.6 m^3/d

Maximal flow rate of waste water: Q10 = 0.06 m^3/h

Waste water volume per cycle (3 cycles a day): VdZ = 0.20 m^3

Average reactor volume: 2.38 m^3

Maximal reactor volume: 2.48 m^3

Minimal reactor volume: 2.28 m^3

Total volume of the accumulating zone: 2.65 m^3

Sludge volume in the accumulating zone: 2.21 m^3

Waste water volume in the accumulating zone: 0.44 m^3

4.14.7 Power units

The AQUAmax® is based on the submerged motor aerator and one submerged pump.

-	Submerged motor aerator	0.33 kW
-	Submerged pump	0.2 kW
-	Control panel	0.003 kW.

4.14.8 Nominal power consumption

Table 18: Annual power consumption

Annual energy consumption AQUAmax® BASIC

PE	**2**	**4**	**6**	**8**	**10**	**12**	**16**
Aerator							
Power consumption [kW]	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Annual energy consumption [kWh/y]	255.1	361.4	456.4	542.0	619	690	754
Discharge pump							
Power consumption [kW]	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Annual energy consumption [kWh/y]	5.5	11.0	16.4	21.9	27.4	32.9	43.8
Sludge pump							
Power consumption [kW]	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Annual energy consumption [kWh/y]	2.9	3.0	3.1	3.2	3.3	3.5	3.6
Control panel (0.003 kW) [kWh/a]	26.3	26.3	26.3	26.3	26.3	26.3	26.3
Total energy consumption [kWh/y]	**289.7**	**401.6**	**502.2**	**593.4**	**676**	**752**	**828**

4.14.9 Operation parameters

Small wastewater treatment plants with aeration of the class C such as AQUAmax® have been tested according to EN 12566-3. The following requirements for effluent concentrations have been achieved by this plant:

BOD_5: ≤ 25 mg/l for a 24 h-mixed homogeneous sample

≤ 40 mg/l for a random homogeneous sample

COD: ≤ 100 mg/l for a 24 h-mixed homogeneous sample

≤ 150 mg/l for a random homogeneous sample

TSS ≤ 75 mg/l for a random sample

Moreover, the AQUAmax® is also tested for stronger German effluent requirements (class D):

BOD_5: ≤ 15 mg/l for a 24 h-mixed homogeneous sample

≤ 20 mg/l for a random homogeneous sample

COD:	≤ 75 mg/l for a 24 h-mixed homogeneous sample
	≤ 90 mg/l for a random homogeneous sample
NH_4-N	≤ 10 mg/l for a 24 h-mixed homogeneous sample
TIN	≤ 25 mg/l for a 24 h-mixed homogeneous sample
TSS	≤ 50 mg/l for a random sample

4.14.10 Maintenance

The AQUAmax® is a fully-biological wastewater treatment plant according to EN 12566 part 3. Therewith, the plant has to be maintained by a specialised enterprise twice a year.

The maintenance consists of the following:

- Examination of the performance book to establish all regular processes.
- Controlling of the main units (especially compressors and air lifts), comparison of their operation with the manufacturer data.
- Checking of the automatic control units.
- Assessment of optimality of such operation parameters as DO (dissolved oxygen) and SVI (sludge volume index).
- Checking of the sludge depth in the zone of primary clarification.
- Carrying out of the general cleaning such as sludge removal.
- Checking of the structural parts of the treatment plant.
- Controlling of the aeration adequacy.
- Measuring of DO, SVI, t, pH, TSS, COD.
- Making a note about the maintenance in the performance book.

4.14.11 References

Since 1999, the year the German company ATB Umwelttechnologien GmbH was founded by Mr. Markus Baumann, more than 38,000 units of the AQUAmax have been sold and installed. During these years, ATB's products have been delivered all over Europe and to overseas countries such as Canada, Mexico, Vietnam and China. The AQUAmax® has also won several environmental awards and ATB has become the market leader in Germany.

4.15 Mall – SanoClean XL

4.15.1 Manufacturer

Mall GmbH, Hüfinger Straße 39 - 45, D-78166 Donaueschingen
Contact person: Mr. Stephan Klemens
Tel: 771 / 8005-201; Fax: 0771 / 8005-3201

E-Mail: stephan.klemens@mall.inft

4.15.2 System name

SanoClean XL, 4 PE, H20, Effluent class D+P

4.15.3 Design capacity

4 PE

4.15.4 CE and/or DIBt approval

National German General Approval
No. Z-55.3-118 in accordance with
DIN 4261, DIN EN 12566 - 3

4.15.5 Technology description and diagrams/photographs

SanoClean XL is a state-of-the-art small wastewater treatment system based on the sequencing batch reactor (SBR) technology.

Use of a sequencing batch reactor means that the natural wastewater load does not flow freely into the system but rather, that an integrated buffer feeds fixed quantities of wastewater into the SBR for sequential treatment cycles (sequencing batch reactors work according to a fill-and-draw system).

With the SanoClean technology designed by Mall GmbH, no rotating or electrical parts are positioned in the wastewater. Compressed air-driven, wear-free mammoth pumps are used to convey the wastewater and sludge.

System design

All of these systems consist of:

- A mechanical treatment stage with buffer effect
- Followed by a sequencing batch reactor.

Mechanical treatment

Mechanical treatment is designed to accomplish the following tasks:

- Wastewater containing coarse material flows freely downhill to enter the system. Coarse material is mechanically separated from the liquor (by gravity).
- Excess sludge from the biological process is stored in the mechanical treatment tank.
- A part of the mechanical treatment tank is also used as buffer space.

The buffer is designed to store wastewater that enters the system during an SBR cycle. The minimum buffer size needed for storage is calculated based on the normal distribution of influent throughout the day, including bathtub peak flows.

To prevent backflow into the inlet pipe during hydraulic overloads, an emergency spillway was inserted between the first tank (mechanical treatment, sludge storage and buffer tank) and second tank (SBR reactor).

SanoClean reactor

Filling phase

In the biological treatment stage, the mammoth pump conveys a defined amount of wastewater (approximately one-fourth of the daily wastewater volume) into the aeration tank once at the beginning of the cycle.

Reaction phase (aeration)

Biological treatment takes place during the reaction phase (aeration). Fine air bubbles are periodically blown through the activated sludge and wastewater by a compressed air diffuser in order to provide the micro-organisms with the oxygen needed for biological treatment.

Settling phase

Aeration is halted during this phase in order to allow sludge to settle to the bottom of the tank and for clear water to accumulate on top.

Drawing/decanting phase

After the settling phase, clear water in the bioreactor is drawn off and discharged into a receiving water body or seepage bed.

The drawing/decanting phase is terminated when the water reaches a minimum level or specified control value.

Excess sludge removal stage

An air lift pump (mammoth pump) conveys excess sludge to the sludge storage unit.

All processes and sludge level measurements are subject to microprocessor control. The air compressor and control valves for the mammoth pumps are connected via controller outlets.

The system is equipped with an economy and vacation switch for low-load periods.

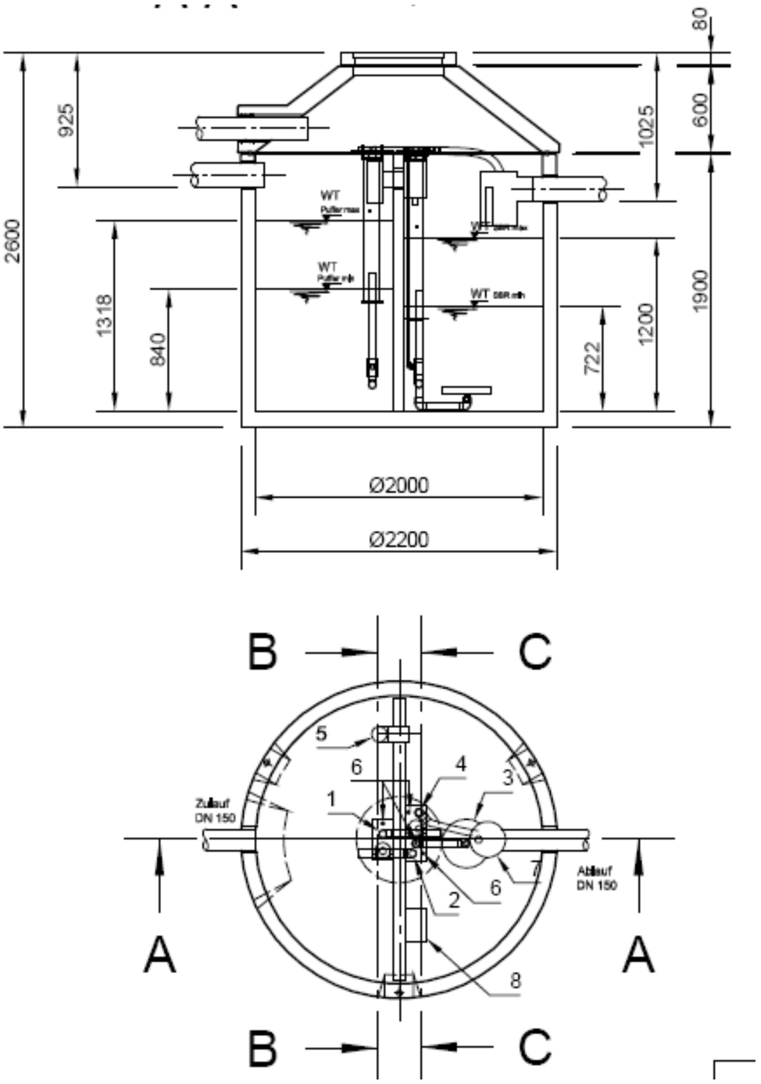


Figure 36: Design of SanoClean XL

4.15.6 Design parameters

Table 19: Summary of all design data

System type	SanoClean XL	4 PE	Model H20	
Treatment class	D+P			
Treatment objective:	Nitrification, denitrification and phosphate elimination			
Treatment process:	Ventilated sequencing biological reactor			
Design population			4	PE
Influent flow conditions				
Daily flow volume	150	l/PE/d	600.00	l/d
Daily average flow	Q/24		25.00	l/h
Daily peak	Q/10		60.00	l/h
Daily BOD$_5$ load	60	g/PE/d	240.00	g/d
Daily COD load	120	g/PE/d	480.00	g/d
Daily NH4-N load	13	g/PE/d	52.00	g/d
Daily P load	1.8	g/PE/d	7.20	g/d
BOD$_5$ concentration			400.00	mg/l
COD concentration			800.00	mg/l
NH4-N concentration			86.67	mg/l
PO4-P concentration			12.00	mg/l
Number of cycles per day			4.00	1/d
Water volume per cycle	Q/cycle		150.00	l/cycle
Pretreatment tank volumes (sludge storage + buffer tank)				
Sludge storage capacity	250	l/PE	1000.00	l
Buffer tank capacity for influent	6 x Q/10+200 l		560,00	l
Upstream denitrification volume	3 x Q cycles		450.00	
Total volume of pretreatment tank	V (PT)		2010.00	l
Selected volume				
Tank diameter	∅		2000.00	mm
Pretreatment tank fraction	PT fraction		0.50	-
Pretreatment tank surface area	A(PT)		1.57	m^2
Maximum water depth	Dmax		1318	mm
Minimum water depth	Dmin		840	mm
Maximum tank volume	Vmax		2.07	m^3
Minimum tank volume	Vmin		1.32	m^3
SBR tank volumes				
Permissible volumetric loading rate	Minimum	kg BOD$_5$/m^3	0.20	kg/m^3
SBR volume	V(min SBR)		1200.00	l
Simultaneous denitrification volume	4 x Q/cycle		600.00	l
Total SBR volume	V(SBR)		1800.00	
Inner diameter of SBR tank	∅		2000.00	mm

SBR tank fraction			0.50	-
SBR tank surface area	A(SBR)		1.57	m^2
Minimum water depth	Dmax		1200	mm
Minimum water depth	Dmin		722	mm
Maximum SBR tank volume	Vmax		1.88	m^3
Minimum SBR tank volume	Vmin		1.13	m^3
Aeration system:				
Oxygen demand for carbon removal	OD-C	1.4 g O2/g BOD_5	336.00	g/d
Oxygen demand for nitrification	OD-N	4.6 g O2/g BOD_5	239.20	g/d
Total oxygen demand	OD		575.20	g/d
	OD load		2.40	g/g
Aeration system:				
Make / Model	NITTO /	LA 60		
Aeration rate at maximum water level			4.80	m^3/h
Electrical power consumption			64.00	W
Diffuser:				
Specific oxygen uptake rate (SOUR)	Rubber membrane plate		18.00	g/m/m^3
Oxygen transfer rate			72.58	g/h
Aeration time per day			7.93	h/d
Aeration time per cycle			1.98	h/cycle
Precipitant dose:				
P concentration to precipitate			4.00	mg/l
P load to precipitate			2.40	g/d
Precipitant:	PAC 2			
Aluminium content			8.90	%
Aluminium dose required			1.30	kg Al / kg P
Aluminium dose			3.12	g/d
Precipitant dose required			35.06	g/d
Precipitant dose required	(Density 1.37)		25.59	ml/d
Duration of supply			150	days
Precipitant supply required			3.84	L
Precipitant tank capacity			8.00	L
Precipitant dosing scheme	4 *	7 ml	28.00	ml/d
			28.00	ml/d
Lift pump:				
Mean influent pumping rate:			1.50	m^3/h
Maximum influent volume/cycle	5 x Q/cycle		750.00	l/cycle
Influent pump run time			0.50	h/cycle
Mean effluent pumping rate			1.50	m^3/h
Maximum effluent volume/cycle			300.00	l/cycle
Effluent pump run time			0.20	h/cycle
Return activated sludge-nitrate/cycle			450.00	l/cycle
Mean return sludge pumping rate			1.00	m^3/h
Return sludge pump run time			0.45	h/cycle
Settling time			1.00	h/cycle

Simultaneous denitrification time	1.00	h/cycle
Aeration time	2.85	h/cycle
Blower cycle	6.00	1/h
Run time factor	0.70	
Blower run time	7.00	min
PAUSE. Blower off	3.00	min

Programme cycle sequence

Start of feeding	0.00	h
End of feeding	0.50	h
Start of denitrification	0.50	h
End of denitrification	1.50	h
Start of aeration	1.50	h
End of nitrification	4.35	h
Start of sedimentation	4.35	h
End of sedimentation	5.35	h
Start of effluent	5.35	h
End of effluent	5.55	h
Start of excess sludge phase	5.55	h
End of excess sludge phase	6.00	h

Feed valve red blower ON	31	min.	T1
Blower run time fraction	31	min.	
Feed batches – addition of PAC	1	Portion	P
Denitrification run time	60	min.	T2
Denitrification valve 2 blue blower ON	1	min.	T3
Denitrification valve 2 blue blower OFF	9	min.	T4
Blower run time fraction	6	min.	
Run time C / N	168	min.	T5
C / N valve 2 blue blower ON	7.00	min.	T6
C / N valve 2 blue blower OFF	3.00	min.	T7
Blower run time fraction	117	min.	
Settling time	60	min.	T8
Clear water run time	13	min.	T9
Clear water valve 3 white blower ON	13	min.	T10
Clear water valve 3 white blower OFF	0	min.	T11
Blower run time fraction	13	min.	
Run time N/S return valve 4 green ON	28	min.	T12
Blower run time fraction	28	min.	
PAUSE valve 2 blue blower OFF	10	min.	T13
PAUSE valve 2 blue blower ON	1	min.	T14
HOLIDAY valve 2 blue blower ON	5	min.	T15
HOLIDAY valve 2 blue blower OFF	55	min.	T16
Total cycle time	360	min.	
Aeration time/cycle	195	min.	
Aeration time/day	780	min.	
	13.0	h/d	

Inner diameter		∅	2,000	mm
Installation depth		2,600	mm	
Inlet depth/outlet depth, Version K		600/925	mm	
Inlet depth/outlet depth, Version B		925/1030	mm	
Maximum water depth, pretreatment	Buffer max.	1,318	mm	
Minimum water depth, pretreatment	Buffer min.	840	mm	
Maximum water depth, SBR tank	SBR max.	1,200	mm	
Minimum water depth, SBR tank	SBR min.	722	mm	
Heaviest individual component		4,530	kg	
Total weight		6,000	kg	

4.15.7 Power units

Compressor (aerator) 64 W, valves 10 W, controller 5 W

4.15.8 Nominal power consumption

1.1 kWh/d

4.15.9 Operating parameters

Standard parameters

Treatment efficiency of SanoClean XL small wastewater treatment plants

Table 20: Treatment efficiency

Parameter	Units	Sample type	Treatment	Effluent concentration
BOD$_5$	mg / l	24-hour composite	Homogenized	< 15
BOD$_5$	mg / l	Random	Homogenized	< 20
COD	mg / l	24-hour composite	Homogenized	
COD	mg / l	Random	Homogenized	< 75
NH$_4$-N	mg / l	24-hour composite	Filtered	< 10
TIN	mg / l	24-hour composite	Filtered	< 25
SS	mg / l	Random		< 50
Phosphate	mg / l	Random	Homogenized	< 2 mg/l

4.15.10 Maintenance

The frequency of maintenance must be three times a year because of P-approval.

SanoClean XL pretreatment tank (sludge storage and buffer) maintenance

In accordance with the system design and construction, maintenance of the SanoClean pretreatment tank should include the following items:

Pretreatment tank maintenance check list

- Are the shaft covers in good condition?
- Are the influent / effluent pipes and submerged pipes unobstructed?
- Have corrosion-related defects occurred?
- Is scum present?
- Was the feed pump tested for proper function?
- If there is a grease separator present: Is it working properly?
- If there is a grease separator present: Is the grease disposed of regularly?
- Is sludge removal being performed properly?
- Are other physical defects present?

SanoClean XL sequencing batch reactor maintenance

In accordance with the system design and construction, SanoClean XL sequencing batch reactor maintenance should include the following items:

SBR maintenance check list

- Is the influent of the SBR free from coarse material?
- Is the aeration system working properly?
- Is the oxygen concentration sufficient?
- Is there enough activated sludge in the reactor? (activated sludge volume)
- Is the excess sludge removal working properly?
- Is the separation of clear water working properly? Is there sufficient depth transparency?
- Is scum present?
- Are the current blower operating hours being logged regularly?
- Is the blower run time being checked regularly? (target/actual value comparison)
- Are other defects present?

Maintenance obligations of the operator

The operator or a person commissioned by the operator must perform the following function tests and tasks at the specified intervals and order sludge removal as needed. The operator is obligated to record all system malfunctions in the operating log and to ensure that they are remedied promptly.

Daily checks

Daily checks are needed to ensure that the system is running properly, as indicated by the green indicator light. If there is a malfunction, red indicator lights will signal the technical defect.

Monthly checks

Visually inspect for return sludge in the outlet.

Inspect the inlet and outlet for signs of clogging.

Determine whether scum is present and, if so, remove to the sludge storage tank.

Read the operating hours meter on the compressor and valves and record the hours in the operating log.

Always record the results of the checks in the operating log! In particular, deficiencies and malfunctions should be recorded.

4.15.11 References

1000 to 1500 of these systems are installed each year. An excerpt from the reference list is enclosed.

Chapter 5

Test Conditions

5.1 Test protocol (Phases 1 to 10)

The aim of the COMPAS study was to test a broad scope of small sewage treatment plants under as extreme as possible operation conditions that exceed the specifications of the construction admission procedures and the EU certification within in a whole year operation period. Especially conditions were to be simulated that the principal VEOLIA has established as representative for one-family-households in France which have comparably high specific water consumption and strong seasonal fluctuations of the intensity of usage throughout the year. This includes regular bath tub water discharges as well as additional loading through guests but also holiday idle and power blackouts. Furthermore, no design values exist in France, so that small sewage treatment plants have to be tested under strict conditions to cover as many extreme situations as possible.

The test program was based on the specifications of EN 12566-3 with increased waste water quantities at intermittent intervals (VEOLIA- test program: “Protocole en conditions sollicitantes®”). The charging program is summarized in the following table, changes compared to EN 12566-3 are bold (see Table 21).

For those SWWTPs in the study were the same conditions. The plants were loaded with the same water, creating a uniform water quality (temperature, composition). Even with hydraulic load, no differences were made.

Table 21: Test protocol: “Protocole en conditions sollicitantes®” (Duration in weeks)

Phase	Description	planned D.	actual D.	Description EN 12566-3	Duration
1	Inoculation phase: 100% load	4	7	Inoculation	Xa)
2	Equilibration phase (establishment of stable balance)	4	4	Normal Operation	6
3	Normal operation: 100% load	8	21	Operation with 50 % load	2
4	***100% load at all times except for 200% load on 3 days/week (weekends, 4 weeks total)***	***4***	***4***	Normal operation - simulated electric break down	6
5	***200% load***	***3***	***3***	No load	2
6	No load	***3***	***3***	Normal Operation	6

Phase	Description	planned D.	actual D.	Description EN 12566-3	Duration
7	***100% load at all times except for 200% load on*** ***3 days/week (weekends; 2 weeks total)***	2	2	Operation with 125 - 150% load (48 h at the beginning)	2
8	Normal operation	4	4	Normal operation - simulated electric break down	6
9	50% load	2	***4***	Operation with 50 % load	2
10	***Normal operation with 3 simulated electrical breakdowns lasting 24 hours each at 48-hour intervals during the third week***	***6***	***4***	Normal Operation	6

a) obtained from the manufacturers

Phase 3 had to be extended in duration due to an oil accident from a nearby factory, which also affected the BDZ facility, where the COMPAS study was performed (see Section 5.2.5). This additional time was needed to allow the systems time to re-stabilise and to ensure that the further course of testing was not impaired.

Before starting Phase 4, we gave the SWWTP manufacturers the opportunity to modify and adapt their systems to the increased hydraulic load conditions. The systems modified and actions taken are described below.

- Nordbeton: Adjustment of pumping regime.
- ATB: Adjustment of control time interval.
- Aquamatic: Installation of a more powerful compressor.

Phase 9 (50% load) was extended by two weeks and Phase 10 shortened by two weeks on account of low use levels in homes in Germany,

5.1.1 Simulated electrical breakdowns

According to the original protocol, three simulated electrical breakdown scenarios lasting 24 hours each and occurring at 48-hour intervals were to be conducted during the third week of Phase 10. However, the first electrical breakdown inadvertently lasted 48 hours, thus reducing the time until the next breakdown to 24 hours.

Table 22: Schedule of simulated electrical breakdowns

(dd.mm.yy)	27.01.09	28.01.09	29.01.09	30.01.09	31.01.09	01.01.09	02.01.09
Planned date:							
Electrical breakdown	x			x			x
Normal operation		x	x		x	x	
Actual date:							
Electrical breakdown	x	x		x			x
Normal operation			x		x	x	

During the electrical breakdowns, influent wastewater feed to the SWWTPs was continued in all cases except one (PREMIER TECH – Ecoflex^{TM}), in which the inflow of wastewater had to be stopped in order to prevent overflow.

All power units not needed for normal operation—that is, those specifically designed for installation at the BDZ test facility (e.g. effluent lift pumps)—remained in operation during the simulated electrical breakdowns. Pumps (see Table 23: (x)) in the following systems remained in operation during the electrical breakdowns

- Lauterbach-Kießling – BKF 4 DN2000 Z1,
- PREMIER TECH – Ecofix® STB-500
- Busse – MF-HKA4.

The following power consumers (see Table 23) were at the individual plants in operation:

aeration system:	Air compressors of any kind
pumps:	any kind
engines:	drive for biodisk system
others:	control, UV desinfection

Table 23: power consumers of all plants

No.	Manufacturer/System	Aeration system	pumps	engines	other
1	Aquamatic GmbH&Co. KG STM 5	1			
2	Martin Bergmann Umwelttechnik BIO- WSB®-N	1	1		
3	Klargester Environmental Ltd Klargester BioDisk BA		1	1	
4	Nordbeton GmbH Biofilter KP253 PAL (PAB)		2		1
5	PREMIER TECH LTEE Textile Biofilter Ecoflex™		1		
6	HUBER DeWaTec GmbH HUBER 3K PLUS®	1			
7	Lauterbach-Kießling GmbH Lauterbach BKF 4 DN2000 Z1		(1)		
8	UFZ Typ UFZ C+H 4 E		1		1
9	PREMIER TECH LTEE Ecofix® Biofilter type STB 500		(1)		
10	BUSSE IS GmbH BUSSE MF type MF-HKA4	2	1 (1)		
11	ATB Umwelttechnologien GmbH AQAU max BASIC	1	2		
12	Mall Umweltsysteme GmbH SanoClean XL 4 EW H20	1	3		

In parentheses: All pumps which are not needed during normal operation (see above)

5.1.2 Hydraulic loading

100% hydraulic load (design load) was originally defined as 150 L/(PE·d). However, in compliance with a decision of the Steering Committee, the 100% load level was increased from 150 L/(PE·d) to 225 L/(PE·d) (i.e. 150% load) on 23 July 2008. This was done to compensate for the low raw sewage concentration (cf. Section 5.2) by increasing the organic load accordingly. Therefore, 150% hydraulic load conditions were basically equivalent to the test conditions specified in EN 12566, Part 3 (EN 12566-3). 200% hydraulic load, however, was defined as 300 L/(PE·d), or two times the original design load of 150 L/(PE·d). Table 24 shows the corresponding hydraulic loads for the individual small wastewater systems according to capacity.

In addition to the daily flow volume, bath water surges of 200 L each in 3 minutes were discharged at 8 pm on each Friday to Tuesday night. This "bathtub flow test" was also more stringent than EN 12566-3, which only requires one such bath water discharge test per week. The bath water discharges increased the weekly average load by about 114 L per day.

Table 24: Hydraulic loading

Hydraulic load [%]	**Hydraulic load** [L/(PE·d)]	**4 PE group** [L/d]	**6 PE group** [L/d]	**9 PE group** [L/d]
100	150	600	900	1350
100 (150)	225	900	1350	2250
200	300	1200	1800	2700
50	75	300	450	675

The daily hydraulic loading schedule was executed in conformity with the specifications of EN 12566-3 (Table 25).

Table 25: Daily hydraulic loading schedule in conformity with EN 12566-3

Time	Duration	Fraction of daily load (%)
0600–0900	3 hours	30%
0900–1200	3 hours	15%
1200–1800	6 hours	0%
1800–2000	2 hours	40%
2000–2300	3 hours	15%
2300–0600	7 hours	0%

5.2 Influent characteristics

5.2.1 Influent concentrations

Because influent concentrations of target parameters were lower than the "standard" concentrations specified in EN 12566-3 when the systems were tested at 100% hydraulic load, the load was increased to 150% hydraulic load on 23 July 2008.

Table 26 shows the mean influent concentrations of target parameters before and after this change.

Table 26: Mean influent concentrations of target parameters before and after the change in hydraulic load

Parameter [mg / l]	BOD_5	COD	TS_O	N	P
Mean concentration before 23 July 2008	196	447	286	40	6.3
Mean concentration from 23 July 2008 on	214	463	263	51	7.3
Overall mean	**203**	**454**	**262**	**47**	**7.0**

Table 27 shows the mean influent concentrations detected in Leipzig (COMPAS) compared to those at other sites. The mean influent concentrations in Leipzig were in conformity with those specified in EN 12566-3. In some cases, they were below the minimum range. The measured concentrations of all target parameters were lower than those specified in the German Association for Water, Wastewater and Waste (DWA) references ranges for raw sewage. Moreover, influent concentrations of all target parameters measured in Leipzig were lower than those measured in the states of Saxony, Thuringia and Bavaria and lower than the national averages for Germany as a whole, leading us to this conclusion that they are relatively low. This was confirmed by further comparison of mean influent concentrations with those measured in Nantes, France and in Altentreptow and Weimar, Germany. Themean influent concentration of the test site Cebedeau (Belgium) reflects what the quality of raw water from a house is really without rain water, so what must treat a SWWTP in the real life (728 mg/L).

Table 27: Comparison of mean influent concentrations in Leipzig-Leutzsch with those in the literature.

Parameter [mg / l]	BOD_5	COD	TS_O	N	P
EN 12566-3 (2003)	150 - 500	300 – 1000	200 - 700	22 - 80	5 -20
Raw sewage (DWA standards)$^{1)}$	400	800	466	73	12
Mean in Leipzig (COMPAS)	**203**	**454**	**262**	**47**	**7.0**
Maximum in Leipzig	**276**	**730**	**570**	**72**	**10.2**
Minimum in Leipzig	**78**	**180**	**140**	**20**	**2.9**
Saxony/Thuringia (DWA 2007)	292	611	-	55	8.9
Germany overall (DWA 2007)	283	513	-	47	7.6
Nantes, France	313	679	313	75	-
Bavaria (DWA Bavaria)	306	560	-	58	9.8
Altentreptow (test site)	554	815	623	64$^{2)}$	7.5
Weimar (test site)	275	615	330	62$^{2)}$	10.7
Cebedeau (test site, Belgium)$^{3)}$	728	-	-	-	-

---

1) At 150 L/(PE·d)

2) NH_4-N only

3) This test site collects and receives exclusively water from a bulding, without rain water

COD ratios

Relative COD values, or the ratio of COD concentration to that of other parameters, were consistent with the reference values.

Table 28: Comparison of COD ratios

Parameter	COMPAS (Leipzig)	ATV A 131	Nantes
COD/BOD$_5$	2.2	2	2.2
COD/N	10.0	11	9.1
COD/SS	1.8	1.7	2.2

5.2.2 Effects of precipitation on wastewater quality

Precipitation data were collected to determine whether precipitation had a diluting effect resulting in the reduction of influent concentrations. The course of precipitation (blue) versus influent COD concentration (black) from March 2008 to Feb. 2009 is shown in Figure 37.

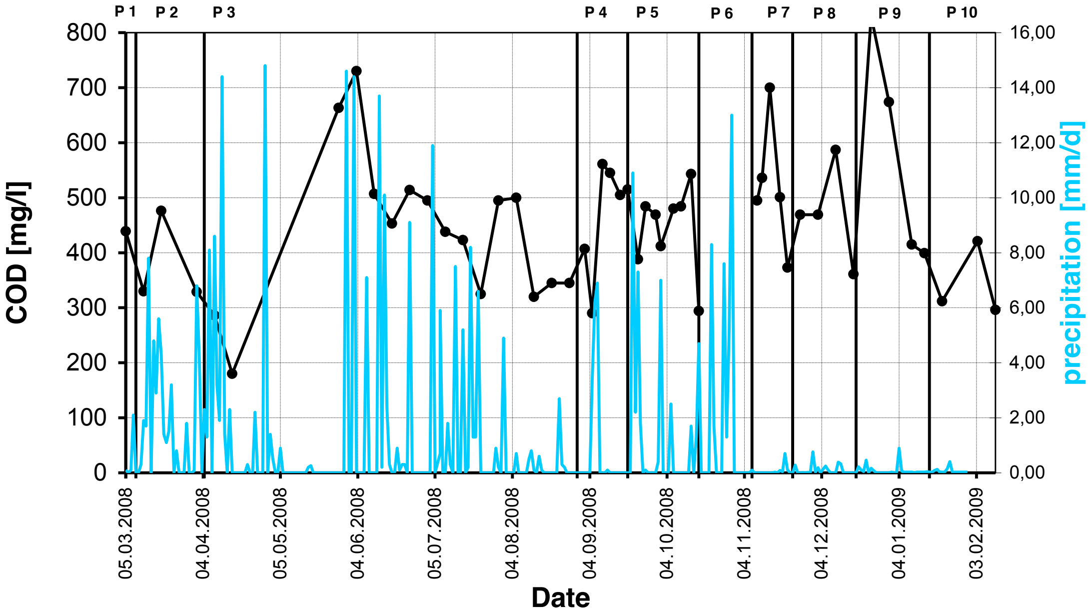


Figure 37: Course of precipitation and influent COD concentration over time (dd.mm.yyyy)

Theoretically, precipitation peaks should coincide with concentration troughs. However, no clear correlations could be ascertained based on the data. Similarly, a test for correlation between influent COD concentration and precipitation level (Figure **38**) did not reveal any evidence correlation between precipitation levels and influent concentrations. The dilution of wastewater presumably occurs due to other causes, e.g. foreign discharges from other sources, which may or may not occur in conjunction with precipitation events.

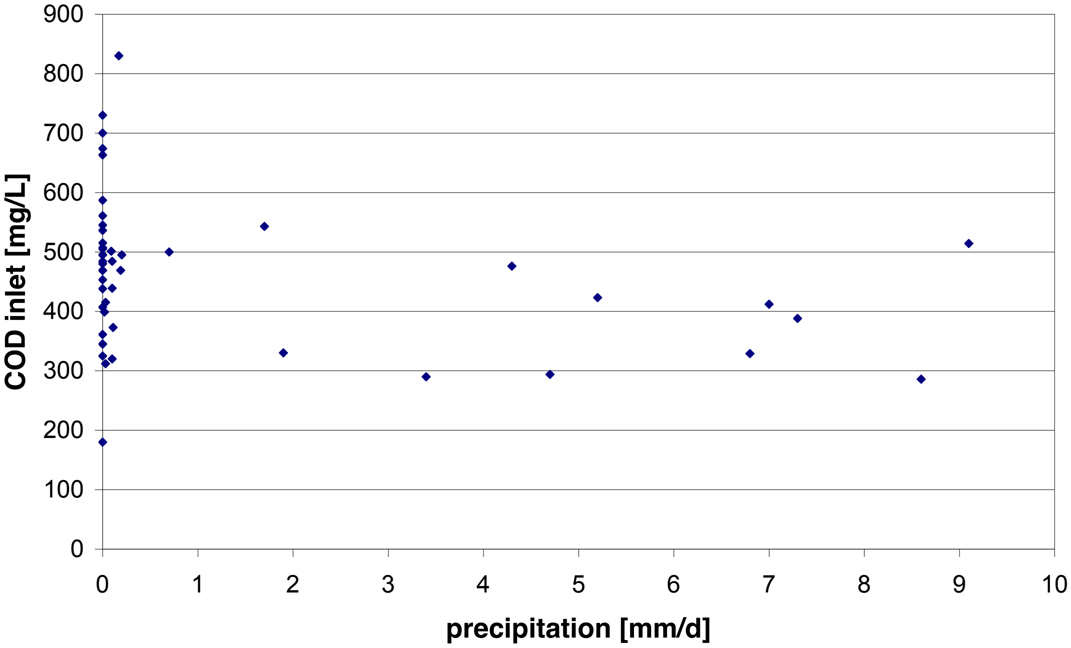


Figure 38: Tests for correlation between influent COD concentrations and precipitation levels

5.2.3 Organic load and capacity utilisation

In the beginning capacity utilisation rates relative to organic load ranged from 54% to 65% for the investigated small wastewater systems. After raising the hydraulic load on 23 July 2008 to compensate for the diluted wastewater quality, the PE-based real load approached the design load specified by the manufacturers (cf. Section 2.5). After the change up until the beginning of Phase 4 (200% load on three days), capacity utilisation rates ranged from 70% to 78%. Table 29 shows the calculated PE-based real loads and capacity utilisation rates for the three system groups before and after the change in hydraulic load up until the beginning of Phase 4. The overall PE-based real load and capacity utilisation rates for the entire study period are also given. On the whole, it was not possible to achieve the target organic load. With capacity utilisation rates of around 80%, however, satisfactory loads were achieved.

Table 29: Specific population equivalent (PE) and capacity utilisation rate (CUR)

Group class	Specific PE before 23 Jul 08	CUR before 23 Jul 08	Specific PE from 23.07.08-27.08. 08 (start of Phase 4)	CUR from 23.07. 08-27.08. 08 (start of Phase 4)	Specific PE overall	CUR overall
	[PE]	[%]	[PE]	[%]	[PE]	[%]
4 PE	2.6	65	3.1	78	3.4	86
6 PE	3.6	61	4.4	73	4.9	81
9 PE	4.9	55	6.3	70	7.0	77

Because the test site could only accommodate three different load levels, the SWWTPs were divided into three size groups according to design population equivalent size. A few of plants differ from the claim of the manufacturers. For these plants the following capacity utilisation rates were obtained:

Aquamatic – STM 5: According to this system is designed approval for 5 PE. This results in an occupancy rate over the entire period of 68%.

Klargester – BioDisk BA: According to the manufacturer has designed this system for 5 PE. This results in an occupancy rate over the entire period of 98%.

Premier Tech - Ecoflex®: According to the manufacturer has designed this system for 5 PE. This results in an occupancy rate over the entire period of 73%.

ATB – AQUAmax BASIC: According to the manufacturer has designed this system for 8 PE This results in an occupancy rate over the entire period of 70%.

5.2.4 Wastewater temperature

Instead of measuring wastewater temperature in the influent, wastewater temperatures were measured once weekly in all reactors (Figure 39). These wastewater temperature curves correspond well with the air temperature curve (Figure 40). The mean wastewater temperature was approximately 14°C. The maximum temperature (21.5°C) was measured in July. In January, the wastewater temperature dropped to 3.3°C due to the very cold winter temperatures.

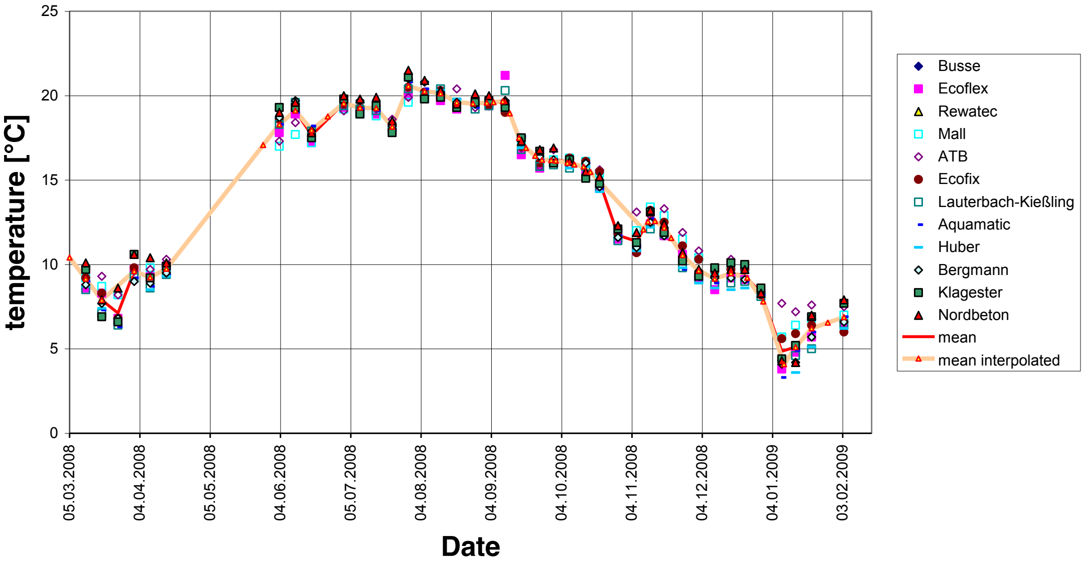


Figure 39: Wastewater temperature

Air temperature measurement data from a private monitoring station in Neukirchen, located 35 km from the test site, are plotted in Figure 40. The curve shows the effects of air temperature on wastewater temperature with sufficient accuracy. The maximum air temperature was approximately 34°C. Temperatures below -20°C were recorded in January 2009.

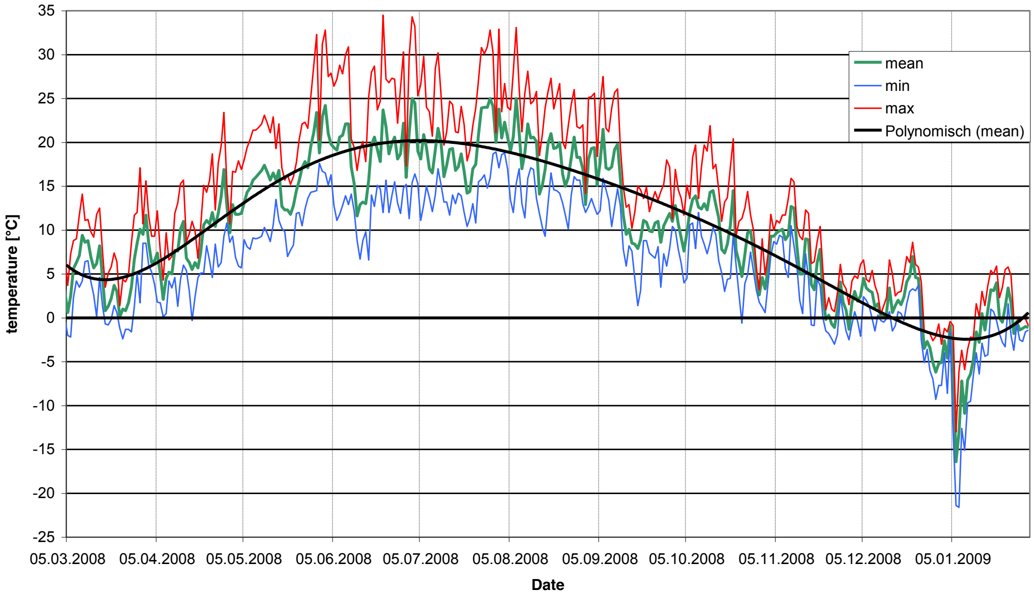


Figure 40: Air temperature curve "Neukirchen"

The distribution of wastewater temperature data collected in the present study (n=394) was compared with that of the data collected in the PIA study from 2001 to 2005 (n=1248). The percentages of temperatures in the two extreme groups, i.e. temperatures greater than 20°C and less than 6°C, were nearly identical. Differences between the percentages of temperatures in the 16 - 20°C group (22% in the PIA study versus 42% in the COMPAS study) and 11 - 15°C group (33% in PIA study versus 16% in COMPAS study) were greater. Overall, more wastewater temperature data from the present study seemed to be in a higher range than those from the reference study. This was confirmed by comparing the means of the two groups. The mean wastewater temperature of the COMPAS study (ca. 13.7°C) was slightly higher than that of the PIA study (12.7°C) (Figure 41 and Figure 42).

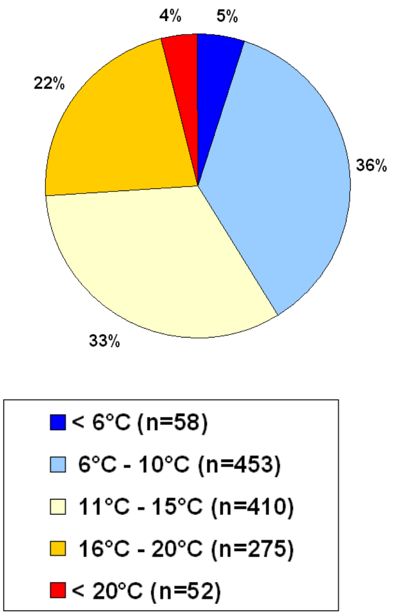


Figure 41: Distribution of wastewater temperatures in the PIA study (PIA, 2005)

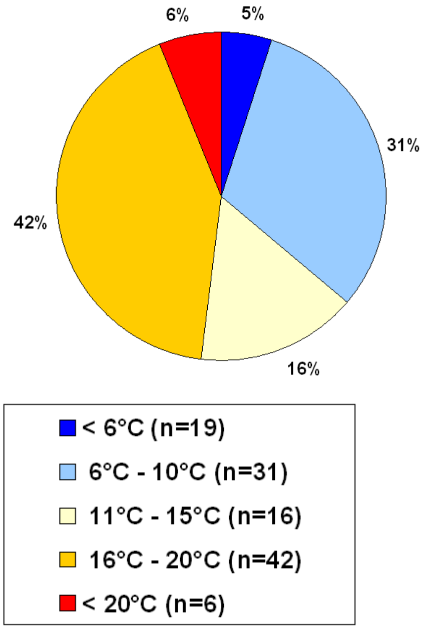


Figure 42: Distribution of wastewater temperatures in the COMPAS study

5.2.5 Oil accident

On 11 June 2008, an old factory released roughly 150 litres of oil into the sewage system. The BDZ test site, located only about 1 km away from the site of the accident, was affected.

In the course of immediate action, wastewater inflow to all wastewater treatment systems at the BDZ facility was switched off from 08:00 to 18:00 hrs. In almost all cases, an oil binding agent (Conex WB1) had to be used to remove the oil from the systems. The primary clarifiers were most severely affected. In once case (ATB AQUAmax BASIC), re-inoculation of activated sludge was required. In the case of the MBR system (BUSSE MF-HKA4), the sludge had to be exchanged and the membrane cleaned. The submerged fixed bed reactor (HUBER 3K PLUS®) was also cleaned. Figure 43 illustrates how the oil binding agent was applied and suctioned out of a primary clarifier.

Figure 43: Oil accident: An oil-binding agent was applied and suctioned out of the primary clarifier.

As a further measure, we waited for effluent concentrations in all of the SWWTPs to stabilize. Consequently, Phase 3 was extended from 3 weeks to 21 weeks.

5.3 Sampling

5.3.1 Sampling system design

The installed sampling system was adapted to the specific technical conditions of the test site (BDZ Training and Demonstration Centre for Decentralised Wastewater Treatment). The sampling system was designed to ensure the collection of representative 24-hour composite samples (in accordance with DIN 12566-3) in the influent and effluent channels of all of the investigated small wastewater systems. The common influent line and separate effluent lines of each individual SWWTP were equipped with a separate sampling system.

5.3.1.1 Influent sampler

The influent sampler took samples directly from the sampling loop of the pipeline supplying the SWWTPs with wastewater. A baffle was used to retain wastewater in the "relaxed-pressure" sampling loop to a height of about 50 mm to ensure that there was a constantly irrigated and well-mixed supply of water for representative sampling (Figure 44). A PB8 sampler manufactured by WTW was used to execute initial volume-proportional and subsequent event-dependent sampling.

Visual inspections were performed to ensure that this sampling point was functioning properly. Agreement between values measured at the influent of the test site and main sewage plant was evaluated by frequent comparative analysis, and the respective protocols were submitted to the client (cf. Section 5.3.5).

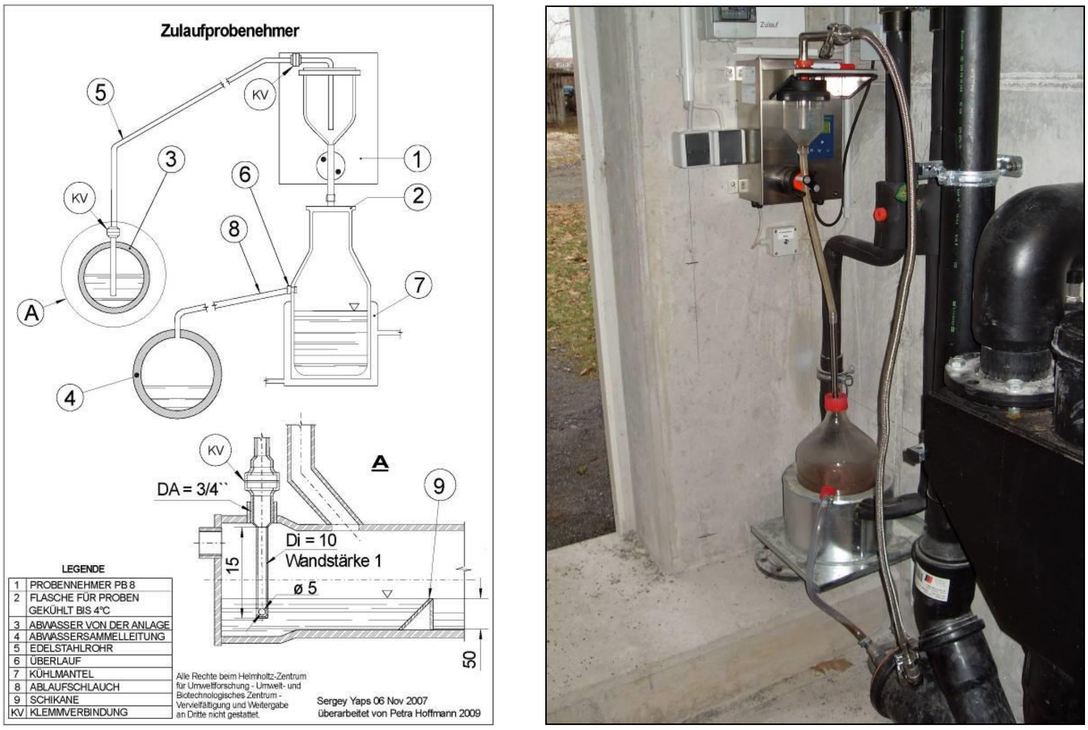
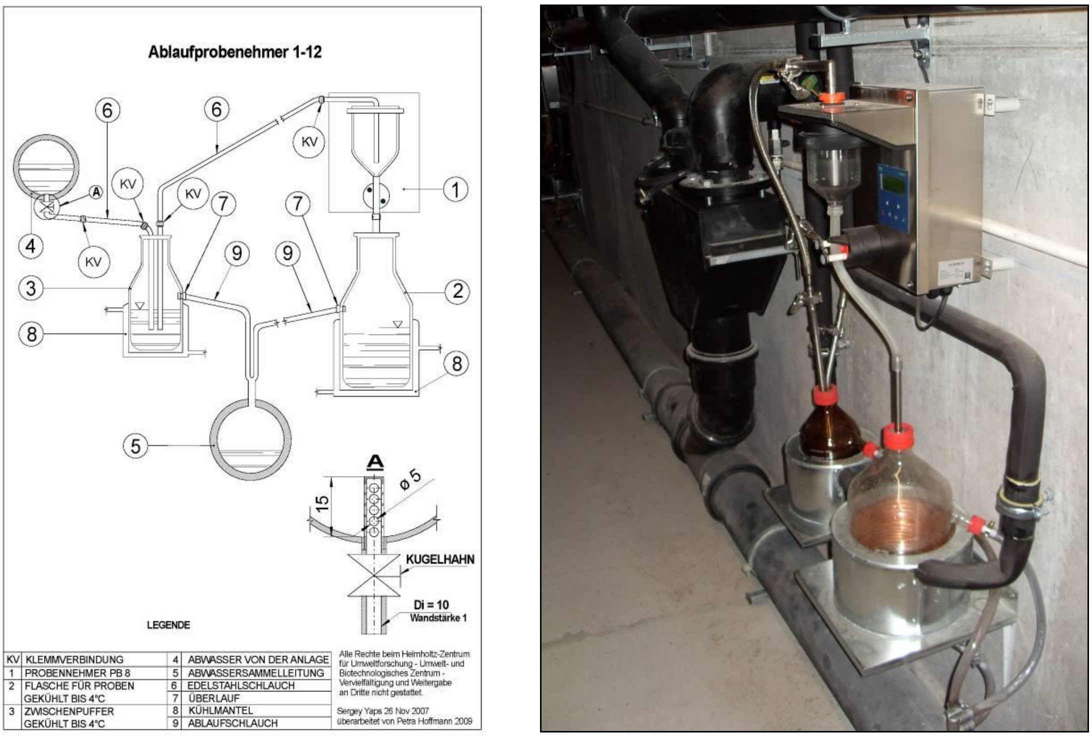


Figure 44: Influent sampling system at the BDZ (COMPAS)

5.3.1.2 Effluent sampler

A sampling point with 5 mm drill holes was installed in the effluent line (4) of each small wastewater system. For sample collection, a fraction of flow (20% of total flow volume) was percolated (strained) into the receiving bottle (3) via *a* ball valve (A). There was a continuous flow of purified effluent wastewater into the 2L receiving bottle, which served as a buffer zone. The PB8 sampler manufactured by WTW (1) was used to extract from the buffer bottle time- and volume-proportional samples, which were collected in a sample bottle (2) for a period of 24 hours. The receiving bottle and sample bottle were cooled to 4°C with the aid of a refrigeration device manufactured by REIMA GmbH (8).



KV	KLEMMVERBINDUNG	4	ABWASSER VON DER ANLAGE
1	PROBENNEHMER PB 8	5	ABWASSERSAMMELLEITUNG
2	FLASCHE FÜR PROBEN GEKÜHLT BIS 4°C	6	EDELSTAHLSCHLAUCH
		7	ÜBERLAUF
3	ZWISCHENPUFFER GEKÜHLT BIS 4°C	8	KÜHLMANTEL
		9	ABLAUFSCHLAUCH

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Sergey Yaps 26 Nov 2007
überarbeitet von Petra Hoffmann 2009

Figure 45: Effluent sampling system at BDZ

5.3.2 Influent sampling regimen

From Phase 4 on, the influent sampler was connected to a programmable logic controller (PLC) that controlled the dosing valve feeding the SWWTPs with raw sewage. An influent sample was collected each time wastewater was dosed to the reference SWWTP (Section 5.7 PREMIER TECH - Ecoflex^{TM}) (Figure 46).

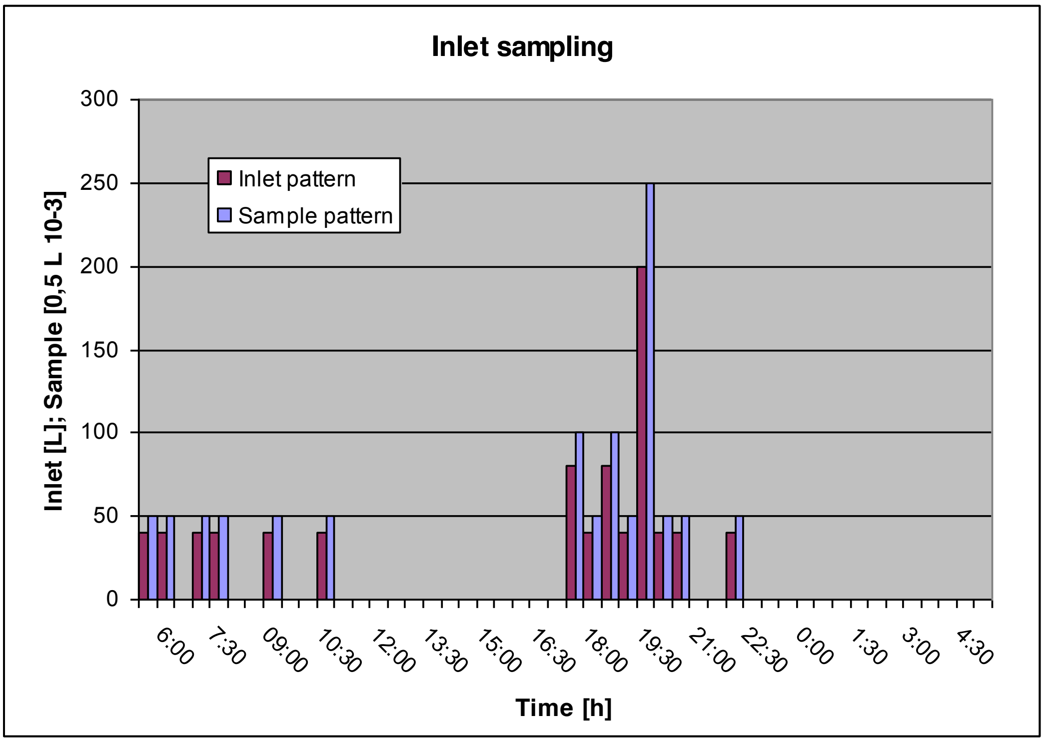

Figure 46: Influent sampling regimen from Phase 4 on

5.3.3 Effluent sampling regimen

It was not possible to implement a standard sampling regimen for all effluent lines due to technical circumstances at BDZ and due to differences in effluent discharge characteristics of the different small wastewater treatment systems.

The SWWTPs were divided into two groups distinguished according to effluent discharge method as follows: systems that discharge treated wastewater discontinuously, i.e. only when they receive fresh raw sewage, and those with continuous effluent discharge.

In the case of SWWTPs with continuous effluent discharge, the effluent sampling regimen was time-proportional during Phases 1 and 2, and volume-proportional during Phase 3 ("four-phase sampling"). In systems with discontinuous effluent discharge, effluent sampling was time-proportional. All effluent samples were collected as 24-hour composite samples.

Effluent sampling started with initial four-phase sample collection followed by the collection of volume-proportional, event-dependent 24-hour composite samples starting in Phase 4.

An overview of sampling regimens according to system and effluent type is presented in Table 30.

Table 30: Sampling regimen according to system and effluent type

Manufacturer	System	Effluent	Sampling
Aquamatic GmbH & Co. KG	STM 5	Continuous	Volume-proportional
Martin Bergmann Umwelttechnik	BIO- WSB®-N	Continuous	Volume-proportional
Klargester Environmental Ltd.	Klargester BioDisc BA	Continuous	Volume-proportional
Nordbeton GmbH	Biofilter KP253 PAL (PAB)	Continuous	Volume-proportional
PREMIER TECH LTEE	Textile Biofilter Ecoflex™	Discontinuous	Time-proportional
HUBER DeWaTec GmbH	HUBER 3K PLUS®	Continuous	Volume-proportional
Lauterbach-Kießling GmbH	Lauterbach BKF 4 DN2000 Z1	Discontinuous (pump shaft)	Time-proportional
UFZ	UFZ C+H 4 E Constructed Wetland	Continuous	Volume-proportional
PREMIER TECH LTEE	Ecofix® STB-500	Discontinuous (pump shaft)	Time-proportional
BUSSE IS GmbH	BUSSE MF-HKA4	Discontinuous	Time-proportional
ATB Umwelttechnologien GmbH	AQUAmax BASIC	Discontinuous	Time-proportional
Mall Umweltsysteme GmbH	SanoClean XL 4 EW H20	Discontinuous	Time-proportional
Influent	-	-	Event-dependent

5.3.3.1 Volume-proportional sampling

In SWWTPs with continuous effluent discharge, effluent sampling was performed using a four-phase sampling method (in the style of volume-proportional sampling) starting in Phase 3.

Sampling times and volumes were set in accordance with the periods of total daily flow of raw sewage (Table 25).

Volume-proportional sampling was performed by dividing the 24-hour sampling period into four phases (Table 31).

Table 31: Event-dependent sampling regimen (four-phase sampling)

Phase	Time	Sample volume / time
Phase 1	06:00 – 12:30 hrs	50 ml / 30 min
Phase 2	12:30 – 18:00 hrs	No sampling performed
Phase 3	18:00 – 23:30 hrs	50 ml / 10 min
Phase 4	23:30 – 06:00 hrs	No sampling performed

The mean ratio of influent load volume in Phase 1 to Phase 3 was 0.43. The ratio of collected sample volume in Phase 1 versus Phase 3 was 0.41. Thus, it was assured that the sampling of systems with continuous effluent discharge was volume-proportional (Table 31).

As shown in Figure 47, 50-ml samples were collected every 30 minutes during Phase 1. The duration of this sampling phase was 6.5 hours, which is 30 minutes longer than the first two inflow phases of the total daily influent load. This additional time was included to allow for detection of potential temporal delays in processes in the individual small wastewater plants.

This step was followed by a 5½-hour pause during which the SWWTPs did not receive any wastewater inflow and, thus, no effluent samples were collected. During Phase 3, in which the SWWTPs received 40% and 15% of the total daily influent load, the sampling rate was increased to 50 ml every 10 minutes. Likewise, no effluent sampling was performed during Phase 4.

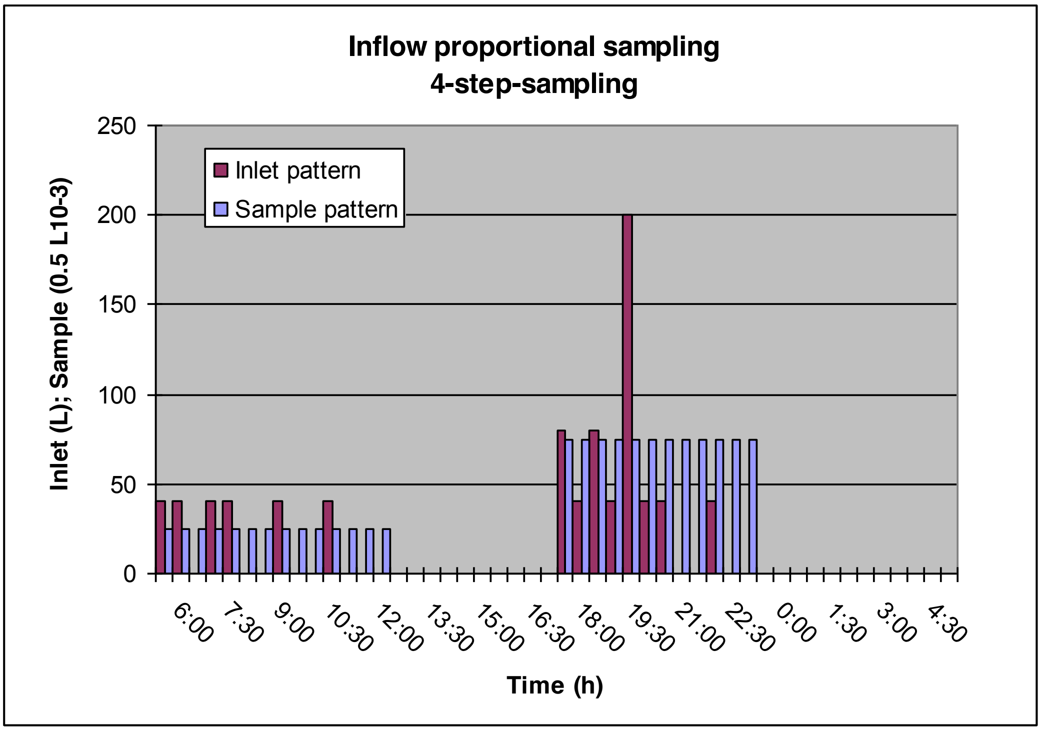

Figure 47: Four-phase sampling regimen

5.3.3.2 Time-proportional sampling

In small wastewater systems with discontinuous (internally regulated) effluent discharge, samples were collected from the receiving bottles in a time-proportional manner. Time-proportional sampling was also performed in systems in which effluent discharge was accomplished by means of a submersible pump and pump shaft. Because these SWWTPs discharged wastewater at different (i.e. unknown) times, 50-ml samples were removed from the receiving bottle of each SWWTP every 30 minutes for 24-hour periods and stored in a refrigerated sample bottle (Figure 48). There was a constant flow of effluent water in the receiving bottles.

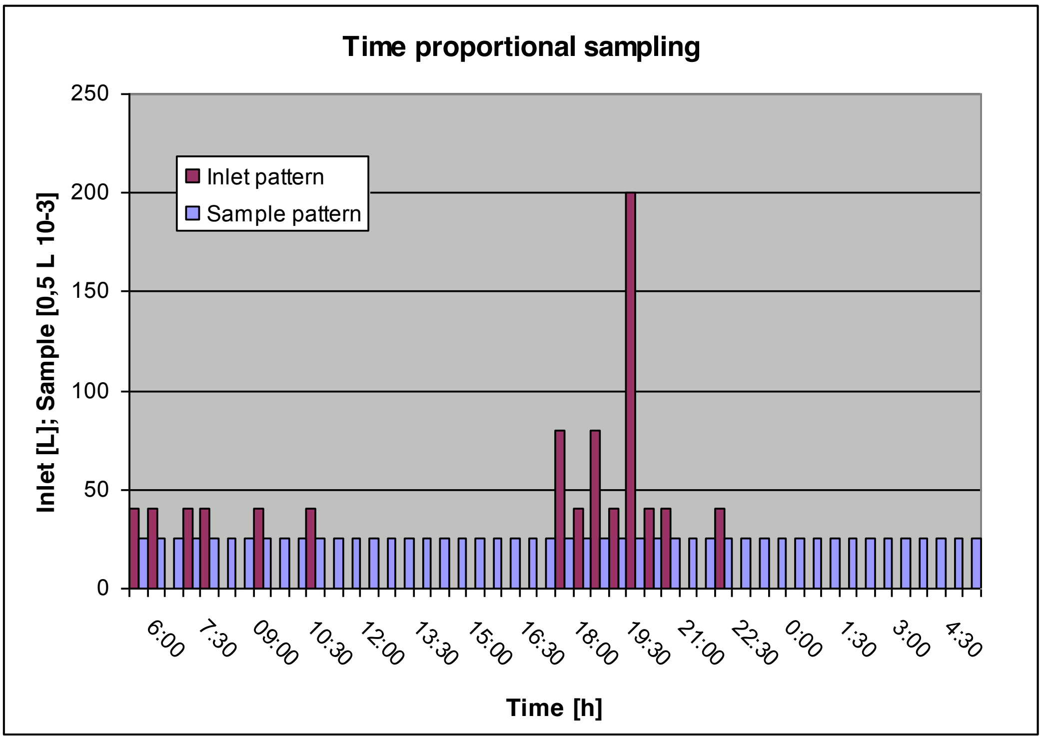

Figure 48: Time-proportional sampling regimen

5.3.4 Sampling procedure

Influent and effluent sampling began at 6 a.m. on each sampling day, at the start of daily influent feed to the SWWTPs, and ended at 6 a.m. on the following day. Samples for each 24-hour composite sample were stored at 4°C. The sample volume required for analysis of all physicochemical parameters was 2 L. In the case of composite samples, redox potential was measured directly after sample collection. The samples were then shaking gently several times for homogenisation, placed in a sample transport container, and taken to the BDZ laboratory. After arrival at the laboratory, conductivity and pH were measured and the samples were dispatched immediately to the central laboratory, where they were immediately prepared and analysed. The sample collection and receiving bottles of the sampling system were then cleaned thoroughly in preparation for the next sampling cycle.

5.3.5 Validation of the influent sampling procedure

The influent sampling procedure had to be validated at the beginning of the test series. Detection of implausible measurements prompted a thorough investigation of the sampling site. For this purposes, measurement data obtained from three sampling points were compared (Figure 49):

-	Sampling point A:	Pump shaft (influent)
-	Sampling point B:	Sampling loop (influent)
-	Sampling point C:	Outlet shaft of the sampling loop

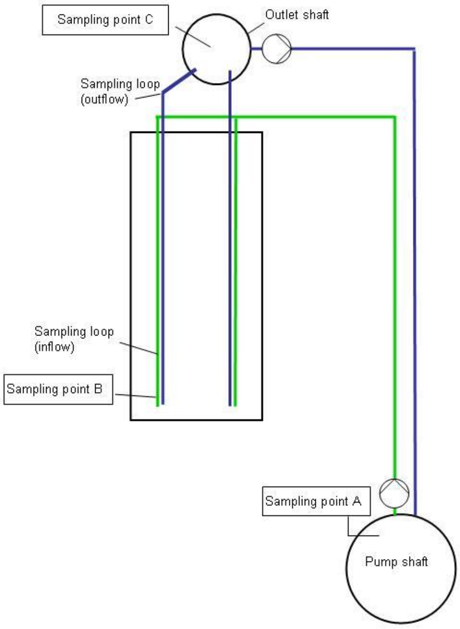

Figure 49: Schematic of the influent sampling points

Contrary to our assumption that samples collected in the influent pump shaft (sampling point A) would have lower concentrations that those collected in the outlet shaft (sampling point C) due to the backflow of purified wastewater, concentrations at **A** were often higher than those at **C** (Table 32). This may have been due to inadequate homogenisation.

Table 32: Influent COD concentrations in 24h composite samples obtained at three sampling points

Date	Inflow (pump shaft)		Entrance of sampling loop		Outlet of sampling loop		Weather data
	Sampling point A		Sampling point B		Sampling point C		
	COD	SS	COD	SS	COD	SS	
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	
23.04.2008	249	230	171	130			dry
24.04.2008	267	160	221	210			dry
28.04.2008	395	230	225	160	253	200	dry/ Rain
29.04.2008	145	150	206	210			Rain
13.04.2008	271	200	256	200	285	200	dry
14.04.2008	256	220	177	110	220	200	dry
15.04.2008	241	190	241	290	207	130	dry
mean	264	197	214	187	241	183	

The degree of homogenisation in the sampling loop was better than that achieved in the pump shaft. Therefore, the sampling loop was used as the sampling point for collection of representative influent samples.

5.4 Analyses / test parameters

5.4.1 Chemical/physical test parameters

Chemical/physical parameters of samples obtained from the effluent lines of the individual SWWTPs and the common influent line were generally determined once a week. The target parameters and methods by which they were analysed are outlined in Table 33.

Table 33: Chemical / physical parameters – Analytical methods

Parameter	Reference methods of analysis
COD	DIN 38409/H41
BOD_5	EN 1899-1
SS	EN 872
P_{tot}	EN ISO 6878
NH_4-N	EN ISO 11732
NO_3-N	EN ISO 10304-2
NO_2-N	EN ISO 10304-2
N_{tot}	TN_b – total bound nitrogen according to DIN 38409, Part 27
pH	pH 340 (WTW, Weilheim, Germany) pH meter
Redox	pH 340i pH meter and SenTix ORP 103 648 electrode (WTW, Weilheim)
Conductivity	LF 340 Microprocessor Conductivity Meter (WTW, Weilheim)

5.4.2 Microbiological parameters

Microbiological tests were performed using 3 samples collected on 3 consecutive days (Dec. 1, Dec. 2 and Dec. 3, 2008) during a short sampling campaign. The target parameters and methods by which they were analysed are outlined in Table 34.

Table 34: Microbiological parameters – Analytical methods

Parameter	Reference methods of analysis
Total coliform bacteria	ISO 9308-2 (MPN method)
Faecal coliform bacteria (E. coli)	ISO 9308-2 (MPN method)
Intestinal enterococci	EN ISO 7899-1 (MPN method)
Salmonella	Based on ISO 6340:1995 (modified MPN method)
Intestinal nematodes	Modified Bailinger method

5.4.3 Test protocols

Analytical data from the original test protocols were entered into Excel spreadsheets created by the TU Berlin and sent to the client by E-mail. The original test protocols are stored in the archives of the UFZ (Centre for Environmental Research) and can be accessed by the client on request.

5.4.4 Handling of data for test limits

In cases where the measured values for a parameter fell below a given limit, the parameter was assigned a value of 0 for purposes of statistical and graphical analysis. In the statistical analysis of minimum values, however, the detection limit (e.g. < 3 mg/L) was the assigned value. The affected analytical limits and values assigned to the affected parameters are shown in Table 35.

Table 35: Analytical limits affected and values assigned for BOD_5, SS and NH_4-N

BOD_5	Concentrations < 3mg/L were assigned a value of 0
SS	Concentrations < 1mg/L were assigned a value of 0
NH_4-N	Concentrations < 0,5mg/L were assigned a value of 0

Chapter 6

Overview of Results

This section provides a brief summary of results for all small wastewater treatment systems tested. Characteristics of the basic types of systems (sessile biomass, suspended biomass, biofilter, membrane bioreactor) will be compared. For a detailed description of the results and characteristics of the individual SWWTPs, see Chapter 7.

6.1 Treatment efficiency

6.1.1 Statistical analysis

Table 36 presents the results of the statistical analysis of overall mean influent and effluent concentrations for the target parameters, COD, NH_4-N and SS. The number of samples for almost all test systems was n=50.

Chemical oxygen demand (COD)

The mean influent COD concentration was 456 mg/L, with values ranging from 830 mg/L maximum and 180 mg/L minimum. Overall effluent COD concentrations for the respective small wastewater systems ranged from 14 mg/L (minimum) to 741 mg/l (maximum), with mean values ranging from 34 mg/L to 196 mg/L. By comparison, the mean effluent COD concentration for Class 1 - 5 wastewater treatment plants in Germany was 28 mg/L in 2007 (DWA, 2008). This suggests a significantly better treatment performance of large SWWTPs. All but two of the investigated SWWTPs yielded effluent COD concentrations below the German and French maximum limit of a mean 150 mg/L and 125 mg/L, respectively.

Biochemical oxygen demand (BOD_5)

The mean influent BOD_5 was 207 mg/L, with values ranging from 301 mg/L maximum and 78 mg/L minimum. Overall effluent concentrations for all systems ranged from < 3 mg/L (minimum) to 424 mg/l (maximum). Mean values ranged from 3 mg/L to 64 mg/L. By comparison, the mean effluent BOD_5 concentration for Class 1 - 5 wastewater treatment systems in Germany was a mean 4.1 mg/L in 2007 (DWA, 2008). Two of the SWWTPs exceeded the German maximum limit of 40 mg/L (mean value). Four of the SWWTPs exceeded the French maximum limit of 25 mg/L (mean value).

Ammonia (NH_4-N)

The mean influent NH4-N concentration was 35.1 mg/L, with values ranging from 54.5 mg/L maximum and 11.6 mg/L minimum. Overall effluent concentrations for all systems ranged from < 0.5 mg/L (minimum) to 49.9 mg/l (maximum), with mean values ranging from 8.1 mg/L to 23.7 mg/L. By comparison, the mean effluent NH_4-N concentration for Class 1 - 5 wastewater treatment systems in Germany was a mean 1.18 mg/L in 2007 (DWA, 2008). Two systems using sessile biomass achieved effluent NH_4-N concentrations < 10 mg/L (nitrification).

Suspended solids (SS)

The mean influent SS concentration was 269 mg/L, with values ranging from 730 mg/L maximum and 120 mg/L minimum. Overall effluent concentrations for all systems ranged from < 1 mg/L (minimum) to 1100 mg/l (maximum), with mean values ranging from 5 mg/L to 117 mg/L. On average, two of the SWWTPs exceeded the French maximum limit of 35 mg/L. Currently, there are no statutory limits for effluent SS concentrations in Germany.

Table 36: Results of the statistical analysis, mean values of effluents

System	mean Effluent		
	COD	SS	NH_4-N
	[mg/l]	[mg/l]	[mg/l]
mean inflow	**456**	**269**	**35**
Limiting values	**150**$^{1)}$	**35**$^{2)}$	**(10)**$^{3)}$
Aquamatic – STM 5	196	117	20
Bergmann – BIO-WSB®-N	53	16	9
Klargester – BioDisk BA	78	21	16
Nordbeton – Biofilter KP253 PAL	92	29	18
PREMIER TECH – Ecoflex$^{TM*)\ **)}$	45	9	8
HUBER - 3K PLUS®	56	11	20
Lauterbach-Kießling – BKF 4	60	14	17
UFZ - PKA Typ UFZ C+H 4 E	34	5	12
PREMIER TECH – Ecofix® Typ STB 500	52	13	9
Busse – MF Typ MF-HKA4	77	25	19
ATB – AQUA max BASIC$^{**)\ ***)}$	163	93	23
Mall – SanoClean XL	70	20	24

*) could not be tested during high-performance work phase due to the process

**) was changed to 4 PE during the 200%-work phase

***) not designed for peak load

1) German limiting value as specified in AbwV

2) French limiting value as specified in “arrêté du 22/6/2007"

3) German limiting value as specified in DIBt group N, not all plants are designed for nitrification

6.1.2 Curves

For better clarity, curves for the 12 small wastewater systems are broken down in two diagrams. The first contains the respective influent and effluent curves for the following SWWTPs:

1. Aquamatic – STM 5
2. Bergmann – BIO- WSB®-N
3. Klargester – BioDisc BA
4. Nordbeton – Biofilter KP253 PAL
5. PREMIER TECH – Ecoflex™
6. HUBER - 3K PLUS®

The second diagram contains the respective influent and effluent curves for the remaining 6 SWWTPs:

7. Lauterbach-Kießling – BKF 4 DN2000 Z1
8. UFZ C+H 4 E Constructed Wetland
9. PREMIER TECH – Ecofix® STB-500
10. Busse – MF-HKA4.
11. ATB – AQUAmax® BASIC
12. Mall – SanoClean XL

6.1.2.1 Chemical and biochemical oxygen demand (COD, BOD_5)

The combined parameters for organic matter were analysed based on the COD curve over the entire study period. The BOD_5 curves are similar. The influent COD concentration ranged from 180 mg/L to just above 830 mg/L. In most of the SWWTPs, effluent values were below 100 mg/L during most phases of testing. The oil accident led to increases, albeit delayed in some cases, in all of the SWWTPs. Nevertheless, all of the concentrations remained below 150 mg/L during this time except in one case. Fourteen days after the oil accident, effluent concentrations in all of the SWWTPs had returned to the original baseline levels. Starting in Phase 4, overloading resulted in concentration increases of variable extent. Three of the SWWTPs (suspended biomass and trickling filter) exceeded the 150 mg/L limit at that phase. At the 200% hydraulic load level (Phase 5), peak effluent values far exceeding the 150 mg/L limit and, in some cases, even higher than the influent concentrations, were observed in four of the investigated systems (suspended biomass, trickling filter, and combined processes). Increased effluent COD concentrations (mean 28.6 to 102.9 mg/L) were detected in the remaining SWWTPs. After Phase 6 (no load), the concentrations stabilised in nearly all SWWTPs. COD peaks were observed directly after system restart, particularly in suspended biomass systems. For details, see Chapter 7. During the four-week 50% load phase (underloading), effluent COD concentrations in nearly all SWWTPs were less than 100 mg/L. Higher concentrations occurred in only two SWWTPs (see above). During the simulated electrical breakdowns, concentrations rose in all of the systems. A temporary increase in hard-to-degrade substances in the influent could be the cause of this phenomenon because it was observed at the same time in nearly all of the SWWTPs studied.

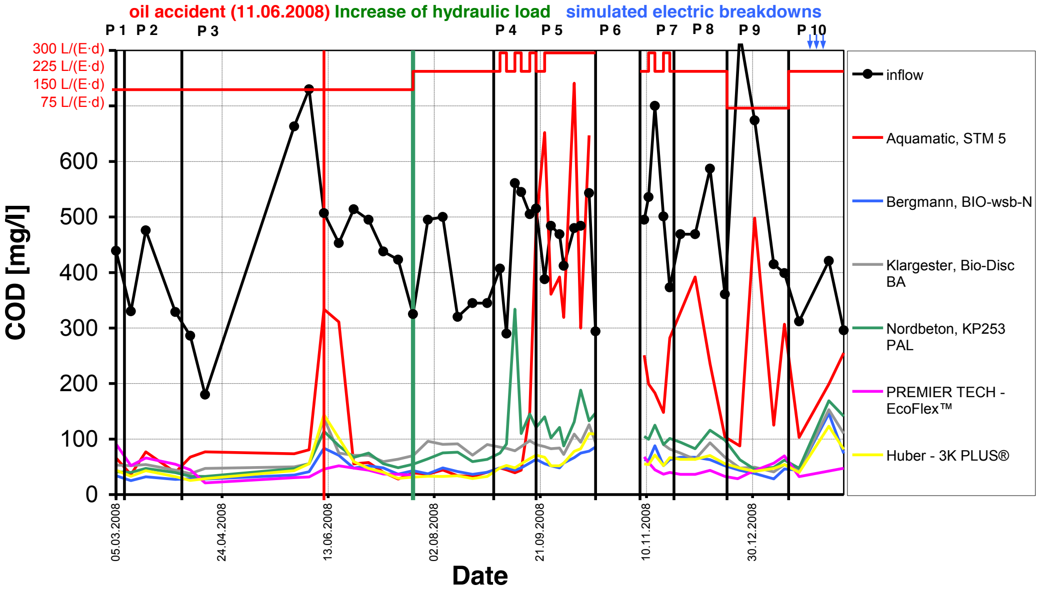

Figure 50: COD curves for systems 1-6

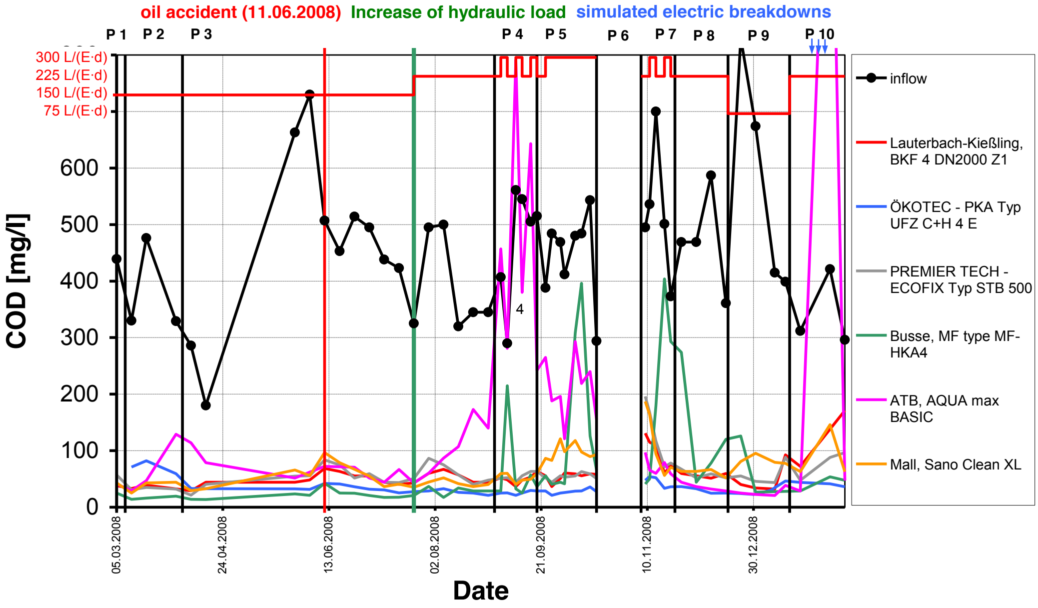

Figure 51: COD curves for systems 7-12

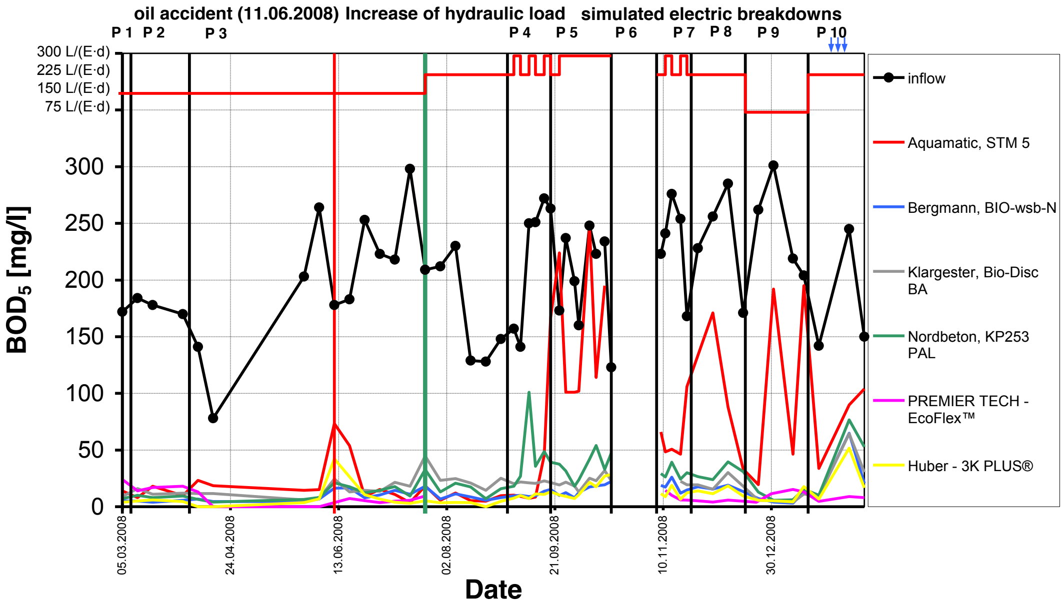

Figure 52: BOD$_5$ curves for systems 1-6

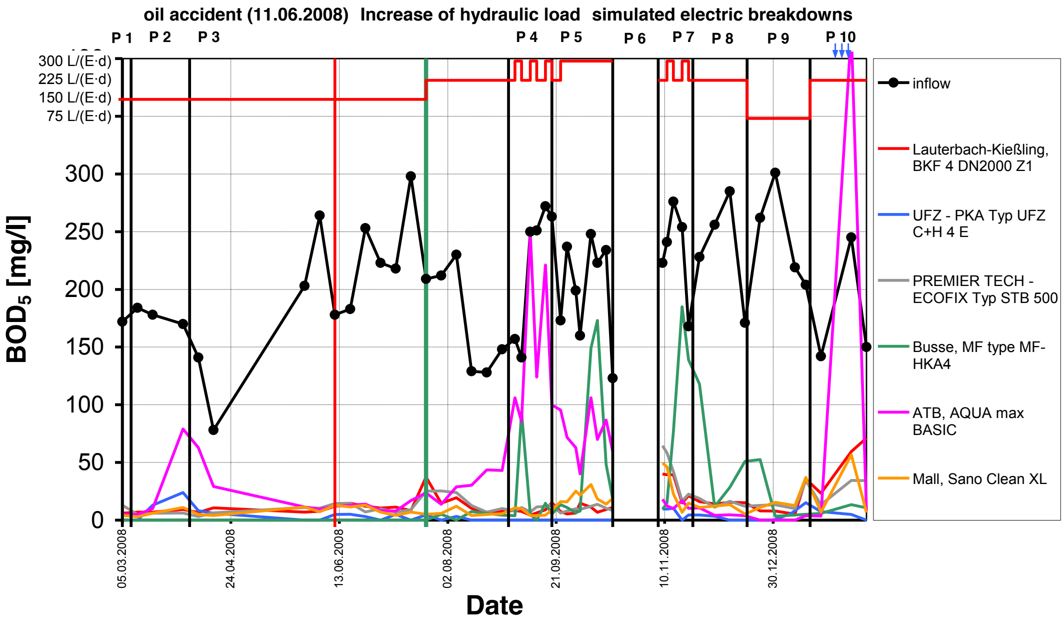

Figure 53: BOD$_5$ curves for systems 7-12

Ammonia (NH_4-N)

The course of the NH_4-N curve reflects the course of nitrification. As a biological process very sensitive to changes in process control, nitrification is a useful indicator of the stability of wastewater treatment systems. Influent NH_4-N concentrations ranged from 11.6 mg/L to 54.5 mg/L. Effluent concentrations displayed wide variation at some plants during some phases of testing, and there was a very large degree of deviation between plants; in areas affected by the oil accident, there was very little increase in measured concentrations at most of the plants. When tested at design hydraulic load (Phases I to IV), nitrification occurred in the majority of SWWTPs, even at temperatures below 6.3°C. Effluent concentrations generally increased at higher load levels. Only the constructed wetland system was able to maintain nitrification. At the reduced load (Phase 8), effluent concentrations decreased again in spite of low temperatures (< 9°C). Due to the very low wastewater temperatures (< 4°C) and increased influent concentrations at the end of Phase 9, effluent concentrations rose again, in some cases, until nitrification collapsed. During the simulated electrical breakdowns in Phase 10, the situation at all of the SWWTPs worsened.

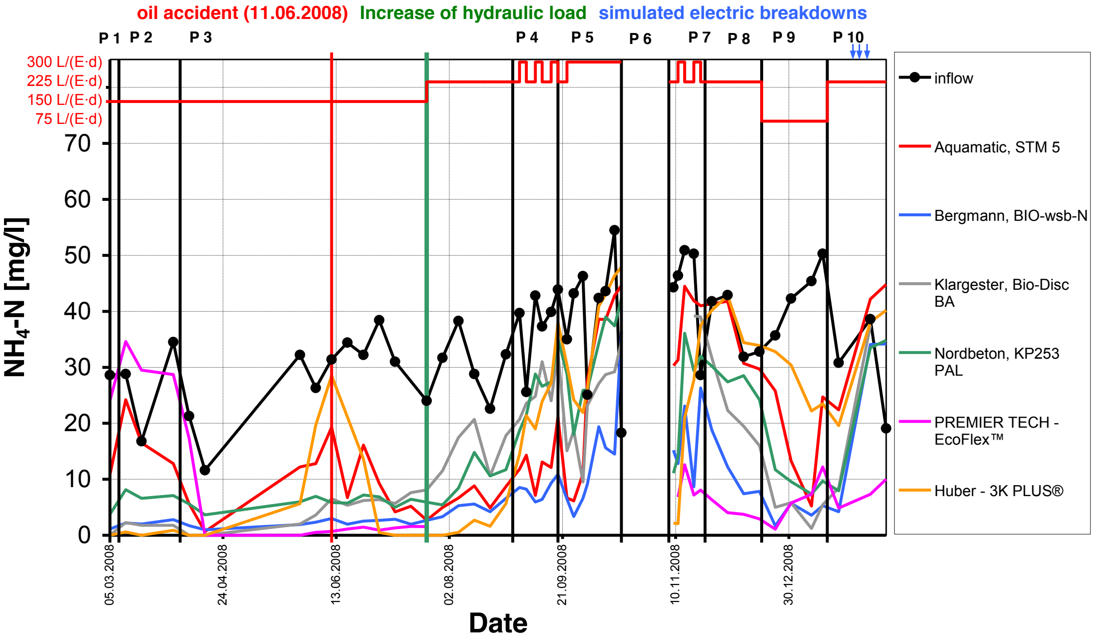

Figure 54: NH_4-N curves for systems 1-6

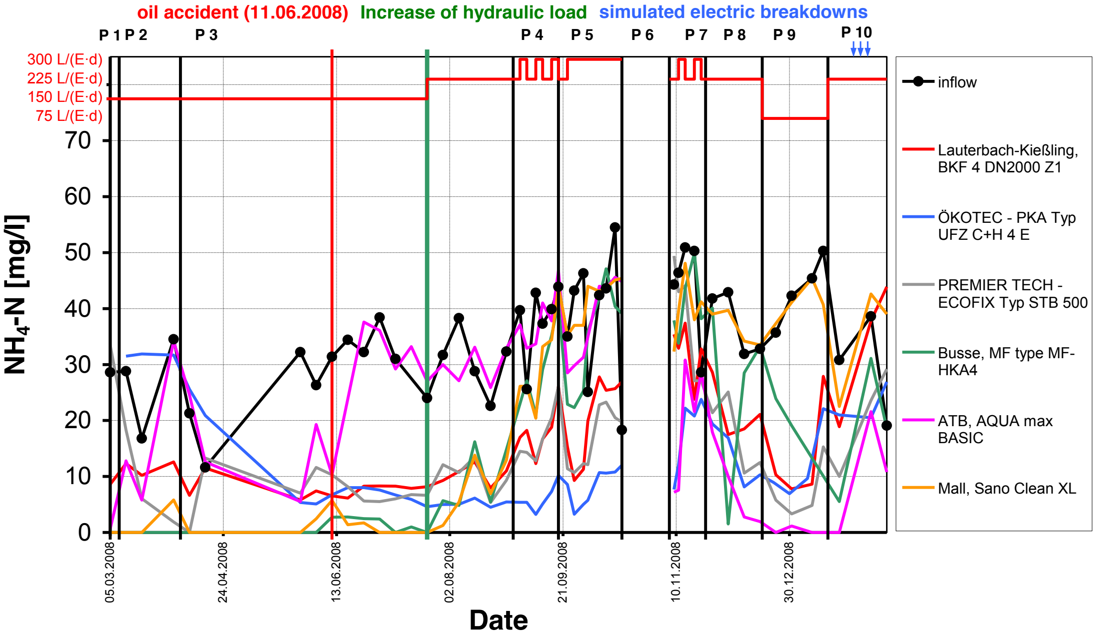

Figure 55: NH_4-N curves for systems 7-12

6.1.2.2 Suspended solids (SS)

Influent suspended solids (SS) concentrations ranged from about 120 mg/L to 730 mg/L. Effluent SS concentrations were less than 50 mg/L during most phases of testing, but very slight increases were observed in phases affected by the oil accident. Increased effluent concentrations were observed during Phases 4 and 5 (overload) due to sludge overflow in some cases (systems with suspended biomass and combined procedures) and during Phase 10 (simulated electrical breakdowns), primarily in suspended biomass systems. SS concentrations were also increased in the trickling filter system. Overall, the SS curves run nearly parallel with the COD curves.

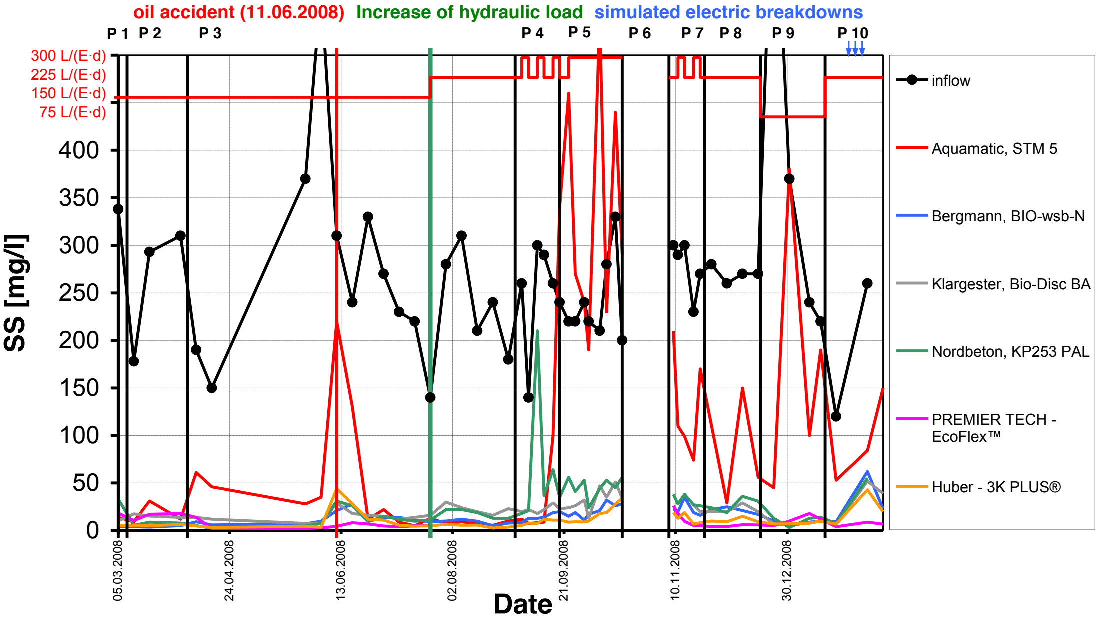

Figure 56: Suspended solids curves for systems 1 - 6

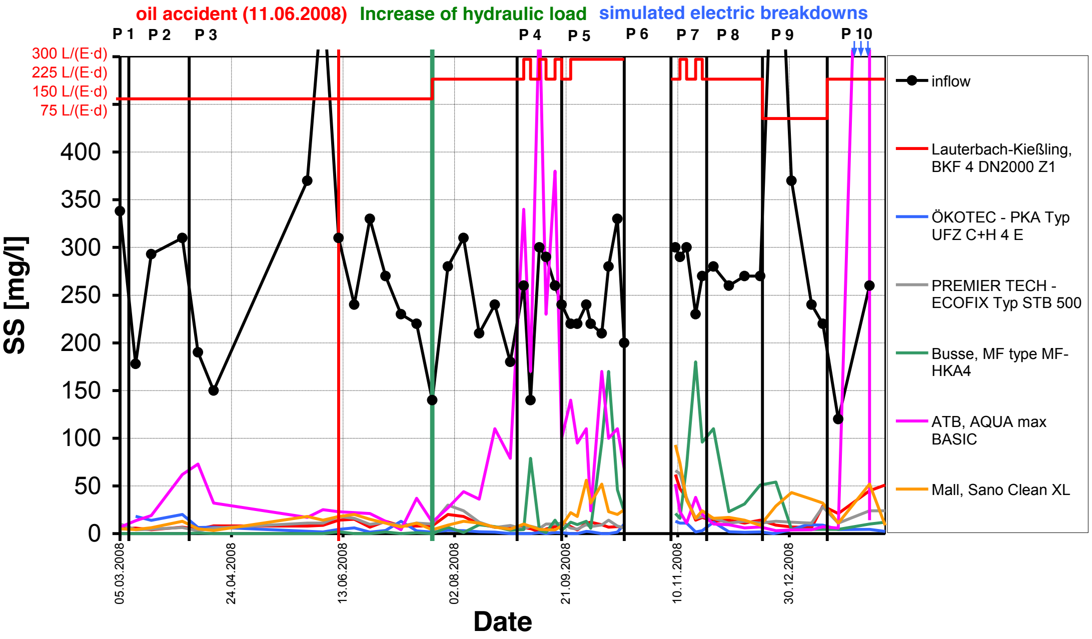

Figure 57: Suspended solids curves for systems 7 - 12

6.1.2.3 Phosphorus

Influent phosphorus concentrations (P_{tot}) ranged from 2.8 mg/L to 10.2 mg/L. During most phases of testing, the corresponding effluent concentrations remained below 10 mg/L and fluctuated around 5 mg/L. The course of effluent concentration generally ran parallel with that of influent concentrations but with a time delay. Because bound phosphorus is carried out with dissolved solids, increased P concentrations occurred concurrent with increased SS concentrations.

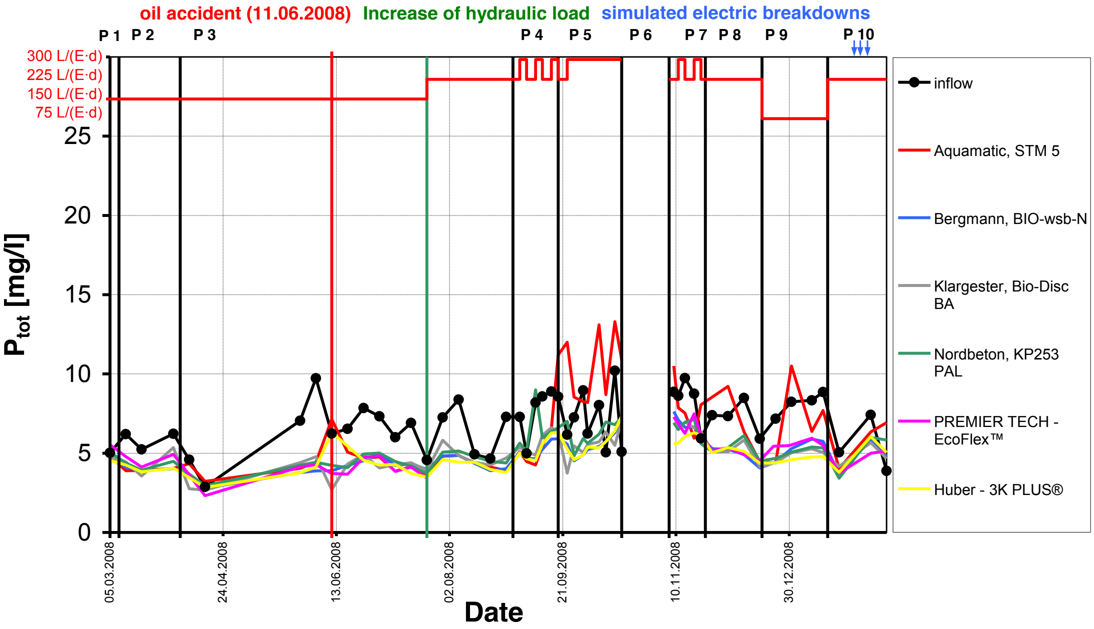

Figure 58: Phosphorus (P_{tot}) curves for systems 1 - 6

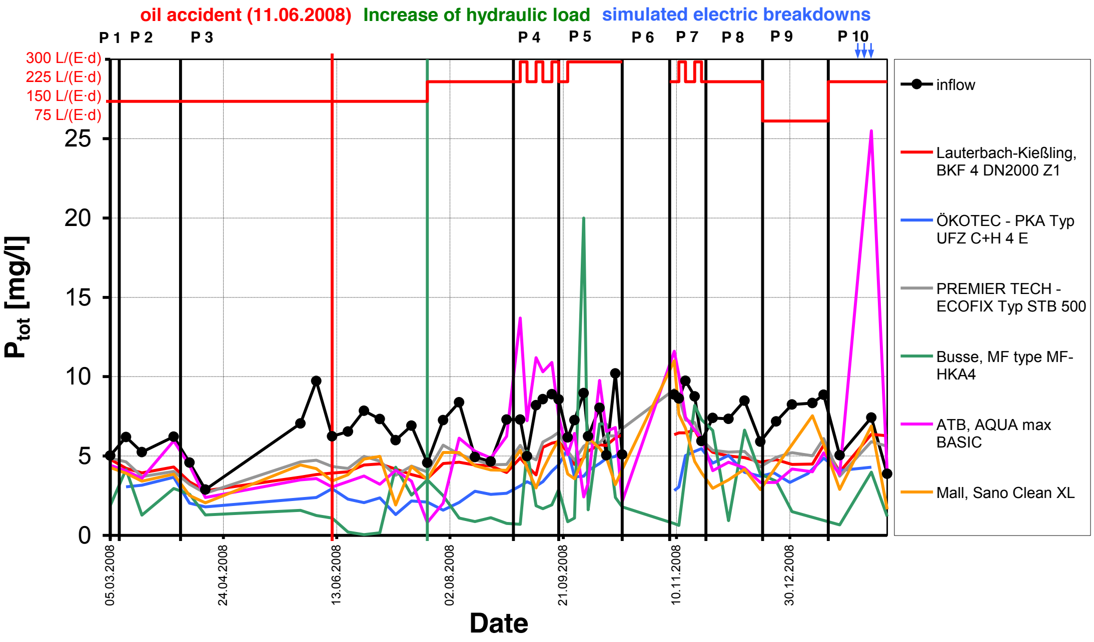

Figure 59: Phosphorus (P_{tot}) curves for systems 7 - 12

6.1.3 Degradation rate

Degradation rates for COD, BOD_5, NH_4-N and SS were expressed as percentage values (cf. Section 2.9). Negative values imply that influent concentrations were smaller than effluent concentrations. Potential reasons for this are redissolution, washout and (back) transformation from the biomass.

The overall mean, maximum and minimum degradation rates for each SWWTP for the entire study period for the parameters COD, BOD_5, SS and NH_4-N are shown in Table 37.

The mean rate of COD degradation ranged from 56% to 92%. In some cases, it was nearly 100% (maximum).

Mean degradation rates for BOD_5 ranged from 68% to 98%, and those for NH_4-N were much lower (29% to 73%).

Mean degradation rates for suspended solids ranged from 53% to 98%, with retention patterns similar to those for BOD_5.

Table 37: Degradation rates (%) for COD, BOD_5, SS and NH_4-N in all SWWTPs

System	COD			BOD_5			SS			NH4-N		
	mean	max	min	mean	max	min	mean	max	min	mean	max	min
	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]
Aquamatic – STM 5	56	93	-68	68	99	-43	53	98	-157	41	94	-144
Bergmann – BIO-WSB®-N	88	95	65	94	99	74	94	99	76	73	96	-99
Klargester – BioDisk BA	81	94	63	90	98	74	91	99	70	52	100	-89
Nordbeton – Biofilter KP253 PAL	79	93	88	88	98	60	89	99	30	47	87	-131
PREMIER TECH – Ecoflex™ *) **)	88	100	69	95	100	80	95	100	65	73	100	-76
HUBER - 3K PLUS®	87	94	63	95	100	76	96	99	83	44	100	-162
Lauterbach-Kießling – BKF 4	86	95	42	92	98	53	95	99	79	48	82	-130
UFZ - PKA Typ UFZ C+H 4 E	92	97	78	98	100	86	98	100	90	60	93	-90
PREMIER TECH – Ecofix Typ STB 500	86	93	60	92	98	71	95	99	78	54	100	-53
Busse – MF Typ MF-HKA4	83	97	18	87	100	17	90	100	22	47	100	-114
ATB – AQUA max BASIC**)	62	97	-221	75	100	-73	62	100	-323	29	100	-145
Mall – SanoClean XL	84	93	62	93	98	77	92	99	69	34	100	-148

*) Could not be tested in high-performance phase due to technical reasons

**) Was switched to 4 PE during the 200% phase

6.1.4 Operational and process stability

Here, the analysis will be restricted to a single parameter, namely, COD. Process stability was described in terms of compliance with statutory limits for the target parameter, which was referred to here as the "stay below probability" (cf. Section 2.10.9). The steeper the curve, the more "stably" the system is operating. The percentage of samples below the maximum limit can be read off the curve in Figure 60.

As determined based on the COD analysis, the process stability of the different SWWTPs varied greatly. Some of the curves are very steep and others very flat. In 8 out of 12 SWWTPs, effluent COD concentrations were below the German (150 mg/L) and French (125 mg/L) statutory limits in more than 90 cases. The systems using suspended biomass, sessile biomass, and combined procedures were the exceptions.

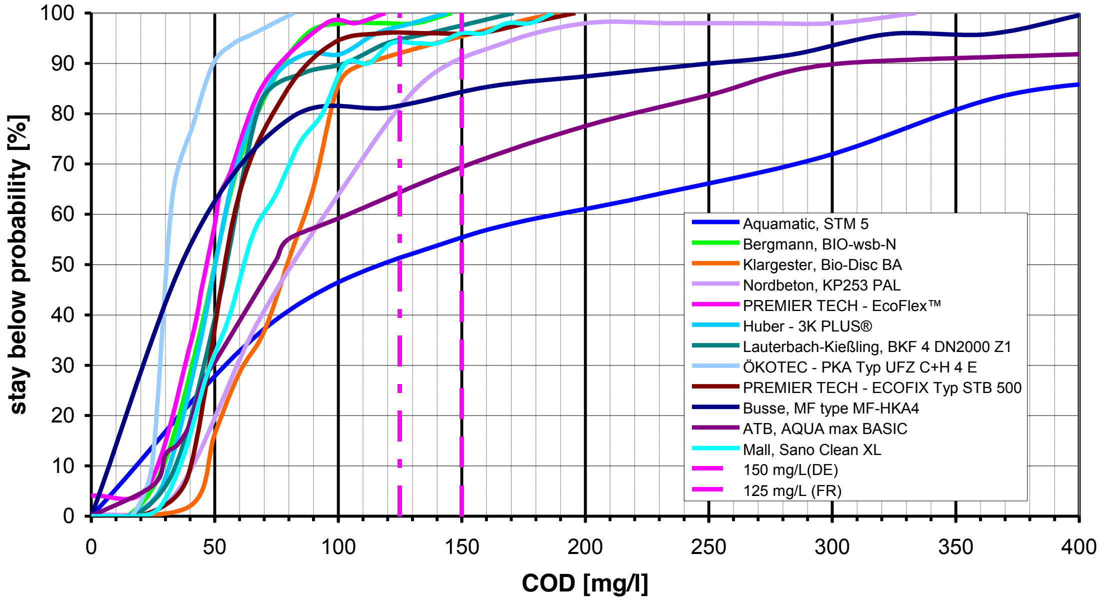

Figure 60: Stay below probability for COD at all SWWTPs

6.1.5 Volume load

Volume load (V_R) is calculated as the quotient of the organic load and reactor volume (cf. Section 2.7). It is an important design parameter, particular in sessile biomass systems.

Table 38 lists both the DIBt specifications for volume load of BOD_5 in small wastewater treatment plants (DIBt, 2006) as well as the corresponding DWA specifications for 50 to 500 PE small wastewater treatment systems with aerobic biological treatment stages in accordance with the German Association for Water, Wastewater and Waste (DWA) provisions in ATV Standard 122 (DWA, 1991).

Table 38: Volume load specifications for BOD_5 in small wastewater systems

Process	**BOD_5 volume load [kg/(m^3·d]**	
	DIBt (2006)	**DWA (1991)**
Trickling filter	≤ 0.15[1]	0.15 – 0.4
Activated sludge	≤ 0.2	≤ 0.2
Activated sludge with membrane filtration	≤ 0.75	_
Sequencing batch reactor	≤ 0.2	_

Figure 61 shows the volume degradation rate as a factor of volume load. The volume degradation rate describes the volume load fraction (see Section 2.8). The further the values lie below the 100% line (100% degradation of volume load), the worse the degradation rate. At BOD_5 volume loads of 0.1 kg/(m^3·d) and higher, marked scattering of data below the 80% line can be observed. At volume loads of 0.1 to 0.3 kg/(m^3·d), volume degradation rates for three SWWTPS (suspended biomass and combined processes) were below 50%. At BOD_5 volume loads of 0.3 kg/(m^3·d) and higher, only 3 SWWTPs (including those with sessile and suspended biomass) achieved volume degradation rates above 80%.

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[1] This rate can be increased to 0.25 kg(/m^3·d) if a storage tank is used to ensure the uniform inflow of wastewater.

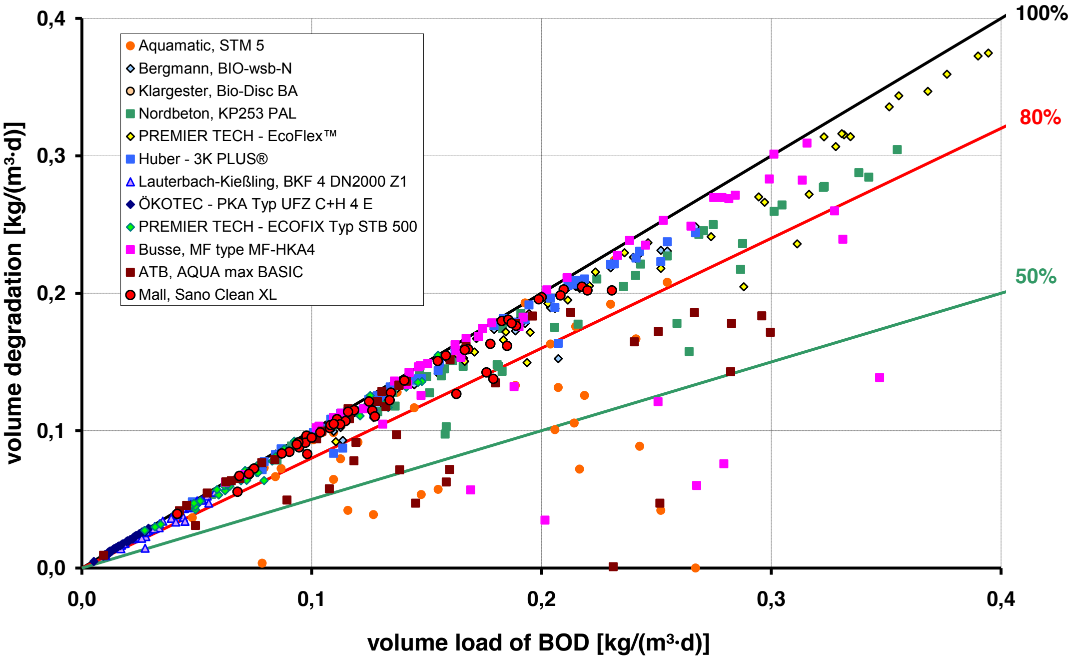


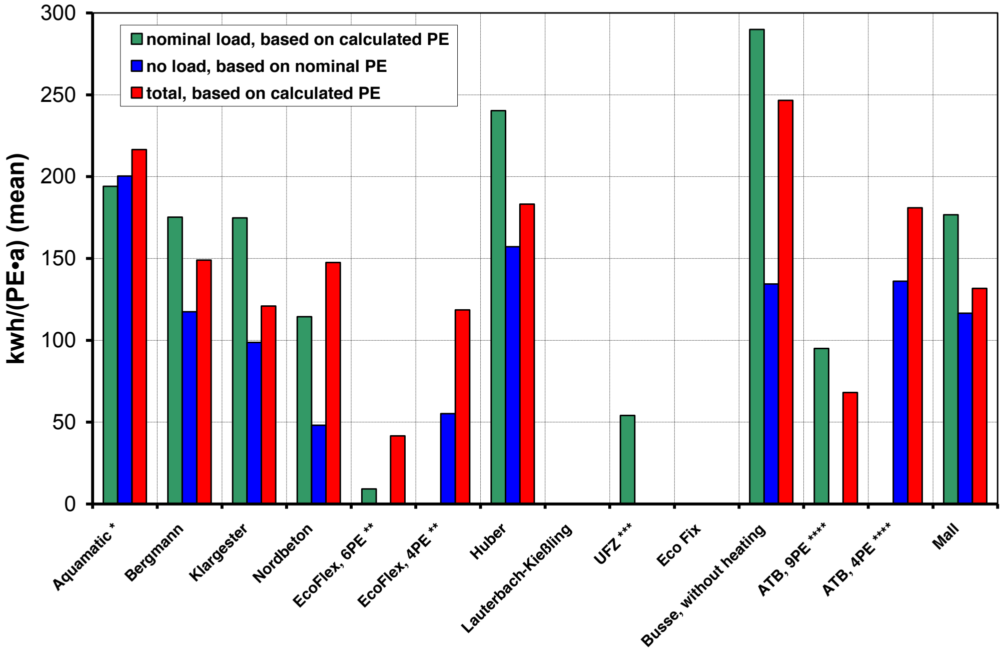
Figure 61: Volume degradation over volume load of BOD_5 for all SWWTPs

6.2 Power consumption

Specific power consumption (mean) of each SWWTP per PE and year at 100% design load (150 L/[PE·d]), no load (Phase 6) and throughout the overall test period (total) is illustrated below (Figure 62).

- 100% design load (150 L/[PE·d]): Mean: 127 kWh/(PE·a)
- No load: Mean: 97 kWh/(PE·a)
- Total study period: Mean: 123 kWh/(PE·a)

In addition to analysing the wastewater systems under different loading conditions, two systems were assessed before and after a change in their basic hydraulic load: Ecoflex^{TM} was switched from 6 PE to 4 PE, and ATB was changed from 9 PE to 4 PE.



* Aquamatic: compressor power increased of 30 to 50 W (11.4.2008, see 7.1.9)
compressor power increased to 80 W (18.7.2008, see 7.1.9)
** PrimierTech-Ecoflex: Conversion from 6 PE to 4 PE at 10.10.2008
*** UFZ: Based on three measurements
**** ATB: : Conversion from 9 PE to 4 PE at 30.9.2008

Figure 62: Specific power consumption of the individual systems

At design load, mean power consumption of the individual SWWTPs ranged from 9 to 290 kWh/(PE·a). Two of the plants (soil filter and coco filter systems) did not consume any power. Under no load conditions (Phase 6), the rates ranged from 48 to 200 kWh/(PE·a). During this period, three systems ran without power and one had an interruption of inflow. Total power consumption rates for the entire study period ranged from 42 to 247 kWh/(PE·a), whereby the non-power-consuming systems were excluded from this estimate.

For comparison, Figure 63 shows the mean specific power consumption rates for Class 1 - 5 wastewater treatment systems in 2008 as defined by the DWA (DWA, 2009 in preparation). Rates ranged from 31 kWh/(PE·a) for Class 5 systems to 78 kWh/(PE·a) for Class 1. Class 1 plants were the biggest power consumers, as reflected by a mean power consumption rate of 65 kWh/(PE·a). Nevertheless, this power consumption rate was significantly lower than the total mean (123 kWh/[PE·a]) of the investigated small wastewater systems during the entire study period (see above).

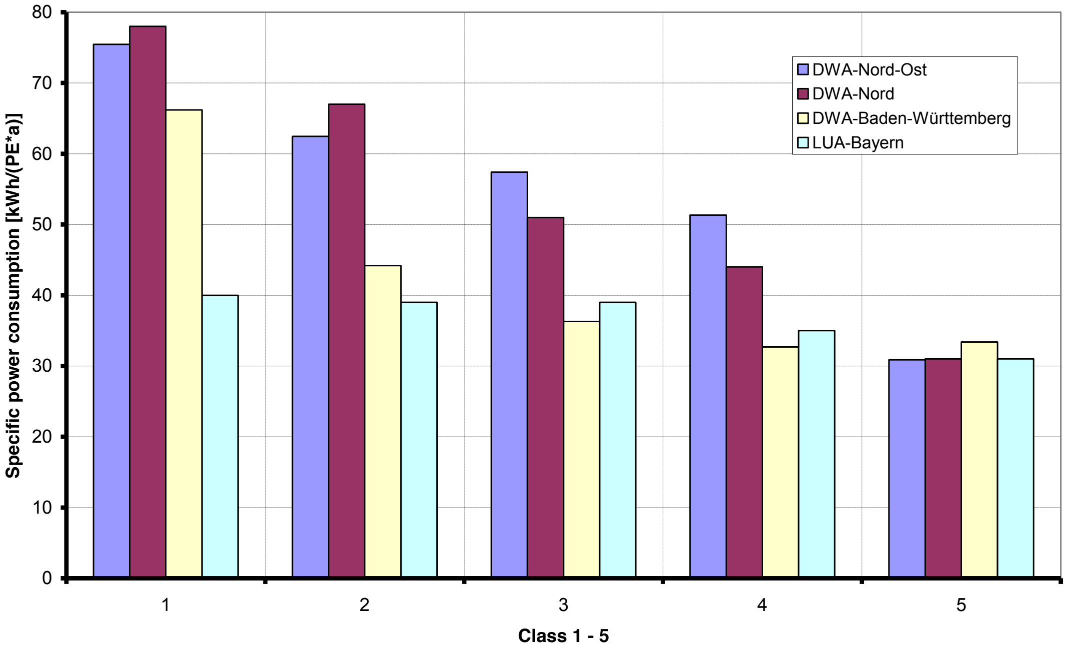


Figure 63: Specific power consumption rates for Class 1 - 5 wastewater treatment plants in the year 2008 (DWA, 2009)

6.3 Sludge

At the end of the test period, sludge samples were collected for analysis of dry matter content and loss on ignition. The sludge volume was estimated based on the measured sludge height and the known container geometry. Consequently, geometry-dependent estimates are relatively imprecise and their power of evidence limited.

The dry matter content (DM) of sludge is calculated as the loss of weight on drying in an oven and is expressed in units of kg/m^3 of g/l. DM values for the investigated small wastewater systems ranged from 6.5 to 77.1 g/l, and the mean value was 37 g/l.

Loss on ignition (LOI) is calculated as the loss of weight following ignition and corresponds to the organic matter fraction of sludge. LOI values for the investigated SWWTPs ranged from 61 to 80 percent; the mean LOI was 69 percent.

Figure 64 shows the specific sludge mass by approximation of the individual SWWTPs, expressed in units of g/(PE·d). The specific sludge mass is the product of sludge volume and dry matter content.

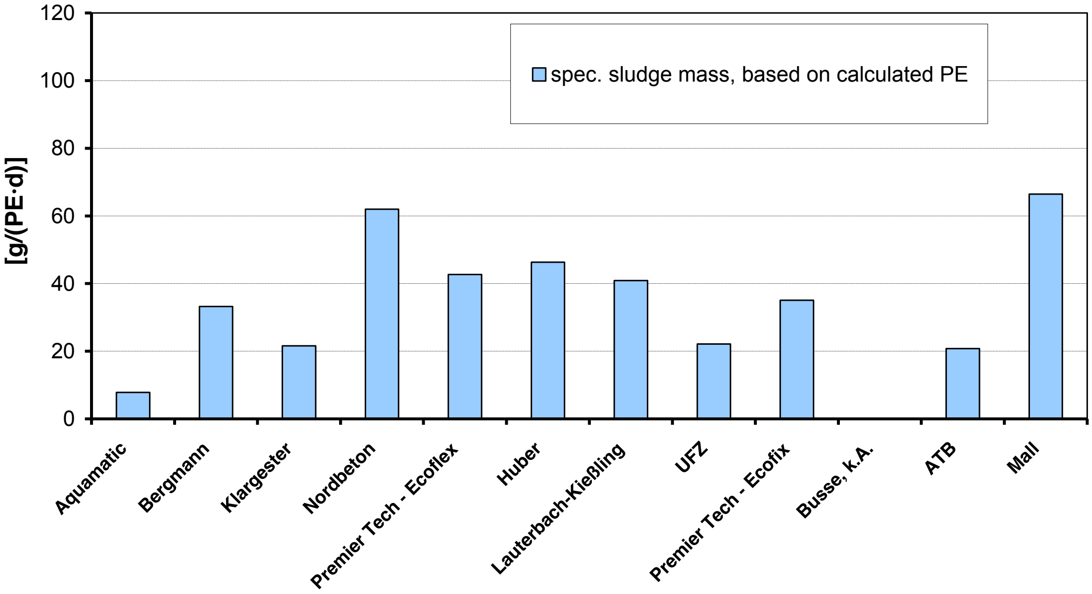


Figure 64: Specific sludge mass of all 12 SWWTPs

The mean specific sludge mass of the 12 SWWTPs was 36 g/(PE·d), which is clearly lower than the corresponding value of approximately 70 g/(PE·d) given in the DWA "Sludge List" (DWA, 2003). In the present study, the lowest specific sludge mass (8 g/[PE·d]) was observed in a combined process SWWTP with excessive sludge overflow, and the highest value (66 g/(PE·d)) was observed in a sessile biomass system.

6.4 Operation and maintenance

This section briefly summarizes the frequencies of maintenance and breakdown of all SWWTPs studied. For a detailed description of data from the respective system operating logs (routine checks, changes in operating settings, operating media/sludge, breakdowns, maintenance work, etc.), see Chapter 7.

At the start of the investigation, influent lines of all SWWTPs were rinsed several times. After an oil accident occurred on 11 June 2008, all of the systems were inspected and cleaned by personnel from Leipzig Municipal Waterworks (KWL) and, in some cases, by the manufacturer. For details on systems in which additional measures were taken after the oil accident, see "Operation and Maintenance in Chapter 7. These two events are not included in the analysis of maintenance intensity presented below.

Table 39 provides a comparison of the actual maintenance frequency versus the specified maintenance frequency according to DIBt effluent class (DIBt, 2006). The information on "breakdowns and repairs" was taken from the respective operating logs.

The actual maintenance frequency generally corresponded to the specified maintenance frequency indicated in the approval. The mean total maintenance time for all maintenance work performed during the entire study period ranged from 90 to 150 minutes (mean: 111 minutes).

Table 39: Maintenance frequency and breakdowns in all 12 SWWTPs

System	Maintenance			Breakdowns and repairs (Comments on required replacement parts, etc.)
	Specified [1/a]	Actual [1/a][1]	Actual [min]	
Aquamatic – STM 5	2	3	140	11 Apr 08: A new, more powerful blower was installed (increase from 30W to 50W). 18 Jul 08: A new 80 W compressor was installed.
Bergmann – BIO- WSB®-N	2	2	90	-
Klargester – BioDisk BA	--	3	90	10 Nov 08: Brief hydraulic system overload occurred due to failure of solenoid valve (not part of the system itself) to close.
Nordbeton – KP253 PAL	2	3	150	The sprinkler pump failed several times during the study period due to high water.

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[1] Maintenance within the total study period (approx. 1 year, from 05 Feb 2008 to 11 Feb 2008)

System	Maintenance			Breakdowns and repairs (Comments on required replacement parts, etc.)
PREMIER TECH – Eco-flex™	1	--	--	30 Jul 08 to 17 Oct 08: The distributor arms failed to distribute water evenly over the filters and were occasionally clogged. 02 to 08 Oct 2008: System was down due to breakdown of pressure filter system. 06 Nov 08: Recirculation line was redirected from the primary treatment tank into the pump shaft.
HUBER - 3K PLUS®	2	3	120	-
Lauterbach-Kießling – BKF 4	2	2	90	-
UFZ C+H 4 E	--	--	--	-
PREMIER TECH – Eco-fix® STB-500	1	--	--	20 Aug 08: Run times of the pump could not be read due to a malfunction (pump not necessary to the real situation). The septic tank was completely submerged.
Busse – MF-HKA4	3	--	--	26 Nov 08: Wastewater spilled out via the emergency overflow. Inflow was switched off until the system was re-started on 01 Dec 08. 02 to 03 Dec 2008: Inflow was switched off. 08 Jan 09: Inflow was switched off because of a malfunction of the heater in the drainage line.
ATB – AQUAmax BASIC	2	3	180	01 to 14 Apr 2008: Aeration system malfunctioned due to a defective pump and blower component. 13 Aug 2008: The water level in the biological reactor was slightly elevated. Some of the wastewater from the primary clarifier spilled via the emergency overflow into the biological reactor. 20 Aug 2008: Water from the primary clarifier spilled over the entire baffle and into the biological reactor. 01 Dec 08: The control unit was replaced by the manufacturer.
Mall – SanoClean XL	3	2	90	27 Mar 08: A new control unit was installed.

6.5 Microbiological parameters

Water samples were collected from the influent and effluent on three consecutive days and tested for the following parameters (cf. Section 2.3):

- Total coliform bacteria
- Faecal coliform bacteria
- Intestinal enterococci
- Salmonella
- Intestinal nematodes (eggs)

Concentrations of the microbiological parameters were much higher in the influent than in the effluent of the 12 small wastewater treatment plants. The influent and effluent of the SWWTPs were samples on the same day. Therefore, results for influent samples can be correlated to the parallel effluent samples to a limited degree. Our microbiological tests showed that a significant reduction of biological load occurred in all 12 SWWTPs studied. However, very large differences between the systems were observed (UIS, 2009).

The degree to which a wastewater sample can be concentrated has a major influence on the microbiological enumeration of nematodes. Samples with high suspended solids concentrations cannot be concentrated to such a large degree. The presence of large numbers of ciliates in the sample is another complicating factor as ciliates are very similar to nematodes in size and shape. On the whole, there have been only isolated cases of nematode eggs being found in quantities of epidemiological relevance (IDUS, 2008).

Microbiological test results for all SWWTPs tested in the COMPAS study are shown in Table 40.

Table 40: Microbiological test results (U IS, 2009 and IDUS, 2008)

Reduction of microbiological parameters (mean of 3 representative samples)					
System	Total coliform	Faecal coliform	Entero-cocci	Salmo-nella	Nematodes
	[log]	[log]	[log]	[log]	[Eggs]
Aquamatic – STM 5	0,5	0,6	1,2	1,9	-11
Bergmann – BIO-WSB®-N	0,2	0,8	1,3	1,8	2
Klargester – BioDisk BA	1,1	0,8	1,7	1,5	-6
Nordbeton – Biofilter KP253 PAL	1,1	0,8	1,3	0,6	0,0
PREMIER TECH – Ecoflex™	1,5	0,9	1,8	1,5	-1
HUBER - 3K PLUS®	1,3	1,2	1,7	1,9	2
Lauterbach-Kießling – BKF 4	1,4	1,1	1,6	1,1	2
UFZ - PKA Typ UFZ C+H 4 E	6,0	0 MPN/ml im Ablauf	5,3	0 MPN/ml inEffluent	4
PREMIER TECH – Ecofix® Typ STB 500	1,3	0,8	1,7	1,5	1
Busse – MF Typ MF-HKA4	0 MPN/ml in Effluent	0 MPN/ml in Effluent	0 MPN/ml in Effluent	0 MPN/ml in Effluent	4
ATB – AQUA max BASIC	1,4	0,8	2,1	2,2	4
Mall – SanoClean XL	1,2	0,8	1,3	1,6	2

Due to the lack of guidelines on monitoring parameters for microbiological testing of small wastewater systems without hygienisation, Directive 2006/7/EC of the European Parliament and of the Council of 15 February 2006 concerning the management of bathing water quality and repealing Directive 76/160/EEC (Official Journal of the European Union, 2006) was consulted for reference (Table 41). Only those SWWTPs with specific hygienisation systems (UV irradiation and MBR technology) achieved the rating of "excellent bathing water quality for coastal waters and transitional waters", as determined based on the parameters "intestinal enterococci" and "Escherichia coli“ (Figure 65 and Figure 66).

Table 41: Results of the water quality assessment based on EU microbiological test parameters (Official Journal of the European Union, 2006)

Inland waters					
	A	B	C	D	E
	Parameter	Excellent quality	Good quality	Sufficient quality	Reference methods of analysis
1	Intestinal entero-cocci (cfu/100 ml)	200 (*)	400 (*)	330 (**)	ISO 7899-1 or ISO 7899-2
2	Escherichia coli (cfu/100 ml)	500 (*)	1000 (*)	900 (**)	ISO 9308-3 or ISO 9308-1
Coastal waters and transitional waters					
	A	B	C	D	E
	Parameter	Excellent quality	Good quality	Sufficient quality	Reference methods of analysis
1	Intestinal entero-cocci (cfu/100 ml)	100 (*)	200 (*)	185 (**)	ISO 7899-1 or ISO 7899-2
2	Escherichia coli (cfu/100 ml)	250 (*)	500 (*)	500 (**)	ISO 9308-3 or ISO 9308-1

(*) Based upon a 95-percentile evaluation.
(**) Based upon a 90-percentile evaluation.

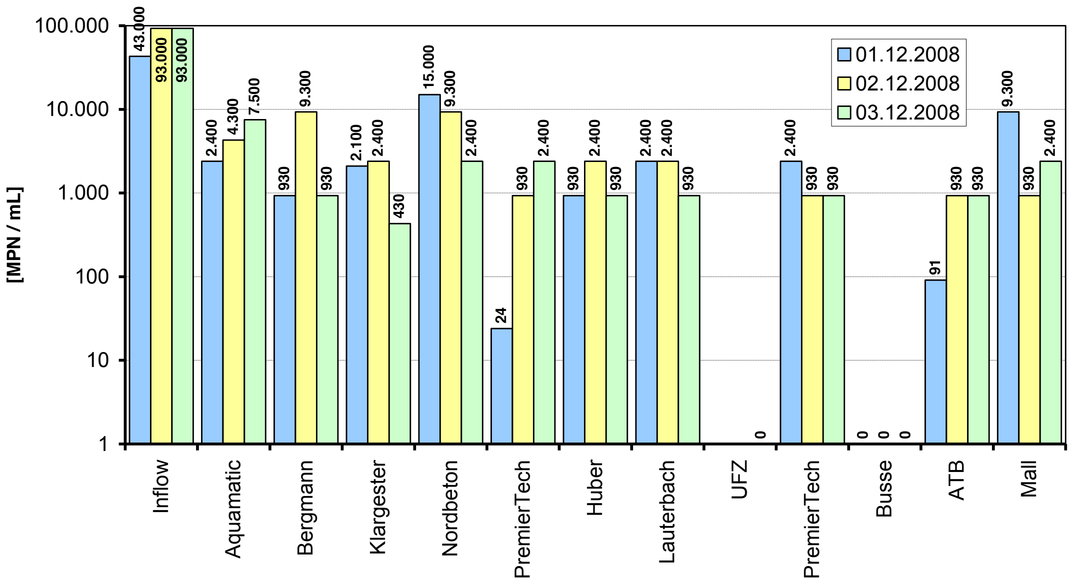

Figure 65: Intestinal enterococci in all 12 SWWTPs

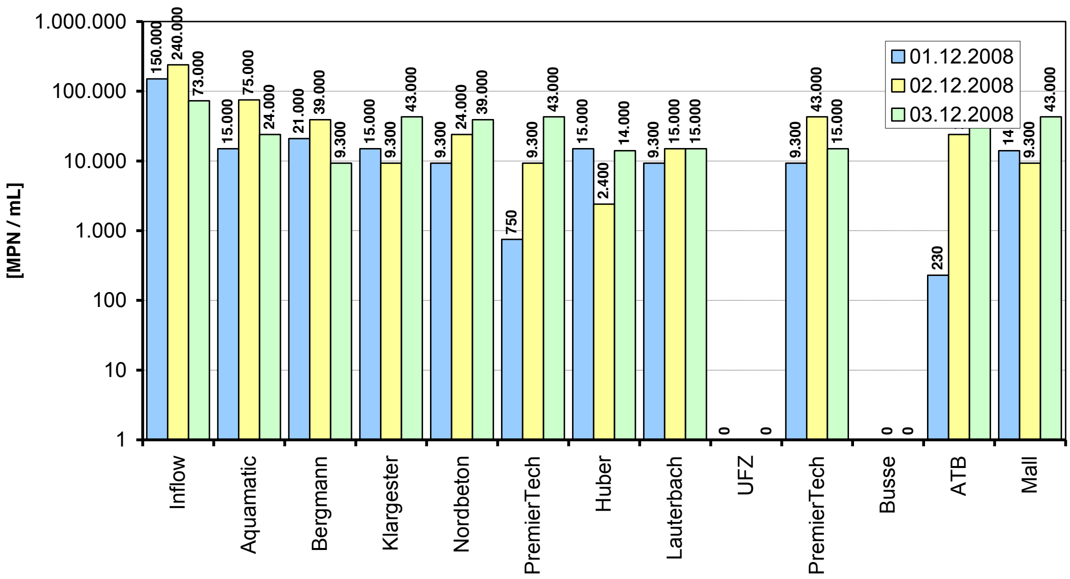

Figure 66: Faecal coliform bacteria at all 12 SWWTPs

The World Health Organisation recommends a purity of ≤ 1 intestinal nematode egg (mean) per litre of purified wastewater used for agricultural irrigation purposes (WHO, 2004). Many of the SWWTPs also failed to meet this standard (Figure 67).

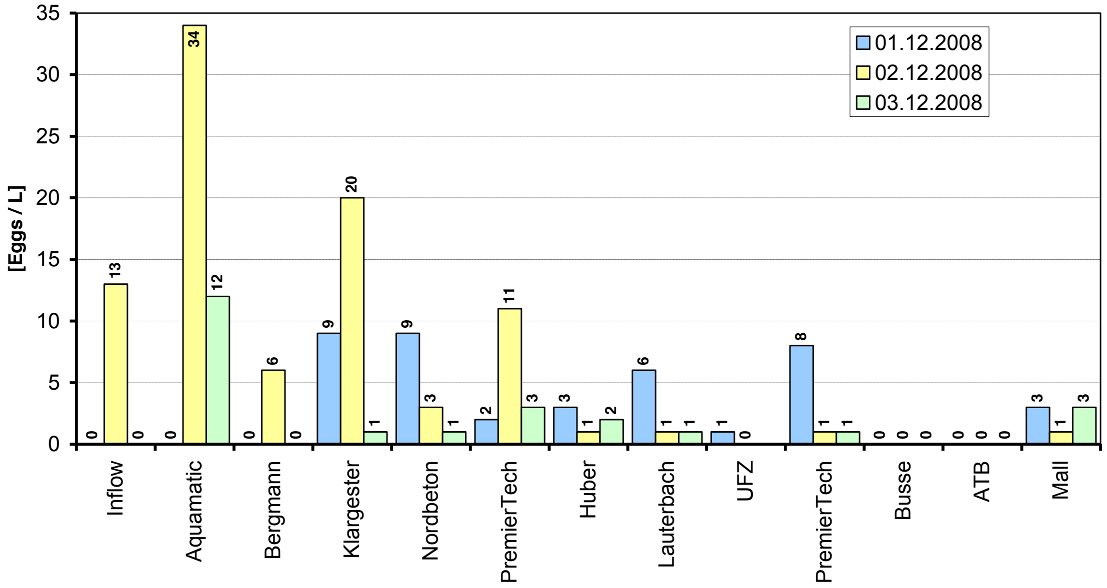

Figure 67: Intestinal nematodes (eggs) in all 12 SWWTPs

Chapter 7

Results of the small wastewater treatment plants studied

7.1 Aquamatic – STM 5

7.1.1 Loading conditions

Aquamatic GmbH & Co. KG installed the STM 5 system, which has a design capacity of 5 PE, but was tested at a load of 4 PE due to the system group classification used in this study (4 PE, 6 PE or 9 PE). The nominal hydraulic load corresponds to 240 g BOD_5/d. According to authorisation, the system should be able to handle influent loads of up to 300 g BOD_5/d.

The nominal hydraulic load is 600 L/d. The system was also tested with 200-litre bathtub discharges 5 times a week which corresponds to approx. 114 L/d (see Section 5.1.2). According to authorisation, the maximum permissible hydraulic load for this system is 750 L/d.

The system was operated under the following influent loadings level:

- Befor 23 July 2008[*]:	2.6 $PE_{BOD,60}$
- 23 Jul 2008 until before 27 Aug 2008:	3.1 $PE_{BOD,60}$
- Overall mean (across entire study period):	3.4 $PE_{BOD,60}$

Therefore, the system achieved a 86% capacity relative to influent BOD_5 over the entire study period.

The manufacturer specifies minimum and maximum volumes for the pretreatment tank. In the case of the pretreatment tank, the minimum volume occurs when the maximum sludge volume was reached. The corresponding residence times were therefore 2 to 3 days for the pretreatment tank, 1.3 days for the bioreactor and 0.6 days for the secondary treatment at a hydraulic load of 4 PE. The overall residence times for the entire system were 4.9 to 5.9 days at 4 PE (average 4.4 days at 4 PE) (see Section 2.6).

7.1.2 Statistical overview of results

Table 42 and Table 43 show the results of the statistical analysis for the entire study period, including the number of samples, the mean, median, minimum (min) and maximum (max) values, the statutory limits in France (FR) and Germany (DE) (see 2.2.1.1 and 2.2.1.1) and the rate of compliance of effluent COD, BOD_5, SS, NH_4-N, N_{tot} and P_{tot} with the statutory lim-

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[*] See Chapter 5.1.2: Due to the low influent concentrations, testing under increased hydraulic load conditions (150%) was discontinued in order to increase the influent load.

its (*stay below probability*). Mean, median, minimum and maximum values as well as the statutory limits in France (FR) and Germany (DE) are expressed in units of mg/L. The number of samples is a dimensionless parameter. The rate of compliance with statutory limits (*stay below probability*) is given in percent.

Table 42: Aquamatic - STM 5 – statistical analysis of COD, BOD_5 and SS

Aquamatic, STM 5	COD		BOD			SS	
	In	Out	In	Load (real)*	Out	In	Out
	[mg/l]	[mg/l]	[mg/l]	[E]	[mg/l]	[mg/l]	[mg/l]
Number of samples	50	49	50	50	49	49	49
mean	456	196	207	3,4	64	269,0	116,8
median	469	104	215	3,2	34	260,0	56,0
min.	180	28	78	1,0	4	120,0	5,0
max.	830	741	301	5,8	248	730,0	540,0
legally binding value (DE / FR)		**150 / 125**			**40 / 25**		**-- / 35**
stay below of legally binding value (DE)		57%			51%		
stay below of legally binding value (FR)		51%			47%		41%

* Load (real) siehe 2.3

Table 43: Aquamatic - STM 5 – Statistical analysis of nitrogen and phosphorus

Aquamatic, STM 5	NH_4-N		N_{tot}		P_{tot}	
	In	Out	In	Out	In	Out
	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]
Number of samples	50	49	50	49	50	49
mean	35,1	19,6	47,4	38,9	7,0	6,4
median	34,8	13,3	46,5	34,2	7,3	5,1
min.	11,6	0,7	19,8	14,4	2,9	3,2
max.	54,5	44,8	71,6	81,9	10,2	13,3
legally binding value (DE / FR)		-- / --		-- / --		-- / --
stay below of legally binding value (DE)						
stay below of legally binding value (FR)						

Chemical oxygen demand (COD)

The system achieved a mean effluent COD of 169 mg/L over the entire study period; the maximum concentration was 741 mg/L. Measured COD levels were below the German statutory limit of 150 mg/L in 57% of cases (see 2.2.1.1), and were below the French statutory limit of 125 mg/L in 51% of cases (see 2.2.1.2). In other words, the measured levels exceeded the German limit in 21 cases and exceeded the French limit in 24 cases (see 7.1.4). The system met the statutory effluent requirements for Germany and France in approximately half of all cases.

Biological oxygen demand (BOD_5)

The system achieved a mean effluent BOD_5 of 64 mg/L over the entire study period; the maximum concentration was 248 mg/L. Measured BOD_5 levels were below the German statutory limit of 40 mg/L in 51% of cases and below the French statutory limit of 25 mg/L in 47% of cases. In other words, the measured levels exceeded the German limit in 24 cases and exceeded the French limit in 26 cases (see 7.1.4). The system met the statutory effluent requirements for Germany and France in approximately half of all cases.

Suspended solids (SS)

The system achieved a mean effluent SS of 117 mg/L over the entire study period; the maximum concentration was 540 mg/L. Measured SS concentrations were below the French statutory limit of 35 mg/L in 41% of cases. In other words, the measured concentrations exceeded the French limit in 29 cases (see 7.1.6). The system met the statutory effluent requirements for France in roughly half of all cases. There are no statutory limits for effluent SS concentrations in Germany.

Nitrogen

- **Ammonia (NH_4-N):**
  The system achieved a mean effluent NH_4-N concentration of 19.6 mg/L over the entire study period; the maximum concentration was 44.8 mg/L (see 7.1.5).
- **Total nitrogen (N_{tot})**
  The system achieved a mean effluent N_{tot} concentration of 38.9 mg/L during the entire study period; the maximum concentration was 81.9 mg/L (see 7.1.5).

Total phosphorus (P_{tot})

The system achieved a mean effluent P_{tot} concentration of 6.4 mg/L during the entire study period; the maximum concentration was 13.3 mg/L (see 7.1.7).

7.1.3 Operational and process stability

Process stability was described in terms of compliance with statutory limits for target parameters (*stay below probability*) (Figure 68). The steeper the curve, the more stably the system is operating. A stable system maintains steady effluent concentrations in spite of changes in influent concentrations, temperatures etc. (see 2.10.9).

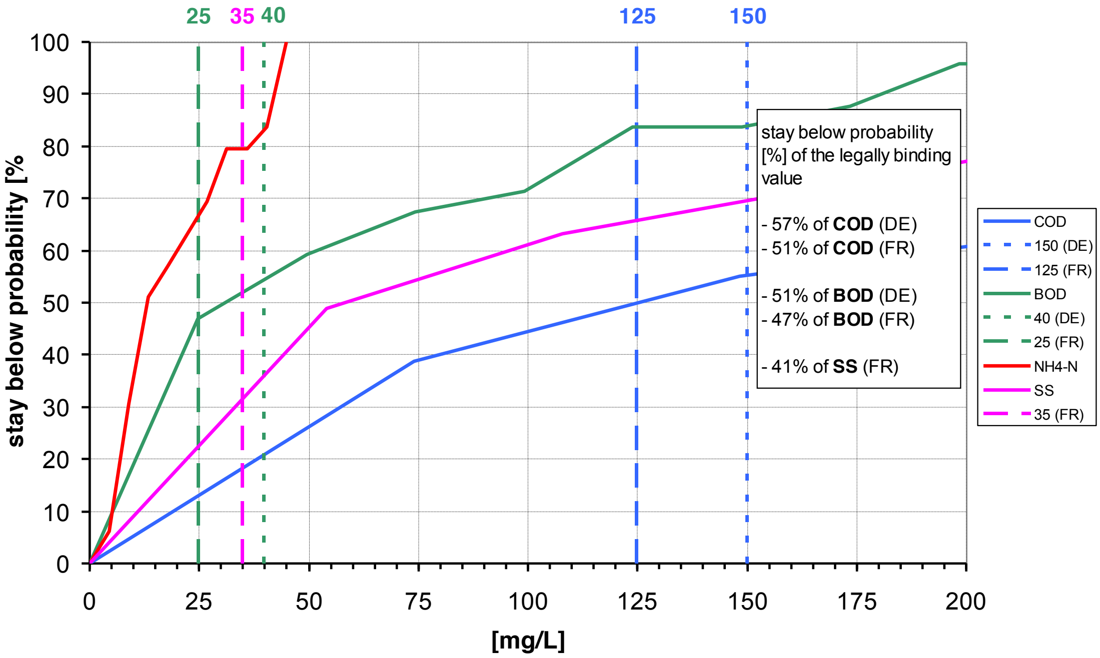

Figure 68: Aquamatic - STM 5 – Stay below probability for COD, BOD$_5$, NH$_4$-N und SS

7.1.4 COD and BOD$_5$ elimination

The combined parameters for organic matter were analysed based on the COD curve over the entire study period. The horizontal lines (Figure 69) at 150 mg/L (125 mg/L) represent the German and French statutory limits. The BOD$_5$ curve shown in Figure 70 is similar to the COD curve. The mean COD/ BOD$_5$ ratio is 3 to 1.

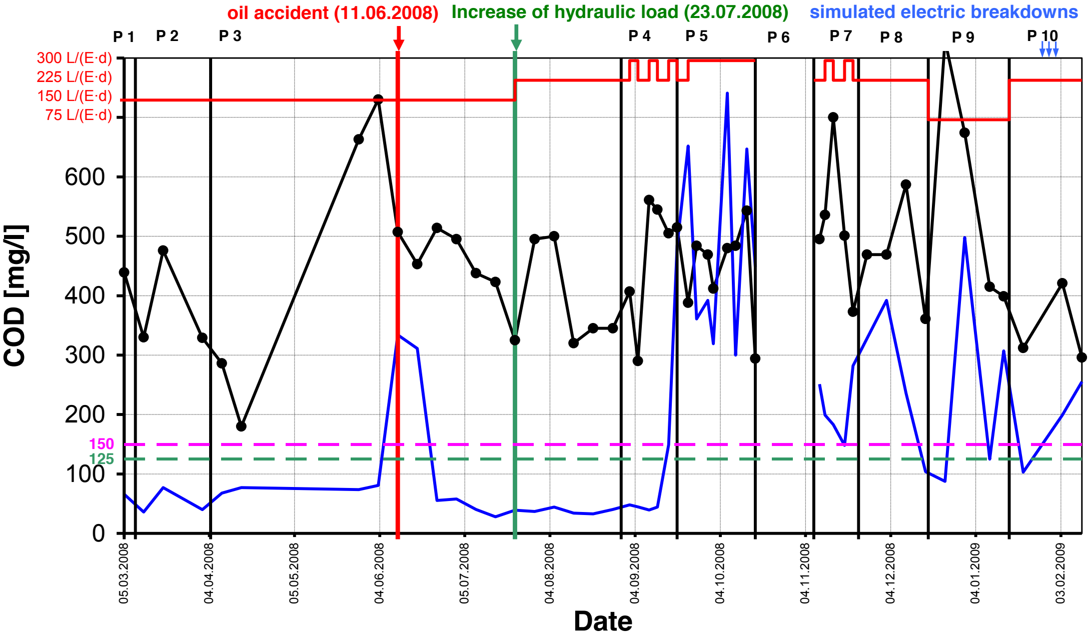

Figure 69: Aquamatic - STM 5 – Influent and effluent COD curves

Until the middle of Phase 4, effluent COD concentrations remained below 100 mg/L (Figure 69). The oil accident resulted in an increase in effluent COD concentrations to more than 300 mg/L. COD concentrations returned to baseline levels within about 14 days although no countermeasures were taken apart from cleaning of the primary treatment. The increased hydraulic load conditions in Phase 3 had no measurable effect on COD concentrations.

In the middle of Phase 4, the 200% hydraulic load increases on three days per week resulted in a sharp rise of effluent COD to more than 700 mg/L. Above-average wastewater temperatures of approx. 17°C initially led to a decrease in O_2 contents and subsequently to a massive loss of the suspended biomass. This was proven by a substantial drop in sludge volume from mean 310 mL/L to below 20 mL/L until 25 September 2008. The O_2 contents rose again, which proved that only a reduced biomass respiration occurred. The sessile biomass obviously could not compensate this loss, since in the following phases the effluent COD concentrations were very unstable on a high level. The probable reason for the sludge escape (see Figure 72) was the exceeding of the permitted surface loading of the secondary treatment which the manufacturer indicated with 0.10 m/h. During the 200% hydraulic load, the surface load was 0.15 m/h relative to $Q_d/10$ (according to authorisation DIBt) and even 0.18 m/h considering the bathtub discharge.

Due to the through flow reactor in a similar situation increased the sludge volume after 25 September 2008 is no longer, and the effluent COD mostly remained above 150 mg/L.

A slight improvement was observed at the beginning of Phase 7, but during the hydraulic load increases, the COD values rose again. Due to the ensuing low temperatures, only insufficient biomass was generated. Also the sessile biomass could not develop an adequate biofilm due to the low contact time of 0.8 to 1.3 days (Phase 5 and Phase 8).

The simulated electrical breakdowns produced a maximum value of 200 mg/L, which slightly increased again thereafter. A temporary increase in persistent substances in the influent could be the cause of this phenomenon because it was observed at the same time in nearly all of the SWWTPs studied (see 7.1.13).

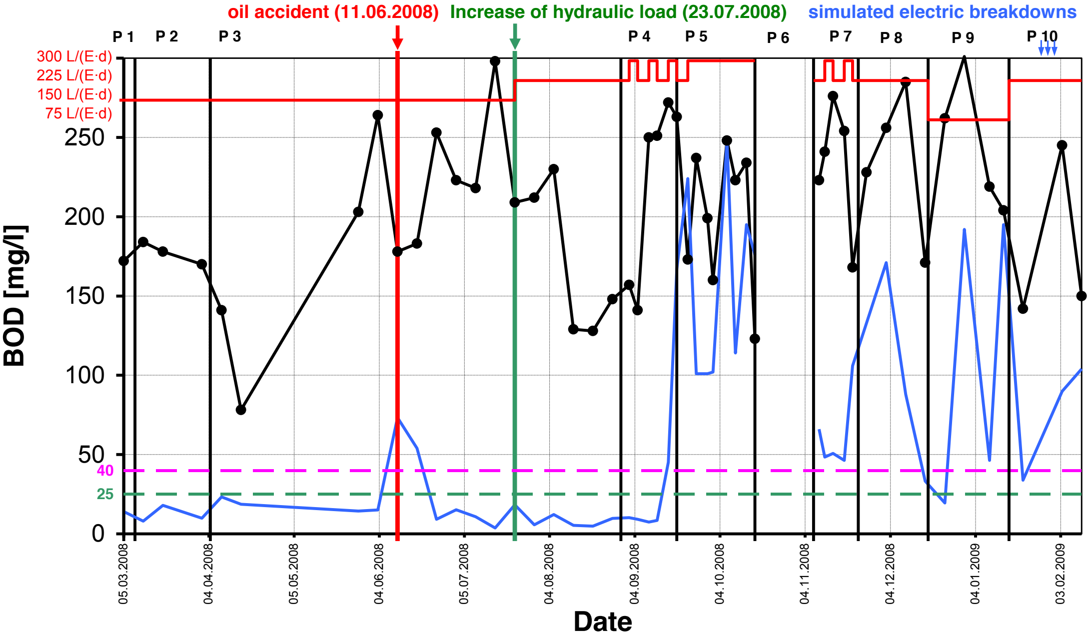

Figure 70: Aquamatic - STM 5 – Influent and effluent BOD_5 curves

7.1.5 Nitrogen

Ammonia (NH_4-N)

The course of the NH_4-N curve reflects the course of nitrification (Figure 71). As a biological process very sensitive to changes in process control, nitrification is a useful indicator of the stability of wastewater treatment systems.

Until the middle of Phase 5 (300 L/PE·d), the system mostly achieved effluent NH_4-N concentrations of below 20 mg/L, often also below 10 mg/L. From Phase 5 on, a sharp increase to 40 mg/L was observed, although the temperatures were still on a very high level within the range measured during the entire study period (mean: 16.4°C for Phase 5). During this time, the system measured oxygen concentrations from 2.5 to 6 O_2/L, which should be sufficient for biological processes. The poor degradation rate can therefore be attributed to the massive reduction of biomass in the consequence of sludge escape.

The temporary improvement of the ammonia degradation rate during phase 9 (5.2 mg/L) can be explained by the low hydraulic load and the effluent failure on 6 January 2009 (see 7.1.11) and the related extended residence time in the system.

Due to the increase of influent concentrations at the end of Phase 9, also the effluent concentrations rose continuously and led again to a nitrification breakdown (above 20 mg/L). After the electric breakdowns (see above – COD), the effluent contained even more ammonia than the influent, which may be related to the very low wastewater temperatures (approx. 3°C).

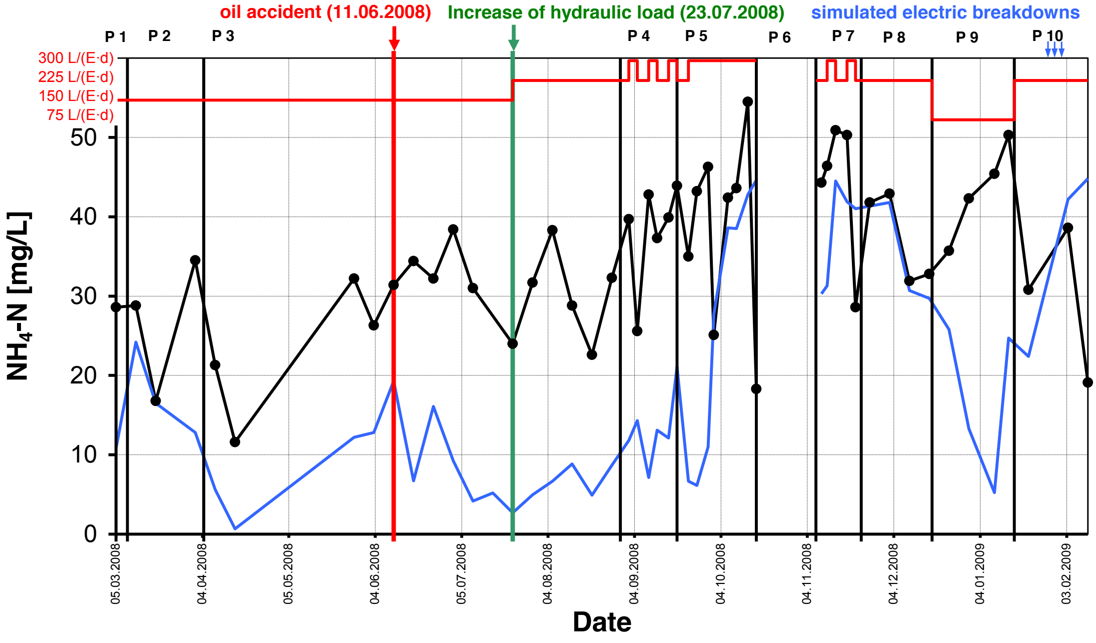

Figure 71: Aquamatic - STM 5 – Influent and effluent NH_4-N curves

Inorganic nitrogen

The inorganic nitrogen curve is provided in the Appendix.

The inorganic nitrogen concentrations ranged from 10 to 20 mg/L until the end of Phase 3. These concentrations were 5 to 10 mg/L below the influent concentrations, so that it can be assumed that partial denitrification (up to 50%) took place. The oil accident did not cause any noticeable disturbances in the denitrification process. Only from Phase 4 on, the inorganic nitrogen concentrations increased up to 50 mg/L (see 7.1.4) due to insufficient sludge volume. No further significant denitrification occurred thereafter.

7.1.6 Suspended solids

Until the middle of Phase 4, the effluent SS concentrations mainly remained below 35 mg/L (Figure 72). Only during the transition from Phase 2 to Phase 3, the effluent concentrations increased. In addition, the effluent SS concentrations rose to values above 200 mg/L at the time of the oil accident. Although no other countermeasures were taken except the oil removal from the pretreatment tank, the concentrations levelled off at the initial values after 2 weeks. The increase in nominal hydraulic load during Phase 3 had no measurable impact. The additional hydraulic load of 200% at three days per week led to a jump in effluent SS concentrations to above 500 mg/L in the middle of Phase 4. At above average wastewater temperatures of approx. 17°C, the O_2 content initially dropped and in the following a massive loss of suspended biomass occurred, which was substantiated by the sharp decrease in sludge volume from approx. mean 310 mg/L to below 20 mg/L until 25 September 2008. The O_2 content rose again, which also proves that biomass respiration took place only at a reduced level. The sessile biomass obviously could not compensate this loss, since the effluent SS concentrations were subject to considerable variations at a high level during the subsequent phases The probable reason for the sludge escape (see Figure 72) is the exceeding of the permitted surface load of the secondary treatment tank, which is indicated at 0.10 m/h by the manufacturer. During the hydraulic load of 200% the surface load performed was at 0.15 m/h relative to $Q_d/10$ (according to authorisation criteria of DIBt) and considering the bathtub discharge even at 0.18 m/h.

Due to a flush reactor the sludge volume did not rise again after 25 September 2008. The effluent SS concentrations remained most widely above 200 mg/L. A slight improvement was observed from the beginning of Phase 7 on until the end of Phase 8, when values from 200 mg/L to below 25 mg/L appeared. Owing to the subsequent low temperatures only insufficient biomass could be generated. Also the sessile biomass could not produce an adequate biofilm which was presumably due to the low contact time.

During the electric breakdowns, a maximum value of approx. 100 mg/L was achieved, which still slightly increased thereafter. This might be explained by the temporary increase of persistent substances in the influent, because this phenomenon was observed at the same time in nearly all of the SWWTPs studied (see 7.1.13).

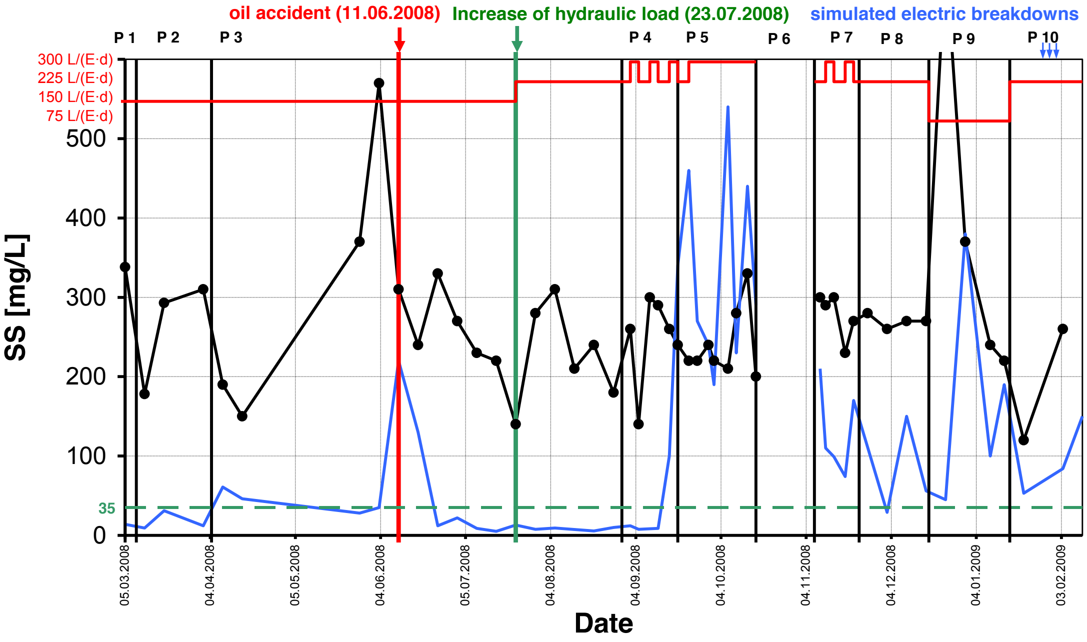

Figure 72: Aquamatic - STM 5 – Influent and effluent SS curves

7.1.7 Phosphorus

The phosphorus elimination (Figure 73) was low independent from the hydraulic load during the entire study period. Effluent phosphorus concentrations ran parallel to the influent concentrations, but generally with a slight time-delay.

Comparison with suspended solids concentrations demonstrates that effluent phosphorus concentrations are directly proportional to SS concentrations because bound phosphorus is also eliminated with suspended solids. In this case, phosphorus is not degraded but rather bound and eliminated with the sludge and the suspended solids.

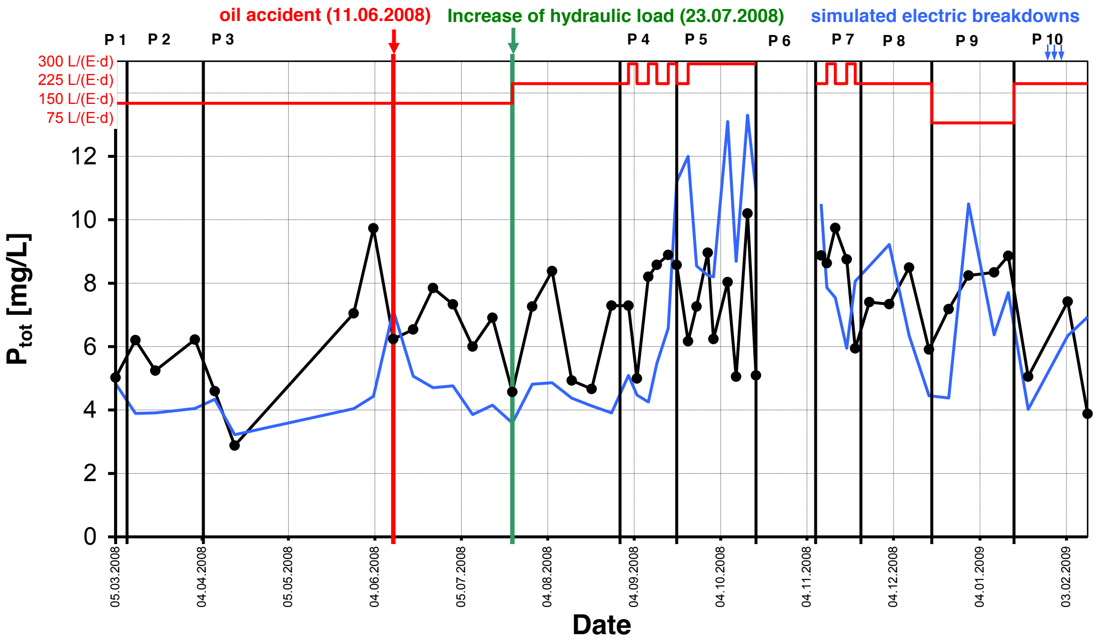

Figure 73: Aquamatic - STM 5 – Influent and effluent P_{tot} curves

7.1.8 Degradation rates

Degradation rates for COD, BOD_5, NH_4-N, N_{tot}, P_{tot} and SS (Table 44, Table 45, Table 46, see 2.9)) are expressed as percentage values. Negative values mean that influent concentrations were smaller than effluent concentrations. Potential reasons for this are redissolution, washout and (back) transformation from the biomass.

Phosphorus is not eliminated, but partly is settled in the primary treatment tank as soon as is incorporated in the biomass and so it is returned with the excess sludge to the primary treatment tank.

The mean degradation rate was 56% for COD and 68% for BOD_5. Mean elimination rates were 41% for NH_4-N, 15% for N_{tot} and 5% for phosphorus.

Table 44: Aquamatic - STM 5- Degradation rates (%) for COD, BOD_5, NH_4-N, N_{tot}, SS and P during the complete period

Aquamatic, STM 5	η_{COD}	η_{BOD}	$\eta_{NH4\text{-}N}$	η_{Ntot}	η_{P}	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	49	49	49	49	49	48
mean	56	68	41	15	5	53
median	70	82	52	23	20	69
min.	-68	-43	-144	-132	-114	-157
max.	93	99	94	66	54	98

Table 45: Aquamatic - STM 5- Degradation rates (%) for COD, BOD_5, NH_4-N, N_{tot}, SS and P during the 100% phases (Phases 1, 2 and 3)

Aquamatic, STM 5	η_{COD}	η_{BOD}	$\eta_{NH4\text{-}N}$	$\eta_{N\text{-}tot}$	η_{P}	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	20	20	20	20	20	20
mean	81	90	66	31	26	87
median	89	94	73	29	34	95
min.	31	59	2	-12	-14	29
max.	93	99	94	66	54	98

Table 46: Aquamatic - STM 5- Degradation rates (%) for COD, BOD_5, NH_4-N, N_{tot}, SS and P during the overload phases (Phases 4, 5 and 7)

Aquamatic, STM 5	η_{COD}	η_{BOD}	$\eta_{NH4\text{-}N}$	$\eta_{N\text{-}tot}$	η_{P}	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	19	19	19	19	19	19
mean	33	52	30	7	-15	17
median	38	57	33	12	-18	30
min.	-68	-43	-144	-132	-114	-157
max.	93	97	86	50	48	97

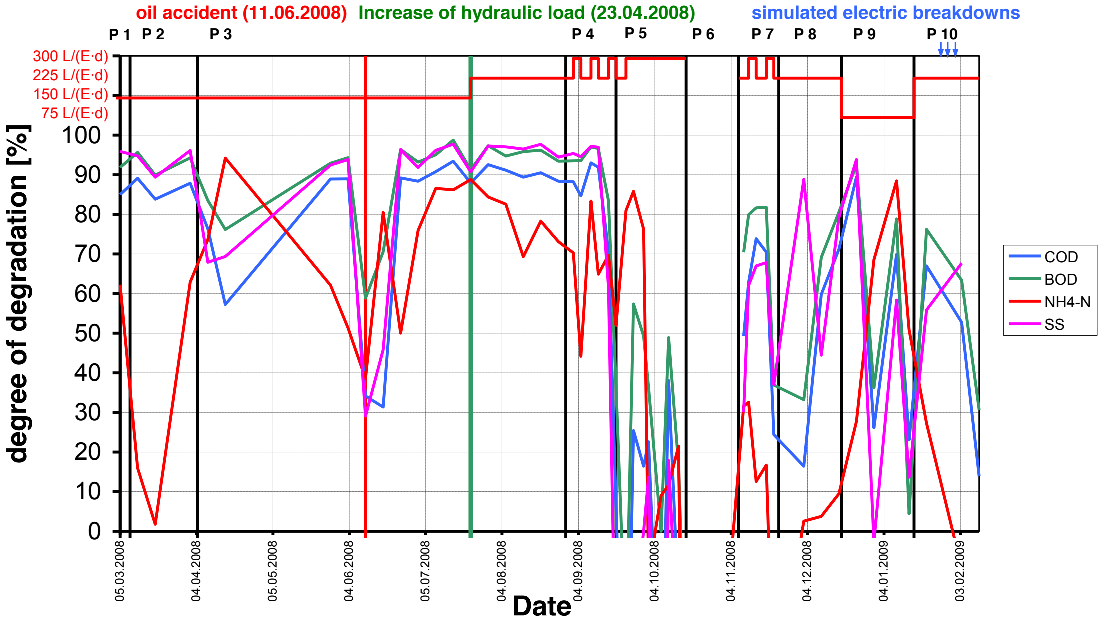

Figure 74: Aquamatic - STM 5 – Degradation curves COD, BOD$_5$, NH$_4$-N and SS

The COD degradation rate was higher (81%) during the nominal load testing than during the entire study period (56%) which was due to the lower influent rate. Degradation rates during the hydraulic overload phases tend to be clearly lower. The lowest COD elimination rate was observed during Phase 5 (300 L/d). The degradation curves show that the degradation rate varied between 80% and 90% until the middle of phase 5 (Figure 74). The first drop occurred middle of April and was caused by the minor influent concentrations and the relatively constant effluent values. After the oil accident, the degradation rates decreased sharply to levels of approx. 30-40% for COD, NH$_4$-N and SS and to 60% for BOD$_5$. The rates returned to average levels in about 2 weeks.

From the end of Phase 4 on, degradation rates for all parameters (COD, BOD$_5$, NH$_4$-N, SS) tumbled and did not stabilise again during the rest of the study period. All degradation rates ranged from below 0% to partially above 90%. This behaviour does not correspond to a stable operation.

More detailed analyses of effluent values are presented in 7.1.4.

7.1.9 Power consumption

Power consumption (Figure 75) was classified according to the population-specific hydraulic load (no load, 75, 150, 225, 225+300, 300 L/(PE·d)); the load corresponded to the nominal population equivalent value (4 PE).

Mean power consumption values are given in kWh/(PE·a) (see 2.3). Since power consumption in Phase 6 (no load) was calculated based on the nominal hydraulic load (4 PE), the estimated specific power consumption may be lower under other hydraulic load conditions because the values were calculated as the quotient of measured power consumption and the population equivalent of wastewater flow. At higher loads, the hydraulic population equivalent is often higher than the nominal population equivalent; consequently, power consumption per inhabitant is lower.

Power consumption was measured as the total power consumed by the system. The rotary movement of the submerged rotating disc as well as the aeration is ensured by means of a compressed air drive. Alternatively the rotation can also be started by a motor drive (see 4.3). The following power consumers were therefore included in the calculations:

- Compressor (increased from 30W to 50W to 80W, see 7.1.11)

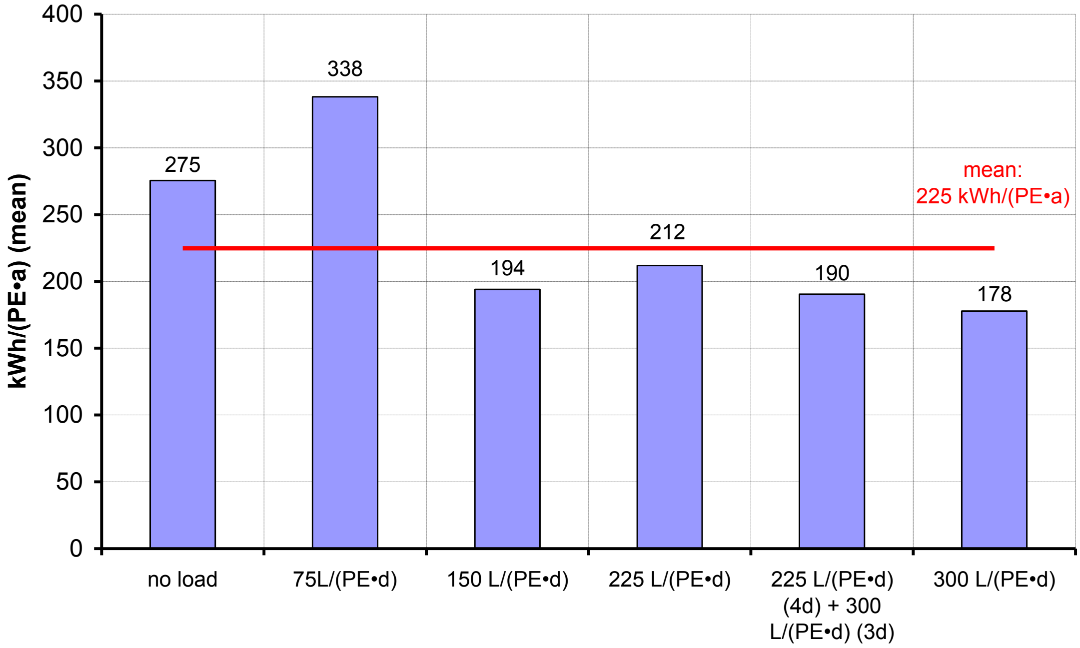

Figure 75: Aquamatic - STM 5 – Power consumption

Total power consumption at the plant during the entire study period was a mean 225 kWh/(PE a). Calculated based on the average population equivalent of 3.4 PE (based on BOD_5) (see 2.3), this corresponds to a daily power consumption rate of 2.1 kWh/d.

Population-independent consumption was 3.0 kWh/d, as calculated based on the power consumption of 275 kWh/(PE a) at 4 PE during Phase 6 (no load).

7.1.10 Sludge

The sludge volume was determined based on the measured sludge height and the known container geometry. As such geometry-dependent estimates are relatively imprecise, their power of evidence is limited. In addition, it has to be taken into consideration that considerable quantities of sludge escaped via the secondary treatment tank during the period. Presuming a mean effluent SS concentration, these quantities can roughly be estimated to be at a level of 100 g/TS(E·d). Furthermore, via an incline of 60° the return sludge ran back from the secondary treatment tank directly to the bioreactor, where it was absorbed and evenly distributed in the biotank by means of a sluge plate which is fixed at the disc. The sludge was therefore only insufficiently thickened, which led to a very poor TS content of the both bioreactor and surplus sludge.

The overall sludge production during the entire study period was 1.5 m^3. At a sludge dry matter content of 6.51 g/L (measured), this corresponds to a sludge mass of 9.75 kg.

The specific sludge volume at the calculated actual load of 3.4 PE is 8.0 gTS/(E d).

7.1.11 Operation and maintenance

Figure 76 shows all unusual events occurring over the entire study period while the system was in operation. Hydraulic loads and influent COD concentrations are also shown for better clarity. The diagram shows the course of events over time.

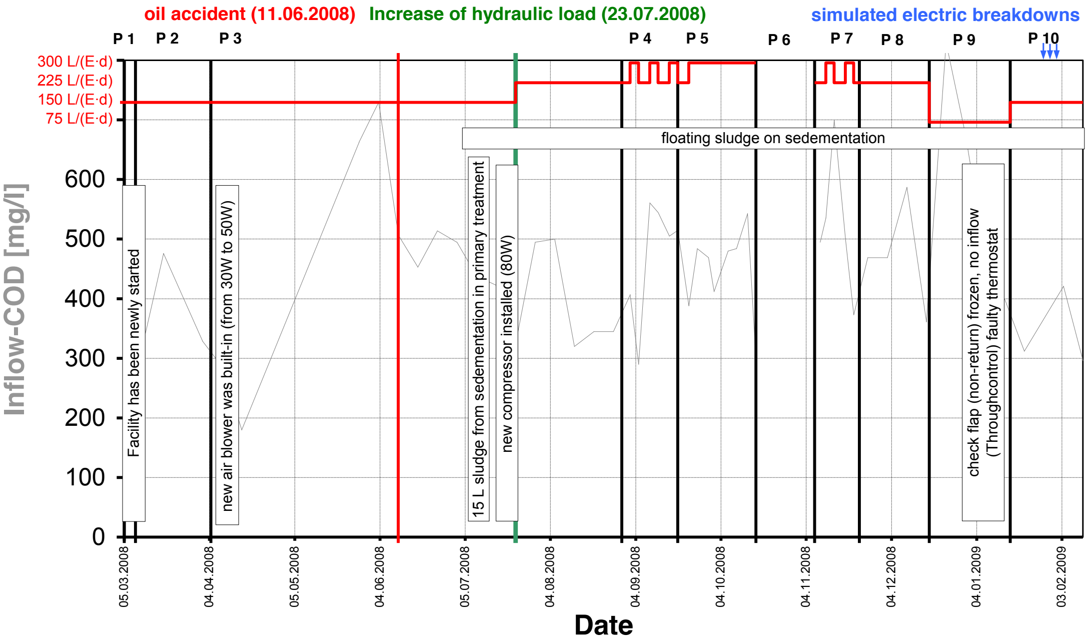

Figure 76: Aquamatic STM 5 – Maintenance log analysis

On 15 February 2008 the entire system was maintained (this event is not listed in the diagram).

On 7 March 2008 the system was restarted.

9 March, on 9 July and on 10 October 2008 the system was also maintained.

On 11 April 2008 a more efficient compressor was installed (from 30W to 50W).

On 9 July 2008 approx. 15L sludge was pumped from the secondary to the pretreatment tank, on 18 July 2008, a new 80W compressor was installed.

From 2 July 2008 on, floating sludge constantly appeared on the secondary treatment tank.

On 06 January 2009 08:00 hrs until 07 January 2009 12:00 hrs inflow was obstructed due to a frozen non-return check valve. The non-return check flap was not part of the standard equipment of the Aquamatic-STM 5 system but rather of the test facility. Therefore Aquamatic was not responsible for the malfunction.

7.1.12 Microbiology

Effluent water samples were collected on three consecutive days and tested for total coliform bacteria, faecal coliform bacteria, intestinal enterococci, salmonella and intestinal nematodes (see 5.4.2). The results of the microbiological analysis are presented in Table 47.

On average of three consecutive days, total coliform bacteria were reduced by 0.5 log steps, faecal coliform bacteria by 0.6 log steps, intestinal enterococci by 1.2 log steps and salmonella by around 1.9 log steps. In intestinal nematodes, there was an avarage increase of 11 eggs/L, although this may be explained by statistical uncertainty in the determination of the number. In addition, the simultaneous sampling in the influent and effluent did not consider the time lag during the system passage.

It can generally be assumed that the number of faecal coliform bacteria undergoes a one- to two-log reduction per treatment stage (compare DWA, 1998). This was not achieved by this plant with a mean of 0.6-log reduction.

As expected, effluent microbiological quality did not meet bathing water quality standard.

Table 47: Aquamatic - STM 5 – Microbiological analysis

Date		1 Dec 08			2 Dec 08			3 Dec 08			Mean
		[MPN/ mL]	[log]	Δ [log]	[MPN/ mL]	[log]	Δ [log]	[MPN/ mL]	[log]	Δ [log]	Δ [log]
Total coliform bacteria	Influent	930,000	5.97	0.31	390,000	5.59	0.72	430,000	5.63	1.00	0.5
	Effluent	460,000	5.66		75,000	4.88		43,000	4.63		
Faecal coliform bacteria	Influent	150,000	5.18	1.00	240,000	5.38	0.51	73,000	4.86	0.48	0.6
	Effluent	15,000	4.18		75,000	4.88		24,000	4.38		
Intestinal enterococci	Influent	43,000	4.63	1.25	93,000	4.97	1.34	93,000	4.97	1.09	1.2
	Effluent	2,400	3.38		4,300	3.63		7,500	3.88		
Salmonella	Influent	2,100	3.32	0.96	750	2.88	1.23	46,000	4.66	2.22	1.9
	Effluent	230	2.36		44	1.64		280	2.45		
Intestinal nematodes		[Eggs/L]		Δ [Eggs]	[Eggs/L]		Δ [Eggs]	[Eggs/L]		Δ [Eggs]	Δ [Eggs]
	Influent	<1		0	13$^{1)}$		-21	<1		-12	-11
	Effluent	<1			34			12$^{1)}$			

1) statistical uncertainty in determination of the egg counts

"< 1" is assumed to be zero

7.1.13 Comparison of the test results with reports and literature data

Chemical oxygen demand

According to DIBt effluent class C requirement (see Table 2), the system should achieve effluent COD concentrations of < 100 mg/L in composite samples. Measured concentrations were below 100 mg/L in 47% of cases. In addition, they were below the manufacturer's specification of 100 mg/L in 90% of cases during nominal load phases 1, 2 and 3.

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008) is approx. 65 mg/L in the 100% phase, which is comparable to the mean 79 mg/L (100% load) achieved by the Aquamatic-STM 5 system during phases 1 to 3. The overall mean effluent COD concentration achieved by the Aquamatic - STM 5 system was much higher (196 mg/L).

Considering that the average effluent COD concentration of submerged rotating filter systems which are the most similar to the Aquamatic system, in practice was determined to be 144 mg/L (STRAUB 2008), the mean 196 mg/l achieved by the Aquamatic-STM 5 system is thus clearly above the reference average.

In a test series performed in Dorf Mecklenburg, Germany (Jiroudi 2005), the submerged rotary filters used there (4 PE, 26 measurements) achieved a mean effluent COD concentration of 96 mg/L, which is much lower than the values achieved by the investigational system over the entire study period, but slightly above the level achieved during the 100% phase (79 mg/L). In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 1.087 mg/L (223 mg/L - 2.128 mg/L, 135 measurements).

Biological oxygen demand in five days

According to DIBt effluent class C requirement (see Table 2), the system should achieve effluent BOD_5 concentrations of < 25 mg/L in composite samples. Measured concentrations were below 25 mg/L in 47% of cases. In addition, they were below the manufacturer's specification of 25 mg/L in 90% of cases during nominal load phases 1, 2 and 3.

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008) is approx. 12 mg/L in the 100% phase, which is comparable to the mean 17 mg/L (100% load) achieved by the Aquamatic-STM 5 system during phases 1 to 3. The overall mean effluent BOD_5 concentration achieved by the Aquamatic-STM 5 system was much higher (64 mg/L).

Considering that the average effluent BOD_5 concentration of submerged rotating filter systems which are the most similar to the Aquamatic system, in practice was determined to be 23 mg/L (STRAUB 2008), the mean 64 mg/l achieved by the Aquamatic-STM 5 system is thus clearly above the reference average.

In a test series performed in *Dorf Mecklenburg*, Germany (JIROUDI 2005), the submerged rotary filters used there (4 PE, 7 measurements) achieved a mean effluent BOD_5 concentration of 23 mg/L, which is much lower than the values achieved by the investigational system over the entire study period, but slightly above the level achieved during the 100% phase (17 mg/L). In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 598 mg/L (160 mg/L - 960 mg/L, 136 measurements).

Ammonia (NH_4-N)

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008) is approx. 5 mg/L in the 100% phase. Even during the hydraulic load (Phases 1 to 3), the investigational system only rarely reached this low effluent NH_4-N concentration (mean 10 mg/L). Over the entire study period, the mean effluent NH_4-N concentration was 19.6 mg/L and thus four times higher than the average value.

Considering that the average effluent concentration of submerged rotating filter systems in practice was determined to be 34 mg/L (STRAUB 2008), the mean 19.6 mg/l achieved by the Aquamatic-STM 5 system is thus slightly below the reference average, but also includes data for measurements at water temperatures below 12°C (cf. STRAUB 2008).

In a test series performed in *Dorf Mecklenburg*, Germany (JIROUDI 2005), the submerged rotary filters used there (4 PE, 20 measurements) achieved a mean effluent NH_4-N concentration of 10 mg/L, which is much lower than the values achieved by the investigational system over the entire study period, but matched exactly the level achieved during the 100% phase (10 mg/L). In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 72 mg/L (24 mg/L - 114 mg/L, 137 measurements).

Suspended solids

According to DIBt effluent class C requirement (see Table 2), the system should achieve effluent SS concentrations of < 75mg/L for one samples. Measured concentrations (taken from 1 composite sample) were below 75 mg/L in 55% of cases.

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008) is approx. 25 mg/L in the 100% phase, which is below the mean 34 mg/L (100% load) achieved by the Aquamatic-STM 5 system during phases 1 to 3. The overall mean effluent SS concentration achieved by the Aquamatic-STM 5 system was much higher (117 mg/L).

Considering that the average effluent SS concentration of submerged rotating filter systems in practice was determined to be 29 mg/L (STRAUB 2008), the mean 116.8 mg/l achieved by the Aquamatic-STM 5 system is thus clearly above the reference average.

In a test series performed in *Dorf Mecklenburg*, Germany (JIROUDI 2005), the submerged rotary filters used there (4 PE, 10 measurements) achieved a mean effluent SS concentration of 25 mg/L, which is much lower than the values achieved by the investigational system over the entire study period, but only slightly below the level achieved during the 100% phase (34 mg/L).

Simulated electric breakdowns

The increase in effluent concentrations observed during the simulated electric breakdowns (Figure 69, Figure 70, Figure 71 und Figure 72) may be directly attributable to the electrical breakdowns themselves independent of increased influent concentrations or the presence of persistent substances. In a comparison study carried out in Nantes (VIGNOLES, CAUCHI, 2009), similar peaks were observed during simulated electric breakdowns in (almost) all plants independent of whether they required electricity of not. The researchers in Nantes could not find a plausible explanation for this phenomenon. This issue requires further research.

Power consumption

Daily power consumption of the investigational system was found to be 2.1 kWh/d. Average power consumption rates for 3 submerged rotary filter systems tested at the PIA test facility in Aachen, Germany (DORGELOH 2008) which are most likely comparable to the investigational system (air blower for drive and aeration of the submerged rotary filter system), is 0.3 kWh/(PE·d), and thus half as much as the average values of 0.62 kWh/(PE·d) determined for the investigational system. Power consumption rates for the systems tested at the PIA test facility Aachen ranged from approx. 0.28 kWh/(PE·d) to 0.32 kWh/(PE·d). Power consumption of the investigational system is thus above this range.

In a test series performed in *Dorf Mecklenburg*, Germany (JIROUDI 2005), the annual power consumption rate of the submerged rotary filter system used there was 44 kWh/(PE·a). This corresponds to 0.5 kWh/d and is thus slightly below the rate of the investigational system.

Sludge

Based on the data in DWA, 2003 a total solids concentration of approx. 70 g/(PE d) was expected. According to the measurements, the actual load was 8.0 g/(PE·d) which corresponds to one tenth of the expected sludge volume. This is predominantly due to the increased sludge escape which was estimated to be at approx. 100 g TS/(E·d) (see effluent values of suspended solids Figure 72)

It arises from the manufacturer's authorisation that the sludge content should be kept at a level between 300 and 350 mL/L during maintenance. Until 17 September 2008, the average was 310 mL/L which exactly matched this level. After 17 September 2008, this value sharply decreased to an average of 13.5 mL/L. This could also explain the dramatic deterioration of the overall cleaning performance of the system. One reason for this decline in sludge content is probably the sludge escape via the clear water outlet (see 7.1.4).

Microbiological parameters

The investigational system achieved effluent faecal coliform bacteria counts of roughly 43,000 to 460,000 per 100 ml. This is far above the range determined by STRAUB ET AL. 2008 yielding a mean of 8,400 bacteria counts per 100 ml for fixed bed systems, with a minimum value of 570 and a maximum value of 24,000 counts per 100 ml. The investigational system had an average log reduction of 0.6 log steps. This is well below the log reduction of 1.1 log steps by STRAUB ET AL. 2008.

In a test series performed in *Dorf Mecklenburg* (JIROUDI 2005), the submerged rotary filter system used there (4 PE) reduced the total coliform bacteria to 7.2×10^4/100 mL and faecal coliform bacteria to 4.1×10^4/100 mL, which is clearly lower than the values measured by the investigational system. The investigational system had an average log reduction of 0.5 log steps. This is well below the faecal coliforms log reduction of 3.2 log steps by JIROUDI 2005.

7.1.14 Summary

The investigational system was operated at a load of 3.4 PE over the entire study period. Until the middle of Phase 4, the discharge values were low, except during the oil accident. After the increase of the hydraulic load from Phase 4 on, a massive sludge escape occurred, presumably due to the hydraulic overload of the secondary treatment. As a consequence, the microbiology of the system was insufficient which led to a considerable deterioration of the discharge values. After 17 September 2008, the values were mostly above the statutory limits, because the sludge quantities continued to be poor until the end of the study period. Altogether, the cleaning performance proved to be very stable until 16 September 2008. After this date, the cleaning performance was rather unsatisfactory (see above).

The aeration capacity was increased two times through the installation of a more efficient compressor. After the oil accident, floating sludge was nearly continuously observed on the secondary treatment tank of the system

The power consumption was above the experienced data of other rotating filter systems, which can however, used as a reference with some reservations only, since they were not compressor equipped to run the drive and aeration of the system.

7.2 Bergmann – BIO- WSB®-N

7.2.1 Loading conditions

Bergmann installed the BIO-WSB®-N system which has a design capacity of 4 PE and was tested accordingly. The nominal BOD_5 load according to authorisation is 240 g /d.

The nominal hydraulic load was 600 L/d. The system was also tested with 200-litre bathtub discharges 5 times a week corresponding to approx. 114 L/d (see Chapter 5.1.2). According to authorisation, the system should be able to handle maximal hydraulic loads of 600 L/d plus one bathtub discharge per week.

The system was operated under the following influent loadings level::

- Befor 23 July 2008[*]: 2.6 $PE_{BOD,60}$
- 23 Jul 2008 until before 27 Aug 2008: 3.1 $PE_{BOD,60}$
- Overall mean (across entire study period): 3.4 $PE_{BOD,60}$

Therefore, the system achieved a 86% capacity relative to influent BOD_5 over the entire study period.

The manufacturer specifies minimum and maximum volumes for the pretreatment tank (coarse desludging), the biofilm reactor as well as for the secondary sedimentation tank. The corresponding resident times were therefore 2.0 to 2.6 days for the pretreatment tank, 0.8 to 1.2 days for the biofilm reactor and 0.8 to 1.2 days for the secondary sedimentation tank. The overall resident times for the entire system were 3.6 to 4.9 days (average 4.3 days) (see 2.6).

7.2.2 Statistical overview of results

Table 48 and Table 49 show the results of the statistical analysis for the entire study period, including the number of samples, the mean, median, minimum (min) and maximum (max) values, the statutory limits in France (FR), Germany (DE) (see Chapter 2.2.1.1 and 2.2.1.2) and the rates of compliance of effluent COD, BOD_5, SS, NH_4-N, N_{tot} and P_{tot}.with the statutory limits (*stay below probability*). Mean, median, minimum and maximum values as well as the statutory limits in France (FR) and Germany (DE) are expressed in units of mb/L. The number of samples is a dimensionless parameter. The stay below probability is given in percent (%).

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[*] See Chapter 5.1.2: Due to the low influent concentrations, testing under increased hydraulic load conditions (150%) was discontinued in order to increase the influent load.

Table 48: Bergmann BIO-WSB®-N – Statistical analysis of COD, BOD$_5$ and SS

Bergmann, BIO-wsb-N	COD		BOD			SS	
	In	Out	In	Load (real)*	Out	In	Out
	[mg/l]	[mg/l]	[mg/l]	[E]	[mg/l]	[mg/l]	[mg/l]
Number of samples	50	50	50	50	50	49	50
mean	456	53	207	3,4	13	269,0	15,7
median	469	48	215	3,2	11	260,0	13,5
min.	180	25	78	1,0	3	120,0	3,7
max.	830	146	301	5,8	65	730,0	62,0
legally binding value (DE / FR)		**150 / 125**			**40 / 25**		**-- / 35**
stay below of legally binding value (DE)		100%			98%		
stay below of legally binding value (FR)		98%			96%		96%

* Load (real) see 2.3

Table 49: Bergmann BIO-WSB®-N – Statistical analysis of nitrogen and phosphorus

Bergmann, BIO-wsb-N	NH_4-N		N_{tot}		P_{tot}	
	In	Out	In	Out	In	Out
	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]
Number of samples	50	50	50	50	50	50
mean	35,1	8,8	47,4	39,1	7,0	5,0
median	34,8	5,8	46,5	37,6	7,3	4,8
min.	11,6	1,0	19,8	24,6	2,9	2,8
max.	54,5	36,4	71,6	64,2	10,2	7,6
legally binding value (DE / FR)		-- / --		-- / --		-- / --
stay below of legally binding value (DE)						
stay below of legally binding value (FR)						

Chemical oxygen demand (COD)

The system achieved a mean effluent COD of 53 mg/L over the entire study period; the maximum concentration was 146 mg/L. Measured COD levels were below the German statutory limit of 150 mb/L in 100% of cases (see 2.2.1.1), and were below the French statutory limits of 125 mg/L (see 2.2.1.2) in 98 %. In other words, the measured levels did not exceed the German limit in one single case and exceeded the French limit in one case (see 7.2.4). The BIO-WSB®-N system met the statutory effluent requirements for Germany and France in (nearly) all cases.

Biological oyygen demand (BOD$_5$)

The system achieved a mean effluent BOD$_5$ of 13 mg/L over the entire study period; the maximim concentration was 65 mg/L. Measured BOD$_5$ levels were below the German statutory limit of 40 mg/L in 98% of cases, and were below the French statutory limit of 25 mg/L in 96%. In other words, the measured levels exceeded the German limit in one case and exceeded the French limit in 2 cases (see 7.2.4). The system met the statutory effluent requirements for Germany and France in (nearly) all cases.

Suspended solids (SS)

The system achieved a mean effluent SS concentration of 15.7 mg/L over the entire study period; the maximum concentration was 62 mg/L. Measured SS concentrations were below the French statutory limit of 35 mg/L in 96% of cases. In other words, the measured concentrations exceeded the French limit in 2 cases (see 7.2.6). The system met the statutory effluent requirements for France in most cases. There are no statutory limits for effluent SS concentrations in Germany.

Nitrogen

- **Ammonia (NH_4-N)**
  The system achieved a mean effluent NH_4-N concentration of 8.8 mg/L over the entire study period; the maximum concentration was 36.4 mg/L (see 7.2.5). The system thus met the DIBt requirements for N.
- **Total nitrogen (N_{tot})**
  The system achieved a mean effluent N_{tot} concentration of 39.1 mg/L over the entire study period; the maximum concentration was 64 mg/L (see 7.2.5).

Total phosphorus (P_{tot})

The system achieved a mean effluent P_{tot} of 5.0 mg/L over the entire study period; the maximum concentration was 7.6 mg/L (see 7.2.7).

7.2.3 Operational and process stability

Process stability was described in terms of compliance with statutory limits for target parameters (*stay below probability*) (Figure 77). The steeper the curve, the more stably the system is operating. A stable system maintains steady effluent concentrations in spite of changes in influent concentrations, temperatures etc. (see 2.10.9).

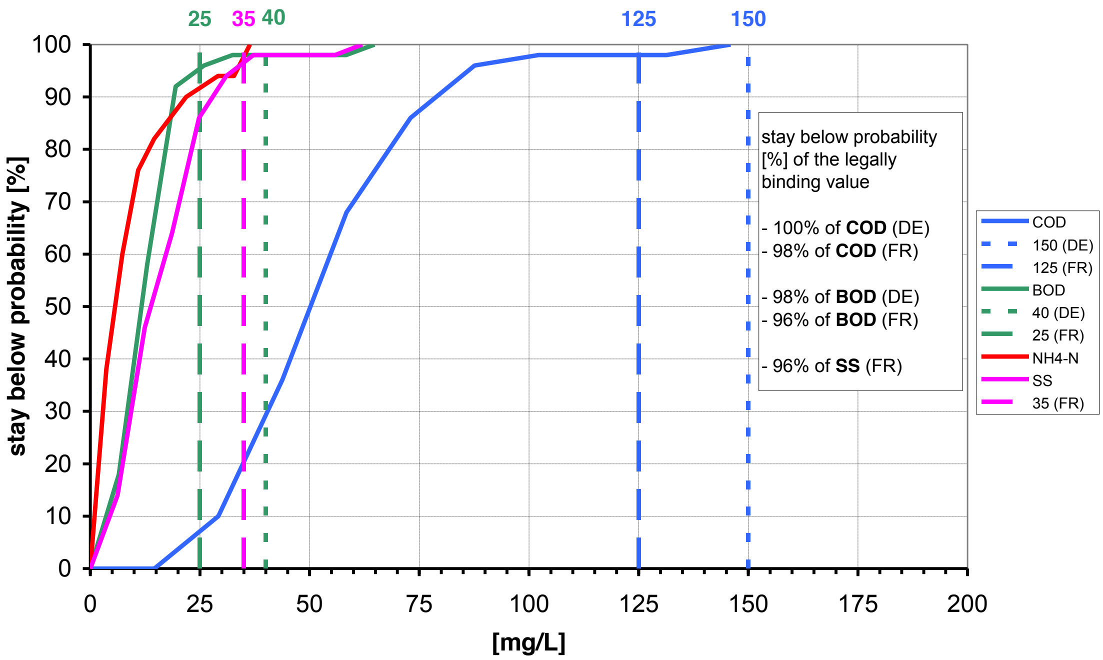

Figure 77: Bergmann BIO-WSB®-N – Stay below probability for COD, BOD$_5$, NH$_4$-N and SS

7.2.4 COD- and BOD$_5$ elimination

The combined parameters for organic matter were analysed based on the COD curve over the entire study period. The horizontal lines (Figure 78) at 150 mg/L (125 mg/l) represent the German and French statutory limits.

The BOD$_5$ curve shown in Figure 79 is similar to the COD curve. The mean COD/ BOD$_5$ ratio is 4 to 1.

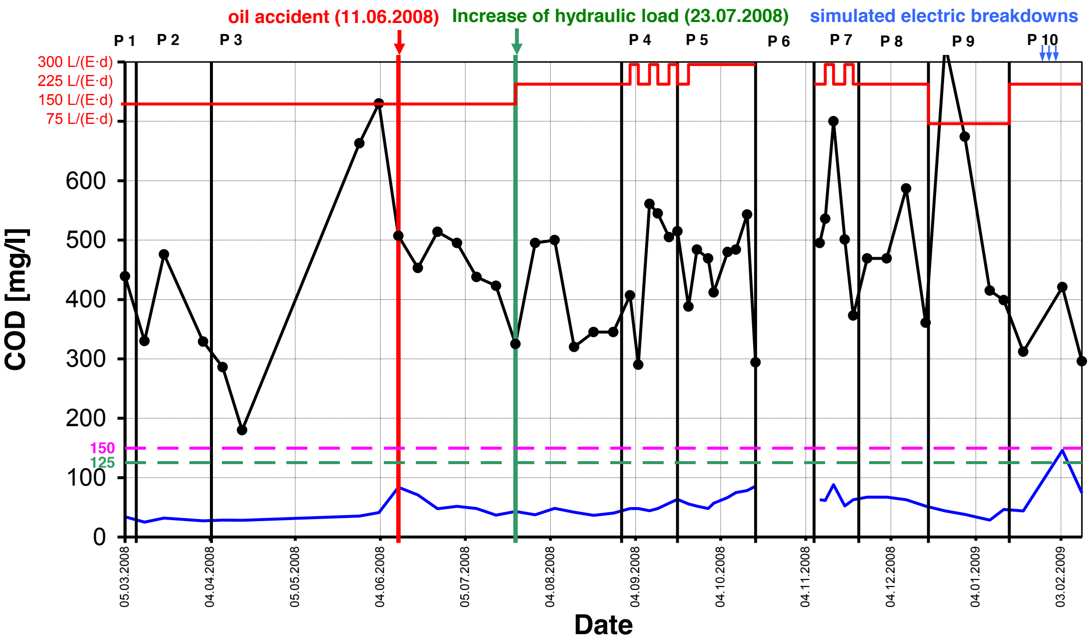

Figure 78: Bergmann BIO-WSB$^{®}$-N – Influent and effluent COD curves

With one exception, effluent COD concentrations remained below 100 mg/L (Figure 78). The oil accident resulted in a slight increase in effluent COD. COD concentrations returned to baseline levels within about 14 days although no countermeasures were taken apart from cleaning of the primary treatment. The increased hydraulic laod conditions in Phase 3 had no measureable effect on COD concentrations. Intermittent 200% hydraulic load increases on 3 days per week as well as the continuous four-week 200% increase in hydraulic load (Phase 5) resulted only in a slight elevation of effluent COD concentration to a maximum of 85 mg/L.

After completion of Phase 6 (3 weeks without any load) no significant increase was observed. Phases 8 and 9 were performed with a lower hydraulic load and resulted on a decrease of effluent COD to a minimum of 28 mg/L, despite higher influent concentrations and lower temperatures of more than 830 mg/L.

The short-term increase in effluent COD levels noticed after the re-start following the simulated electric breakdowns could be due to a temporary increase in persistent substances in the influent, because this phenomenon was observed at the same time in nearly all of the SWWTPs studied. (see 7.2.13).

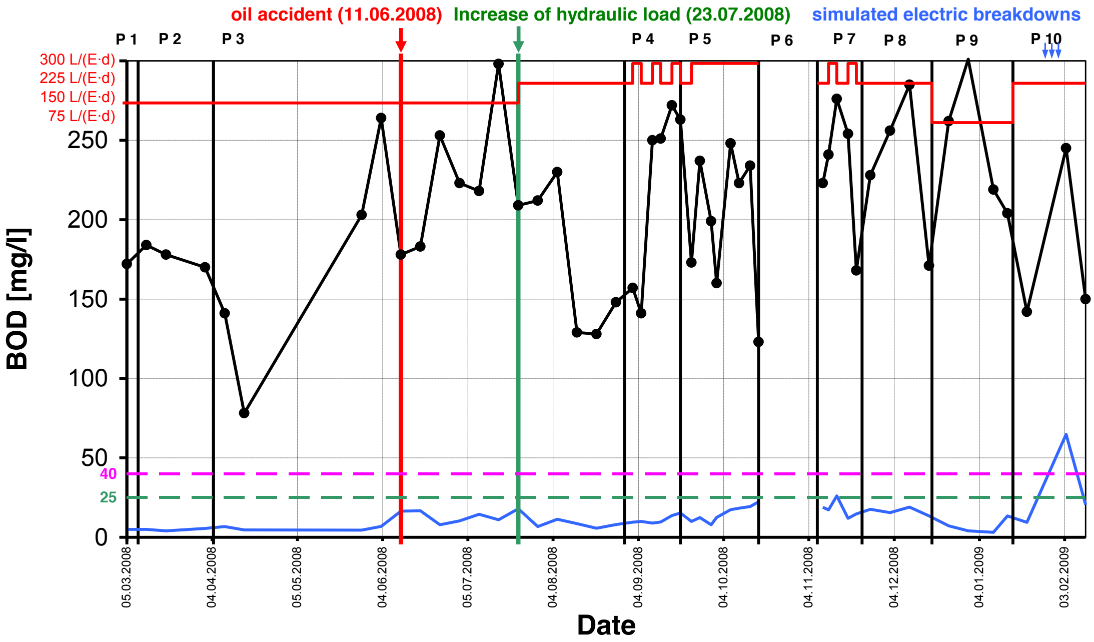

Figure 79: Bergmann BIO-WSB$^{®}$-N – Influent and effluent BOD_5 curves

7.2.5 Nitrogen

<u>Ammonia (NH_4-H)</u>

The course of the NH_4-H curve reflects the course of nitrification (Figure 80). As a biological process very sensitive to changes in process control, nitrification is a useful indicator for changes in wastewater treatment systems.

From 23 July 2008 on, effluent NH_4-H concentrations rose continuously from approx. 3 mg/L to approx. 7 mg/L in response to an increase in hydraulic load from 150 L/(PE·d) to 225 L/(PE·d), although the tempratures were the warmest of the entire test period (a mean 18.4°C during Phase 4). During this time, the system measured oxygen concentrations of 5 to 7 mg O_2/L, which should be sufficient for biological processes. Until the end of Phase 5, the NH_4-H concentrations increased to approx. 35 mg/L. The comparison with the corresponding influent values indicated that no nitrification occurred.

Following the reduction of the hydraulic load from Phase 8 on, the NH_4-H concentrations dropped to a minimum of 1.7 mg/L despite the low wastewater temperatures of far below 12°C (until 5°C).

The simulated electrical breakdowns in Phase 10 induced a sharp rise in effluent NH_4-H concentrations, so that no nitrification occurred afterwards.

The nitrification was interrupted only by the overload of 300 L/d in Phase 5 and in parts also in Phase 7 which is presumably due to the low residence time, but during low temperatures in January the nitrification was not limited.

Also in consequence of the electric breakdowns and probably the missing mixture as a result of the subsequent aeration system malfunction (floatation bed system), no further nitrification occurred.

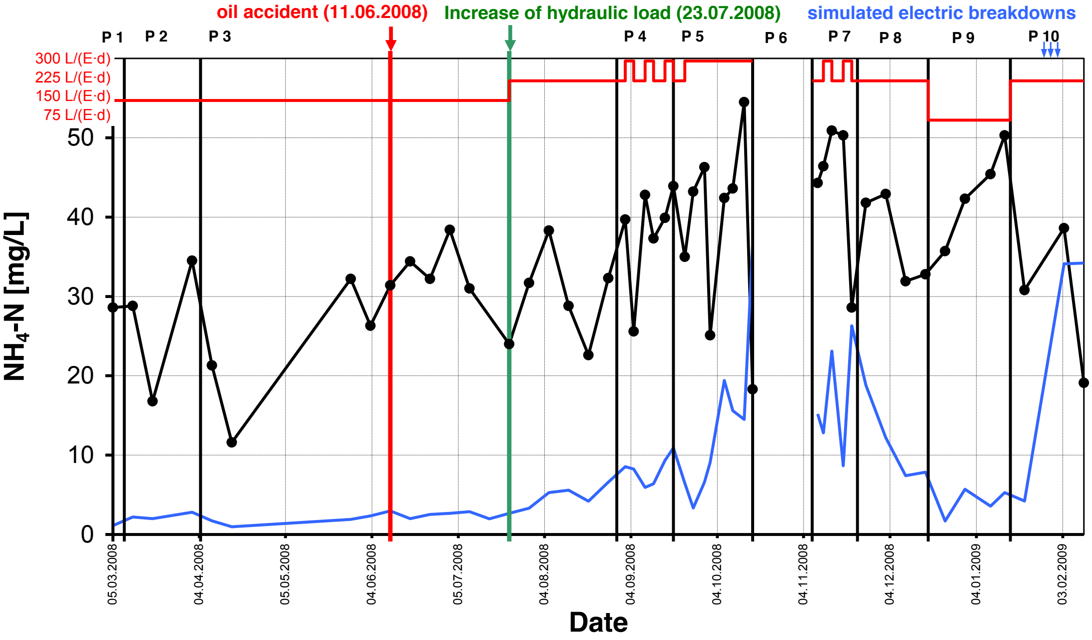

Figure 80: Bergmann BIO-WSB$^{®}$-N – Influent and effluent NH_4-N curves

Inorganic nitrogen

The inorganic nitrogen curve is provided in the Appendix.

In most parts of the test, the effluent concentrations corresponded to the influent concentrations so that no further denitrification was observed.

7.2.6 Suspended solids

The suspended solids concentration (Figure 81) generally remained relatively constant at very low levels less than 25 mg/L. Due to the increase of the hyraulic load in Phases 4, 5 and 7, a slight rise in effluent concentrations occurred. In Phases 8 and 9, the values dropped again to a very low level of below 10 mg/L. During Phase 10, due to the simulated electric breakdowns, the effluent SS concentrations briefly increased again to a maximum of 62 mg/L. This might be attributable to the simulated electric breakdowns (see Chapter 5.1.1) or a persistent substance in the influent, both of which result in biomass death and backflow. This is suspected because similar peaks occurred at almost all of the SWWTPs and is also detectable in the influent COD and BOD_5 concentrations (Figure 78 and Figure 79).

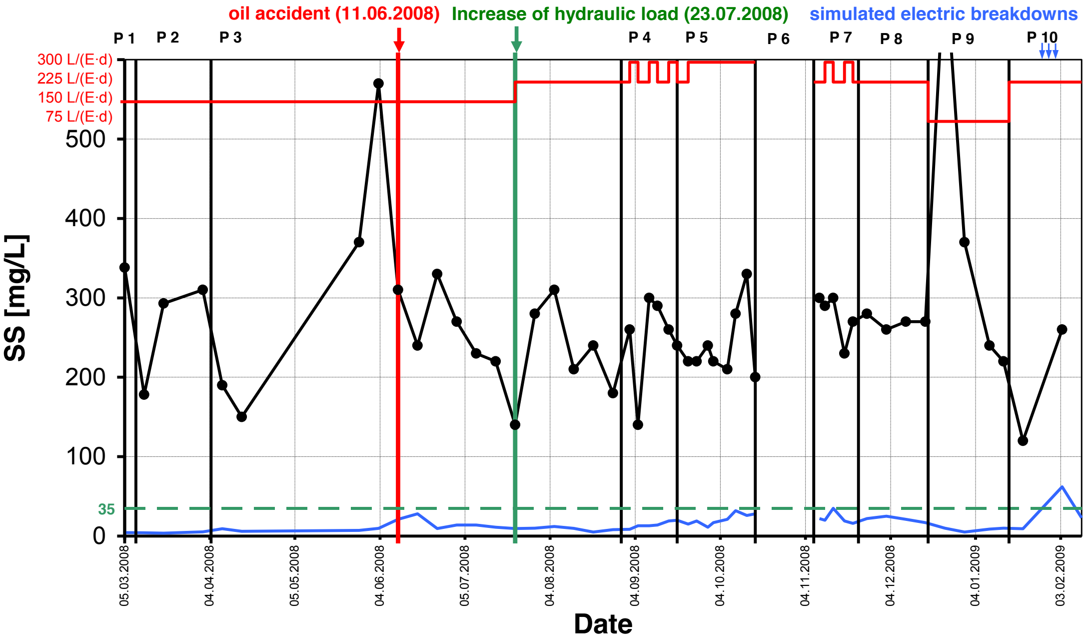

Figure 81: Bergmann BIO-WSB®-N - Influent and effluent SS curve

7.2.7 Phosphorus

With approx. 2 mg/L the phosphorus elimination rate was low and hydraulic load independent during the entire study period. (Figure 82). Effluent phosphorus concentrations ran parallel to the influent concentrations, but generally with a slight time-delay.

Due to the very low level of effluent SS, no direct connection between SS and phosphorus is detectable, although phosphorus is not degraded, but rather bound and removed by the sludge. The effluent phosphorus concentrations therefore depend almost directly from the influent values.

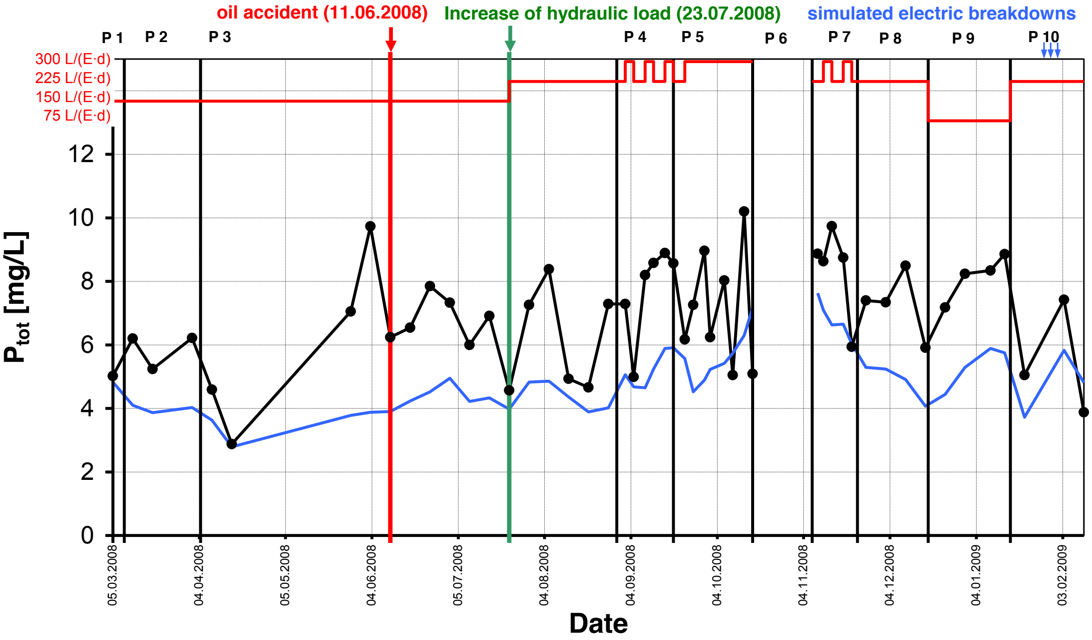

Figure 82: Bergmann BIO-WSB®-N – Influent and effluent P_{tot} curves

7.2.8 Degradation rate

Degradation rates for COD, BOD_5, NH_4-N, N_{tot}, P_{tot} and SS are expressed as percentage values (Table 50, Table 51 and Table 52, see 2.9). Negative values mean that influent concentrations were smaller than effluent concentrations. Potential reasons for this are redissolution, washout and (back) transformation from the biomass. Measurement error is another potential cause, but checks for measurement error were performed in the course of quality assurance. Table 51 contains data from Phases 1, 2 and 3, during which the system was tested at 100% hydraulic load. Table 52 contains data from Phases 4, 5 and 7, during which the system was tested under hydraulic overload conditions.

Phosphorus is not eliminated, but partly is settled in the primary treatment tank as soon as is incorporated in the biomass and so it is returned with excess sludge to the primary treatment tank.

The mean degradation rate was 88% for COD and 94% for BOD_5. Mean elimination rates were 73% for NH_4-N, 14% for N_{tot} and 26% for phosphorus.

Table 50: Bergmann BIO-WSB®-N- Degradation rates (%) for COD, BOD$_5$, NH$_4$-N, N$_{tot}$, SS and P during the complete period

Bergmann, BIO-wsb-N	η_{COD}	η_{BOD}	$\eta_{NH4\text{-}N}$	η_{Ntot}	η_{P}	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	50	50	50	50	50	49
mean	88	94	73	14	26	94
median	88	94	84	17	31	94
min.	65	74	-99	-51	-41	76
max.	95	99	96	53	60	99

Table 51: Bergmann BIO-WSB®-N- Degradation rates (%) for COD, BOD$_5$, NH$_4$-N, N$_{tot}$, SS and P during the 100%-Phases (Phases 1, 2 and 3)

Bergmann, BIO-wsb-N	η_{COD}	η_{BOD}	$\eta_{NH4\text{-}N}$	$\eta_{N\text{-}tot}$	η_{P}	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	20	20	20	20	20	20
mean	90	95	90	-2	30	96
median	90	95	91	2	34	96
min.	83	91	80	-70	3	88
max.	95	98	96	50	60	99

Table 52: Bergmann BIO-WSB®-N- Deagradation rates (%) for COD, BOD$_5$, NH$_4$-N, N$_{tot}$, SS and P during the Overload-Phases (Phases 4, 5 and 7)

Bergmann, BIO-wsb-N	η_{COD}	η_{BOD}	$\eta_{NH4\text{-}N}$	$\eta_{N\text{-}tot}$	η_{P}	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	19	19	19	19	19	19
mean	87	93	61	2	21	92
median	87	93	73	13	31	92
min.	71	82	-99	-107	-41	86
max.	92	96	92	42	45	97

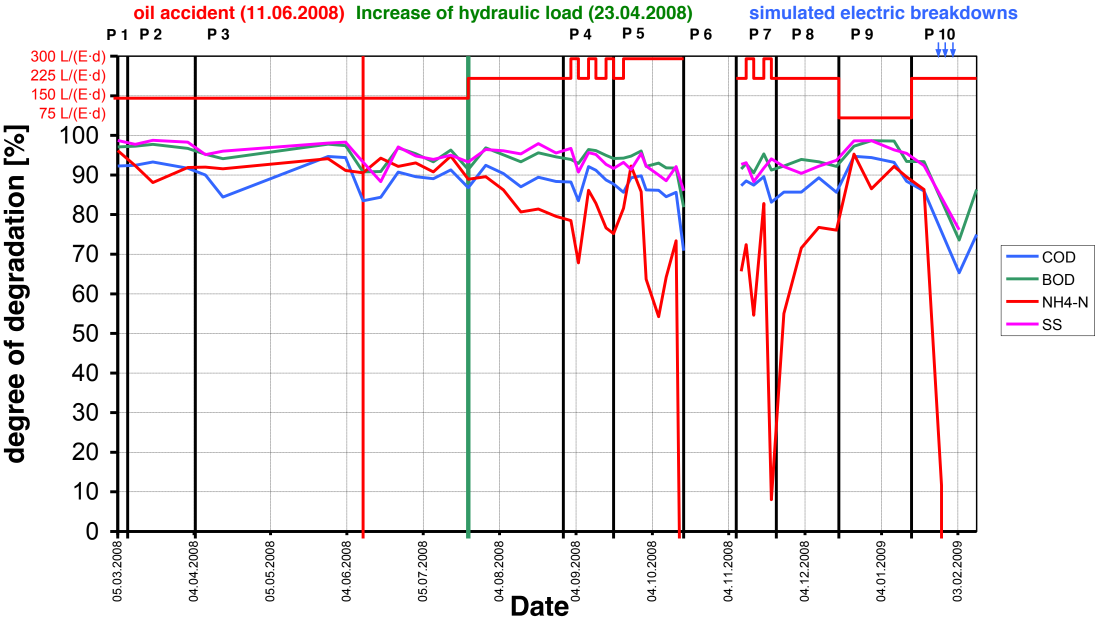

Figure 83: Bergmann BIO-WSB®-N – Degradation curves for COD, BOD_5, NH_4-N, and SS

The COD degradation rate was slightly higher (90%) during nominal load testing than during the entire study period (88%) due to the lower hydraulic load. Degradation rates during the hydraulic overload phases tended to be slightly lower. The lowest efficiency in terms of COD elimination was observed after the simulated electric breakdowns. As shown by the degradation curves (Figure 83), mainly the degradation rate of ammonia dropped after the nominal influent flow rate had been increased from 150 to 225 L(PE d). At the end of Phase 5, it reached a minimum level (similar to COD, BOD_5 and SS). In Phase 7, the degradation rate of ammonia varied between 10% and more than 80%, levelled off at more stable levels of over 90%. Only the simulated electric breakdowns resulted in a sharp decrease of all degredation rates (COD, BOD_5, NH_4-N and SS), NH_4-N even to a negative minimal value.

This excellent purification capacity was achieved although slight floating sludge had appeared during the secondary treatment.

More detailed analyses of effluent values are presented in Section 7.2.4.

7.2.9 Power consumption

Power consumption (Figure 84) was classified according to the population-specific hydraulic load (no load, 75, 150, 225, 225+300 and 300 L/(PE·d); the nominal population equivanlent value corresponded to the authorisation (4 PE).

Mean power consumption values are given in kWh/(PE a) (see 2.3). Since power consumption in Phase 6 (no load) was calculated based on the nominal pollution load (4 PE), the estimated specific power consumption may be lower under other hydrdaulic conditions because the values were calculated as the quotient of measured power consumption and the population equivalent of wastewater flow. At higher loads, the population equivalent is often higher than the nominal population equivalent; consequently, power consumption per inhabitant is lower.

- Compressor (Membrane compressor)
- Submersible motor or elevator (mammoth pump) with magnetic valve for sludge removal

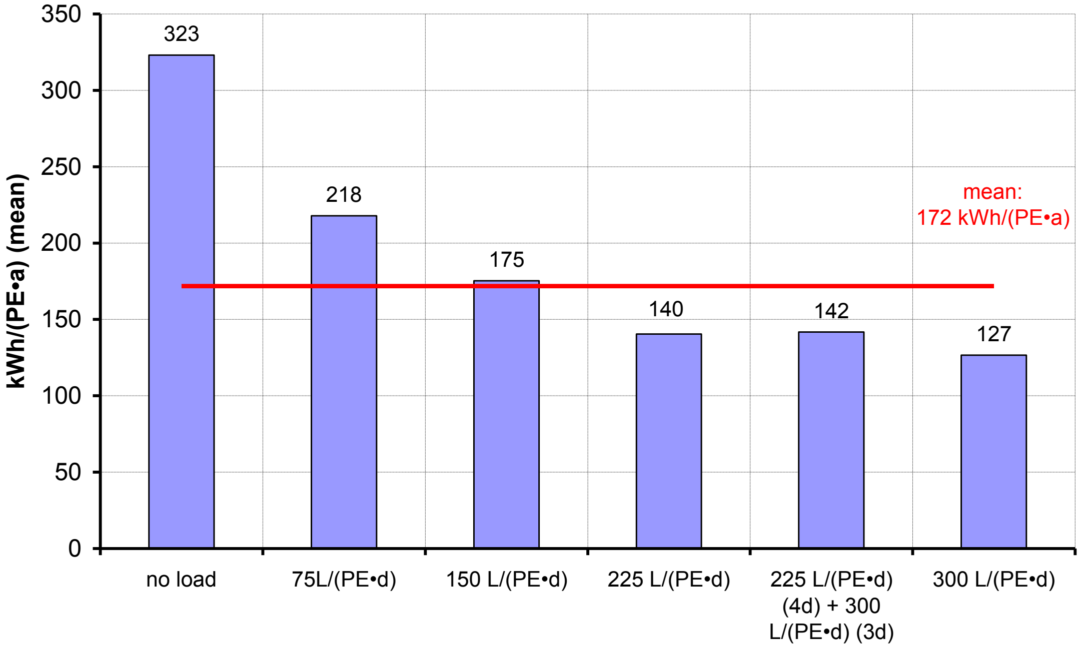

Figure 84: Bergmann BIO-WSB®-N – Power consumption

Total power consumption at the plant during the study period was a mean 125 kWh/(PE·a). Calculated based on the average population equivalent of 3.4 PE (based on BOD_5) (see 2.3), this corresponds to a daily power consumption rate of 1.6 kWh/d.

Population-independent consumption was 3.5 kWh/d, as calculated based on zero load power consumption of 323 kWh/(PE·a) at 4 PE during Phase 6 (no load).

7.2.10 Sludge

The sludge volume was estimated based on the measured sludge height and the known container geometry. As such geometry-dependent estimates are relatively imprecise, their power of evidence is limited.

Overall sludge production during the entire study period was 2.15 m³. At a sludge dry matter content of 19.2 g/L (measured), this corresponds to a sludge mass of 41.23 kg.

The specific sludge volume at the calculated actual load of 3.4 PE is 33.5 g dry matter/E·d.

7.2.11 Operation and maintenance

Figure 85 shows all unusual events occurring over the entire study period while the system was in operation. Hydraulic loads and influent COD concentrations are also shown for better clarity. The diagram shows the course of events over time.

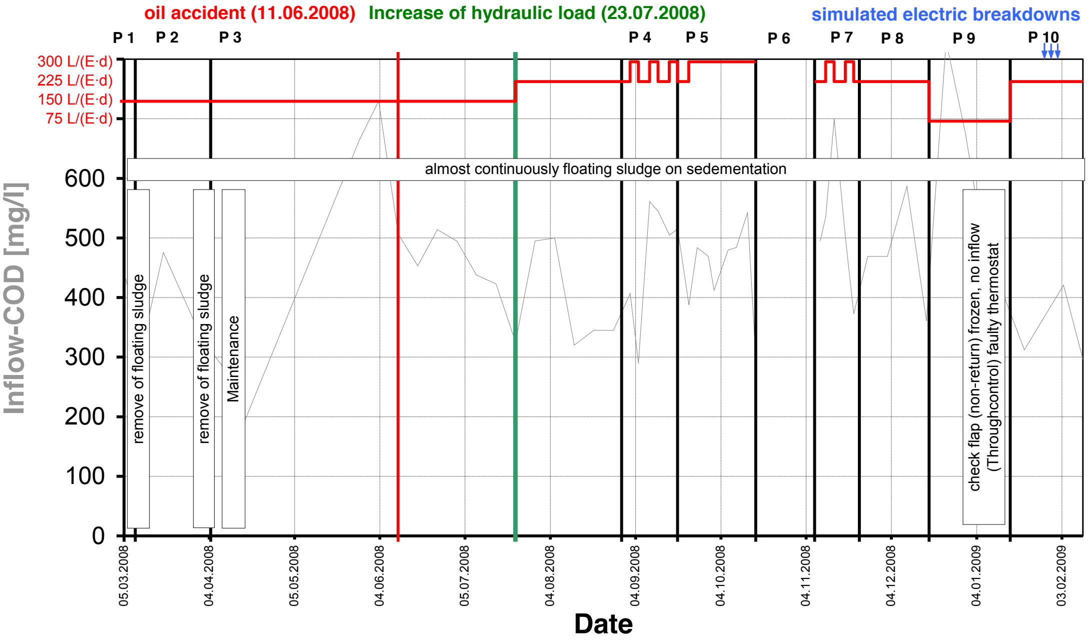

Figure 85: Bergmann BIO-WSB®-N – Maintenance log analysis

During the entire study period, floating sludge occurred almost continuously on the secondary treatment tank. On 12 March and 2 April 2008 the floating sludge was pumped over. The complete system was maintained on 16 April 2008.

From 6 January 2009, 08:00 hrs to 7 January 2009 12:00 hrs no influent took place due to the non-return check flap being frozen. The frozen non-return check flap does not belong to the Bergmann system, but to the test field. For this reason, Bergmann is not responsible for this mistake.

7.2.12 Microbiology

Effluent water samples were collected on three consecutive days and tested for total coliform bacteria, faecal coliform bacteria, intestinal enterococci, salmonella and intestinal nematodes (see 5.4.2). The results of the microbiological analysis are presented in Table 53.

On average of three consecutive days, total coliform bacteria were reduced by 0.2 log steps, faecal coliform bacteria by 0.8 log steps, intestinal enterococci by 1.3 log steps and salmonella by around 1.8 log steps. In intestinal nematodes, there was an avarage reduction of 2 eggs/L. As to total coliform bacteria, a slight increase from the influent to the effluent was observed on 1 December 2008, which might caused by a time lag of influent and effluent at simultaneous sampling.

In reducing of faecal coliform bacteria can usually be expected a degradation of one- to two log steps (see, DWA, 1998), which was almost achieved at this plant with a mean of 0.8-log reduction.

As expected, effluent microbiological quality did not meet bathing water quality standards.

Table 53: Bergmann BIO-WSB®-N – Microbiological analysis

Date		1 Dec 08			2 Dec 08			3 Dec 08			Mean
		[MPN/ mL]	[log]	Δ [log]	[MPN/ mL]	[log]	Δ [log]	[MPN/ mL]	[log]	Δ [log]	Δ [log]
Total coliform bacteria	Influent	930,000	5.97	-0.07	390,000	5.59	0.72	430,000	5.63	1.25	0.2
	Effluent	1,100,000	6.04		75,000	4.88		24,000	4.38		
Faecal coliform bacteria	Influent	150,000	5.18	0.85	240,000	5.38	0.79	73,000	4.86	0.89	0.8
	Effluent	21,000	4.32		39,000	4.59		9,300	3.97		
Intestinal enterococci	Influent	43,000	4.63	1.66	93,000	4.97	1.00	93,000	4.97	2.00	1.3
	Effluent	930	2.97		9,300	3.97		930	2.97		
Salmonella	Influent	2,100	3.32	1.00	750	2.88	0.41	46,000	4.66	2.22	1.8
	Effluent	210	2.32		290	2.46		280	2.45		
		[Eggs/L]		Δ [Eggs]	[Eggs/L]		Δ [Eggs]	[Eggs/L]		Δ [Eggs]	Δ [Eggs]
Intestinal nematodes	Influent	<1		0	13 1)		7	<1		0	2
	Effluent	<1			6 1)			<1			

1) statistical uncertainty in determination of the egg counts

"< 1" is assumed to be zero

7.2.13 Comparison of test results with reports and literature data

Chemical oxygen demand

According to manufacturer's specification (see 4.5.9), the system should achieve effluent COD concentrations of < 75 mg/L in 24-hour composite samples, in accordance with DIBt effluent class N requirements (Table 2). Measured concentrations were below 75 mg/L in 90% of cases. In addition, they were below manufacturer's specification of 75 mg/L in 95% of cases during nominal load phases 1, 2 and 3.

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 65 mg/L in the 100% phase, which is slightly higher than the mean 53 mg/L (100% load) achieved by the BIO-WSB®-N system during the entire period despite stricter test conditions.

Considering that the average effluent COD concentration of systems with moving/fluidized bed filters in practice was determined to be 98 mg/L (STRAUB 2008), the mean 53 mg/L achieved by this system is far below the reference value.

According to FLASCHE 2002, 5 floating bed systems achieved a mean effluent COD concentration of 64.2 mg/L, which is clearly below the mean 53 mg/L achieved by the Bergmann Bio-WSB®-N system.

According to BOLLER 2004, 35 fixed/floating bed systems yielding 62 measurement values achieved a mean effluent COD concentration of 147 mg/L, which is far higher than the mean 53 mg/L achieved by the Bergmann Bio-WSB®-N system.

Biological oxygen demand in five days

According to manufacturer's specification (see 4.5.9), the system should achieve effluent BOD_5 concentrations of < 15 mg/L in 24-hour composite samples, in accordance with DIBt effluent class N requirements (Table 2). Measured concentrations were below 15 mg/L in 68% of cases. In addition, they were below manufacturer's specification of 15 mg/L in 85% of cases during nominal load phases 1, 2 and 3.

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 12 mg/L in the 100% phase, which roughly corresponds to the mean 13 mg/L achieved by the BIO-WSB®-N system during the entire period.

Considering that the average effluent BOD_5 concentration of systems with moving/fluidized bed filters in practice was determined to be 12 mg/L (STRAUB 2008), the mean 13 mg/L are only slightly higher than the reference average.

According to FLASCHE 2002, 5 floating bed systems achieved a mean effluent BOD_5 concentration of 7.2 mg/L, which is clearly below the mean 13 mg/L achieved by the Bergmann Bio-

WSB®-N system. During 100% loading phases this system achieved a mean 9 mg/L which is approximately equal to the 13 mg/L achieved by the SWWTPs studied by FLASCHE 2002

Ammonia (NH_4-N)

According to the manufacturer's specification (see Kap. 4.5.2), the system should achieve effluent NH_4-N concentrations of < 10 mg/L in composite samples, in accordance with DIBt effluent class N requirements (Table 2). Measured concentrations were below 10 mg/L in 74% of cases. In addition, they were below the manufacturer's specification of 10 mg/L in 100% of cases during nominal load phases 1, 2 and 3.

The reference value, calculated as the average of 51 SWWTPs with nitrogen elimination tested at the PIA test facility in Aachen, Germany (DORGELOH 2008) is approximately 5 mg/L in the 100% phase. During this hydraulic load (Phase 1 to 3), the BIO-WSB®-N system achieved values below 5 mg/L (mean 3 mg/L). Only after the hydraulic load increase to 200% and during electric breakdowns, this value was often exceeded.

Considering the average effluent concentration of systems with moving/fluidized bed filtration in practice was determined to be 37 mg/L (STRAUB 2008), the mean 8.8 mg/L are far below this reference average, although also measured values achieved with water temperatures below 12°C were used (see STRAUB 2008).

The 3 floating bed systems tested by FLASCHE 2002 achieved a mean effluent concentration of 10.8 mg/L, which is slightly higher than the overall mean of 8.8 mg/L.

Suspended solids

According to the manufacturer's specification (see Kap. 4.5.9), the system should achieve suspended solids (SS) concentration of < 50 mg/L in random samples, in accordance with DIBt effluent class N requirements (Table 2). Measured concentrations were below 50 mg/L in 98% of cases.

The reference value, calculated as the mean of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 25 mg/L in the 100% phase, which is far higher than the mean 16 mg/L achieved by the BIO-WSB®-N system during the entire period.

Considering the average effluent SS concentration of systems with moving/fluidized bed filtration was determined to be 37 mg/L (STRAUB 2008), the mean 16 mg/L achieved by this system is far below the reference average.

Simulated electric breakdown

The increases in effluent concentrations observed during the simulated electric breakdowns (Figure 78, Figure 79, Figure 80 and Figure 81) may be directly attributable to the electric breakdowns themselves independent of increased influent concentrations or the presence of persistent substances. In a comparison study carried out in Nantes (VIGNOLES, CAUCHI, 2009), similar peaks were observed during simulated electric breakdowns in (almost) all systems independent of whether they required electricity or not. The researchers in Nantes also could not find a plausible explanation for this phenomenon. This issue requires further research.

Power consumption

The power consumption of the investigational system was found to be 172 kWh/(PE·a), which significantly exceeds the manufacturer's specification of 55 kWh/(PE·a).

The reference value of 0.25 kWh/(PE·d), calculated as the average power consumption of 3 activated sludge systems with moving/fluidized bed filtration tested at the PIA test facility Aachen, Germany (DORGELOH 2008), is below the mean 0.47 kWh/(PE·d) achieved by the BIO-WSB®-N system. The consumption of the systems tested at the PIA testfield in Aachen varied from approximately 0.19 kWh/(PE·d) to 0.25 kWh/(PE·d). The power consumption of the investigational system thus considerably exceeded this range.

Sludge

Based on the data in DWA, 2003 a total solids concentration of approximately 70 g/(PE·d) was expected. According to the measurements, the actual load was 33.5g/(PE·d), which is below the expected load. Reasons for this could be that the influent load was lower and/or because the mineralisation rate was increased, i.e. more biomass than ususal was converted and released as CO_2.

Microbiological parameters

The investigestional system achieved effluent faecal coliform bacteria counts from 24.000 to $1.1 \cdot 10^6$ per 100 ml which considerably exceeded the reference average for fluidized bed systems (STRAUB ET AL. 2008), a mean 1.900 per 100 ml with a range (minimum-maximum) of 21 to 6.900 per 100 ml (STRAUB ET AL. 2008). The investigational system had an average log reduction of 0.2 log steps. This is well below the faecal coliforms log reduction of 2.4 log steps by STRAUB ET AL. 2008.

7.2.14 Summary

The investigational system was operated at a load of 3.4 PE over the entire study period. The effluent COD concentrations (mean 53 mg/L) remained below 100 mg/L even at a hydraulic load of 200%, exept for the electric breakdown which produced a peak of 146 mg/L.

Effluent solids concentrations were predominantly less than 35 mg/L (mean 16 mg/L).

On the whole, the cleaning performance of Bergmann BIO-WSB®-N proved to be very stable. No system malfunctions occurred during the study period, exept for the floating sludge which had however, no effect on the treatment performance.

The power consumption was substantially higher than indicated by the manufacturer.

7.3 Klargester – BioDisk BA

7.3.1 Loading conditions

Klargester Environmental installed the BioDisk BA system which has a design capacity of 5 PE, but was tested at a load of 6 PE due to the system group classification used in this study (4 PE, 6 PE and 9 PE). The nominal load was 360 g BOD_5/d. According to authorisation, the system is designed to handle a nominal influent load up to 300 g BOD_5/d.

The nominal hydraulic load was 900 L/d. In addition, the system was tested with 200-litre bathtub discharges 5 times a week, which corresponds to approximately 114 L/d (see 5.1.2). According to the DIBt authorisation, the maximum hydraulic load for this system should, however have not exceeded 750 L/d.

The system was operated under the following influent loadings level:

- Before 23 Jul 2008[*]:	3.6 $PE_{BOD,60}$
- 23 Jul 2008 until before 27 Aug 2008:	4.4 $PE_{BOD,60}$
- Overall average for entire study period:	4.9 $PE_{BOD,60}$

Therefore, the system achieved a 81% capacity relative to influent BOD_5 over the entire study period.

The manufacturer specifies only a maximum volume for both the pretreatment and secondary treatment tank. The corresponding residence times were therefore 2.1 days for the pretreatment tank, 0.3 days for the secondary treatment tank and a residence time of 2.4 days for the entire system, without considering the volume of the bioreactor (see 2.6).

Due to a broken magnetic valve and the connected temporary overload (see 7.3.11), one measured value obtained after Phase 6 (14.11.2008) was not included into the analysis. The faulty valve was not part of the system but belonged to the test facility. Therefore Klargester was not responsible for this malfunction.

7.3.2 Statistical overview of results

Table 54 und Table 55 show the results of the statistical analysis for the entire study period, including the number of samples, the mean, median, minimum (min) and maximum (max) values, the statutory limits in France (FR and Germany (DE) (see 2.2.1.1 and 2.2.1.2) and the rates of compliance of effluent COD, BOD_5, SS, NH_4-N, N_{tot} and P_{tot} with the statutory limits (*stay below probability*). Mean, median, minimum and maximum values as well as the statutory limits in France (FR) and Germany (DE) are expressed in mg/L. The number of samples is a dimensionless parameter. The stay probability is given in percent (%).

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[*] See Chapter 5.1.2: Due to the low influent concentrations, testing under increased hydraulic load conditions (150%) was discontinued in order to increase the influent load.

Table 54: Klargester BioDisk BA – Statistical analysis of COD, BOD_5 and SS

Klargester Bio-Disc BA	COD		BOD			SS	
	In	Out	In	Load (real)*	Out	In	Out
	[mg/l]	[mg/l]	[mg/l]	[E]	[mg/l]	[mg/l]	[mg/l]
Number of samples	50	48	50	50	48	49	48
mean	456	78	207	4,9	19	269,0	21
median	469	77	215	4,4	19	260,0	20
min.	180	38	78	1,5	4	120,0	6
max.	830	153	301	8,3	64	730,0	52
legally binding value (DE / FR)		**150 / 125**			**40 / 25**		**-- / 35**
stay below of legally binding value (DE)		98%			96%		
stay below of legally binding value (FR)		94%			83%		88%

* Load (real) see 2.3

Table 55: Klargester BioDisk BA – Statistical analysis of nitrogen and phosphorus

Klargester Bio-Disc BA	NH_4-N		N_{tot}		P_{tot}	
	In	Out	In	Out	In	Out
	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]
Number of samples	50	48	50	48	50	48
mean	35,1	15,9	47,4	34,6	7,0	5,0
median	34,8	15,6	46,5	34,9	7,3	5,0
min.	11,6	< 0,3	19,8	10,9	2,9	2,7
max.	54,5	39,2	71,6	51,3	10,2	7,1
legally binding value (DE / FR)		**-- / --**		**-- / --**		**-- / --**
stay below of legally binding value (DE)						
stay below of legally binding value (FR)						

Chemical oxygen demand (COD)

The system achieved a mean effluent COD of 78 mg/L over the entire study period; the maximum concentration was 153 mg/L. Measured COD levels were below the German statutory limit of 150 mg/L in 98% of cases (see 2.2.1.1) and were below the French statutory limits of 125 mg/L in 94% of cases (see 2.2.1.2). In other words, the measured levels exceeded the German limit in 1 case and exceeded the French limit in 5 cases (see 7.3.4). The system met the statutory effluent requirements for Germany and France in the vast majority of cases.

Biological oxygen demand (BOD_5)

The system achieved a mean effluent BOD_5 of 19 mg/L over the entire study period; the maximum concentration was 64 mg/L. Measured BOD_5 levels were below the German statutory limit of 40 mg/L in 96% of cases and were below the French statutory limits of 25 mg/L in 83% of cases. In other words, the measured levels exceeded the German limit in 2 cases and exceeded the French limit in 8 cases (see 7.3.4). The system met the statutory effluent requirements for Germany and France in the vast majority of cases.

Suspended solids (SS)

The system achieved a mean effluent SS of 21 mg/L over the entire study period; the maximum concentration was 52 mg/L. Measured SS levels were below the French statutory limits of 35 mg/L in 88% of cases. In other words, the measured levels the French limit in 6 cases (see 7.2.6). The system met the statutory effluent requirements for Germany and France in most of cases. There are no statutory limits for effluent SS concentration in Germany.

Nitrogen

- **Ammonia (NH_4-N):**
  The system achieved a mean effluent NH_4-N concentration of 15.9 mg/L over the entire study period; the maximum concentration was 39.2 mg/L (see 7.3.5).
- **Total nitrogen (N_{tot})**:
  The system achieved a mean effluent N_{tot} concentration of 34.6 mg/L over the entire study period; the maximum concentration was 51.3 mg/L (see 7.3.5).

Total phosphorus

The system achieved a mean effluent P_{tot} concentration of 5.0 mg/L over the entire study period; the maximum concentration was 7.1 mg/L (see 7.3.7).

7.3.3 Operational and process stability

Process stability was described in terms of compliance with statutory limits for target parameters (stay below probability) (Figure 86). The steeper the curve, the more stably the system is operating. A stable system maintains steady effluent concentrations in spite of changes in influent concentrations, temperatures etc. (see 2.10.9).

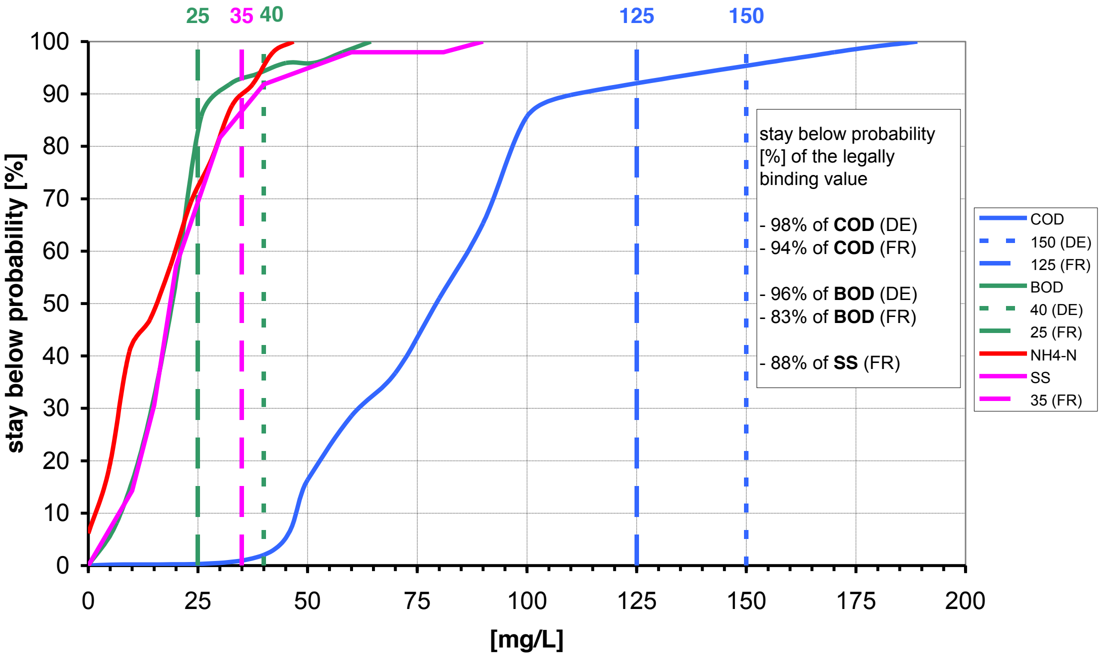

Figure 86: Klargester BioDisk BA – Stay below probability for COD, BOD_5, NH_4-N and SS

7.3.4 COD and BOD_5 elimination

The combined parameters for organic matter were analysed based on the COD curve over the entire study period. The horizontal lines (Figure 87) at 150 mg/L (125 mg/L) represent the German and French statutory limits. Due to a broken magnetic valve, one measured value in Phase 7 was deleted (see 7.3.11). The faulty valve was not part of the BioDisk BA system, but belonged to the test facility. Klargester is therefore not responsible for this malfunction.

The BOD_5 curve shown in Figure 88 is similar to the COD curve- The mean COD/ BOD_5 ratio is 4.1 to 1.

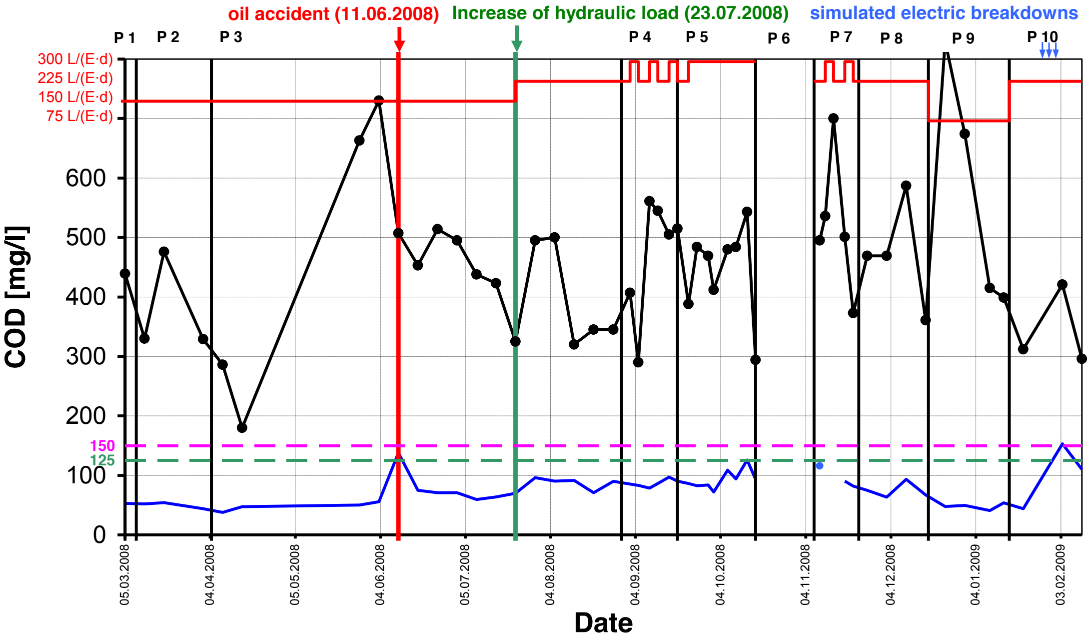

Figure 87: Klargester BioDisk BA – Influent and effluent COD curves

Until 23 Jul 2008, effluent COD concentrations remained mostly below 100 mg/L with few exceptions (Figure 87) and in Phase 9 even at approx. 50 mg/L. The oil accident produced a sharp increase in effluent COD levels. COD concentrations returned to baseline levels within 7 to 8 days, although no countermeasures were taken apart from cleaning of the primary treatment. The increased hydraulic load during Phase 3 only led to a slight reduction of effluent concentrations. Intermittent 200% hydraulic load increases on 3 days per week did not result in any elevation of effluent COD levels, although the first biological stage was partially submerged. However, the continuous four-week 200% increase in hydraulic load (Phase 5) caused a two-fold increase in effluent COD concentrations, which still remained below the 125 mg/L level.

After completion of Phase 6 (3 weeks without any load), no elevated effluent COD levels were observed. The decrease in hydraulic load to 75 L/(PE·d) led to a simultaneous reduction of effluent COD concentrations to approx. 50 mg/L.

The short-term increase in effluent COD levels observed after the re-start following the simulated electric breakdowns could be due to a temporary increase in persistent substances in the influent, because this phenomenon was observed at the same time in nearly all of the SWWTPs studied (see 7.3.13).

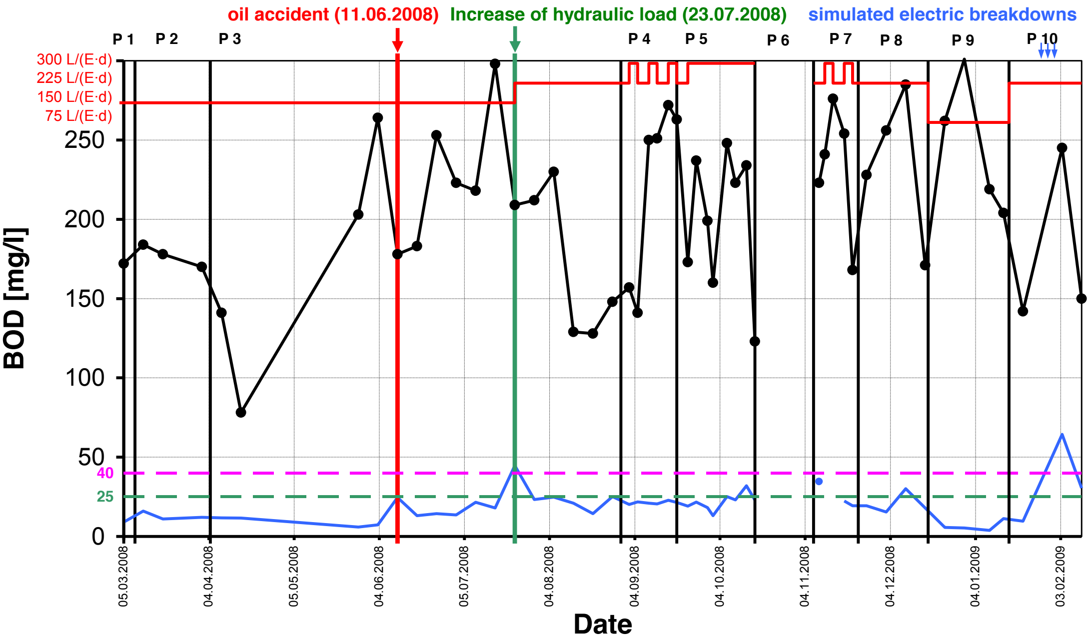

Figure 88: Klargester BioDisk BA – Influent and effluent BOD_5 curves

7.3.5 Nitrogen

Ammonia (NH_4-N)

The course of the ammonia curve reflects the course of nitrification (Figure 89). As a biological process very sensitive to changes in process control, nitrification is a useful indicator of changes in wastewater treatment.

Until Phase 3, almost complete nitrification was observed. In the course of Phase 3, the effluent NH_4-N concentrations continuously increased from 0 to 2 mg/L. From 23 July 2008 on, the effluent NH_4-N concentrations still slightly rose in response to an increase in hydraulic load from 150 L/(PE·d) to 225 L/(PE·d). A short drop was observed before Phase 4 which exactly coincides with the decrease in effluent concentrations. During phases 4 and 5, the effluent NH_4-N concentration ranged between 10 and 30 mg/L, which indicate that the nitrification process was considerably inhibited. The effluent concentrations increased although the temperatures were the highest measured during the entire study period (mean 17.4°C for Phase 4) and dropped only at the end of Phase 5 to almost 12°C.

Along with the decrease in hydraulic load from phases 7 to 9, the effluent NH_4-N concentrations fell sharply and appreciable nitrification was achieved again (NH_4-N = 10 mg/L) in spite of the minimum wastewater temperatures of 4.4 °C.

The simulated electric breakdowns severely affected nitrification and the effluent concentrations reached the influent level and above.

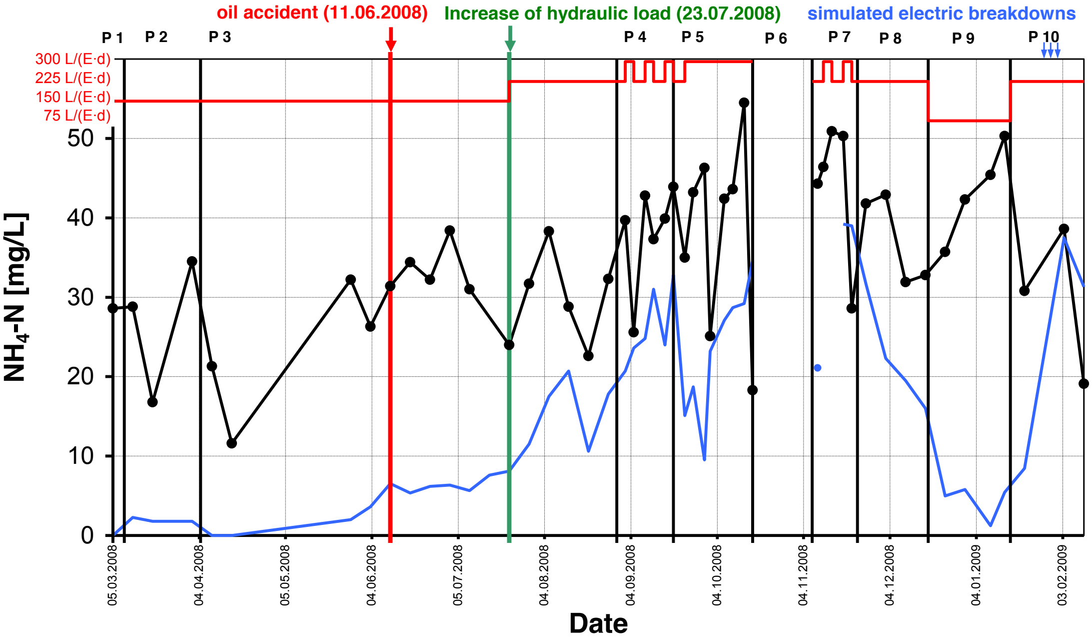

Figure 89: Klargester BioDisk BA – Influent and effluent NH_4-N curves

Inorganic nitrogen

The inorganic nitrogen curve is provided in the Appendix.

Inorganic nitrogen concentrations ran parallel with about 5 mg/L below the influent concentratio, i.e. a slightly denitrification of 30% to 50% took place. Only from Phase 4 on, no further denitrification occurred with no changes up to the end of the study.

7.3.6 Suspended solids

The suspended solids concentration generally remained relatively constant at very low levels less than 35 mg/L (Figure 90). In Phase 5 (300 L/(E·d)), there were two peaks of up to 50 mg/L. The probable reason for the sludge escape (see Figure 90) is the exceeding of the permissible surface load of the secondary treatment tank, which is indicated to be at 0.075 m/h by the manufacturer. During the hydraulic load of 200%, the surface load performed was at 0.257 m/h relative to Q_d/10 (according to authorisation criteria of DIBt) and considering the bathtub discharge even at 0,28 m/h.

After the resting phase (Phase 6), the maximum concentration of 36 mg/L normalised within about 7 days to a level of below 35 mg/L.

During Phase 9, concentrations dropped to the lowest value of below 6 mg/L, which can be explained by the small hydraulic load.

Concentrations briefly exceeded the statutory limit of 35 mg/L again during Phase 10. this may have been caused by the simulated electric breakdowns (see 5.1.1) or a persistent substance both of which result in biomass death and backflow. This is suspected because similar peaks occurred in almost all of the SWWTPs and is also detectable in the influent COD and BOD_5 concentrations (Figure 87 and Figure 88).

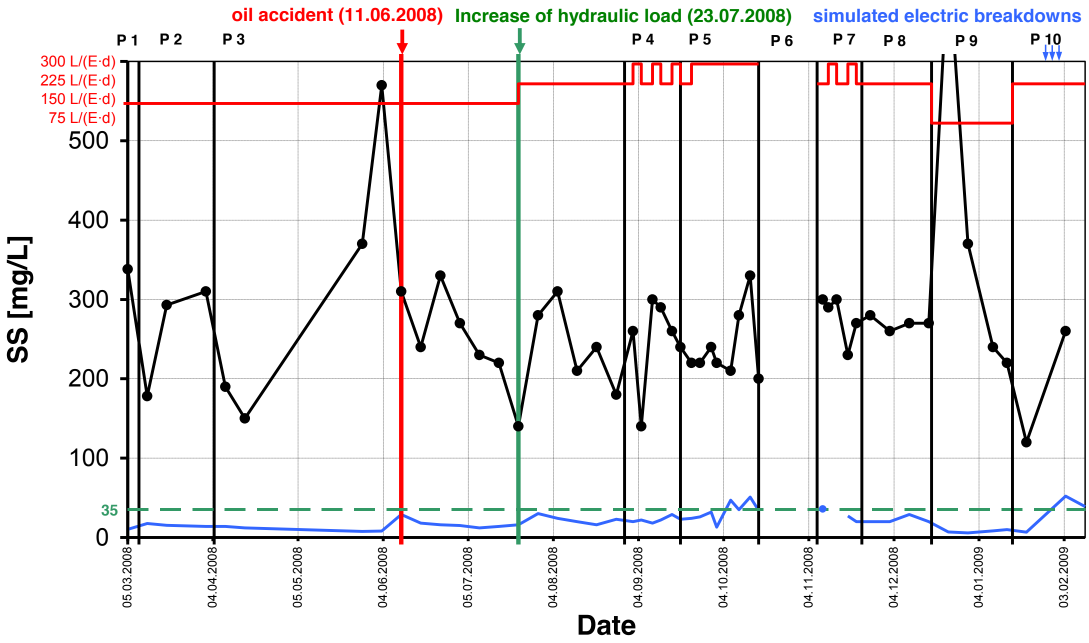

Figure 90: Klargester BioDisk BA – Influent and effluent SS curves

7.3.7 Phosphorus

During the entire study period, the phosphorus elimination was low and hydraulic load independent (Figure 91). Effluent phosphorus concentrations ran parallel to the influent concentration, but generally with a slight time delay.

Due to the very poor effluent SS concentration (see Figure 90), no direct connection between suspended solids and phosphorus was detectable, although phosphorus is not degraded but rather bound and removed by sludge. The effluent phosphorus concentration only depends on the influent concentrations.

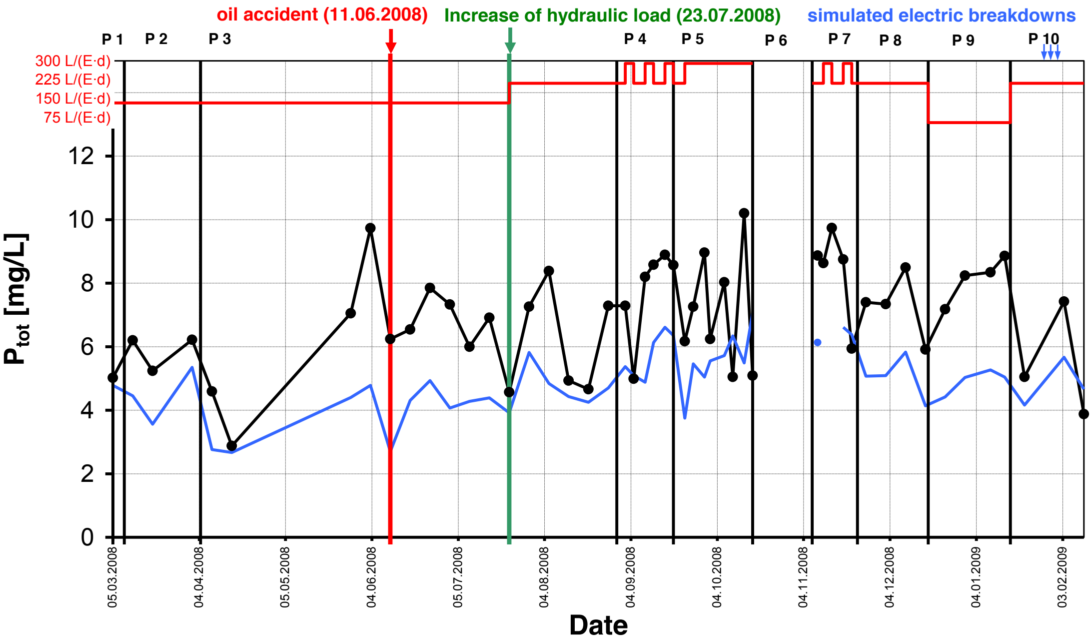

Figure 91: Klargester BioDisk BA – Influent and effluent P_{tot} curves

7.3.8 Degradation rate

Degradation rates for COD, BOD_5, NH_4-N, N_{tot}, P_{tot} and SS are expressed in percentage values (Table 56, Table 57 und Table 58, see 2.9) Negative values mean that influent concentrations are smaller than effluent concentrations. Potential reasons for this are redissolution, washout and (back) transformation from the biomass. Measurement error is another potential cause, but checks for measurement errors were performed in the course of quality assurance. Table 57 contains data from phases 1, 2 and 3, during which the system was tested at 100% hydraulic load. Table 58 contains data from phases 4, 5 and 7, during which the system was tested under hydraulic overload conditions. .

Phosphorus is not eliminated. Instead, it settles in the primary treatment tank or is incorporated in the biomass and is returned with excess sludge to the primary treatment tank.

The mean degradation rate was 82% for COD and 90% for BOD_5. Mean elimination rates were 53% for NH_4-N, 24% for N_{tot} and 25% for P_{tot}.

Table 56: Klargester - BioDisk BA – Degradation rates (%) for COD, BOD_5, NH_4-N, N_{tot}, SS and P during the complete period

Klargester Bio-Disc BA	η_{COD}	η_{BOD}	η_{NH4-N}	η_{tot}	η_{P}	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	48	48	48	48	48	47
mean	82	90	53	24	25	91
median	82	91	56	25	29	92
min.	63	74	-89	-74	-39	78
max.	94	98	100	65	57	99

Table 57: Klargester - BioDisk BA – Degradation rates (%) for COD, BOD_5, NH_4-N, N_{tot}, SS and P during the 100% phases (Phases 1, 2 and 3)

Klargester Bio-Disc BA	η_{COD}	η_{BOD}	η_{NH4-N}	η_{N-tot}	η_{P}	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	20	20	20	20	20	20
mean	83	90	78	27	29	93
median	85	92	83	32	33	93
min.	71	79	28	-7	5	87
max.	92	97	100	66	57	99

Table 58: Klargester - BioDisk BA- Degradation rates (%) for COD, BOD_5, NH_4-N, N_{tot}, SS and P during the overload phases (Phases 4, 5 and 7)

Klargester Bio-Disc BA	η_{COD}	η_{BOD}	η_{NH4-N}	η_{N-tot}	η_{P}	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	17	17	17	17	17	17
mean	79	89	26	-4	19	88
median	81	90	36	9	26	88
min.	68	81	-89	-153	-39	78
max.	86	92	79	40	46	94

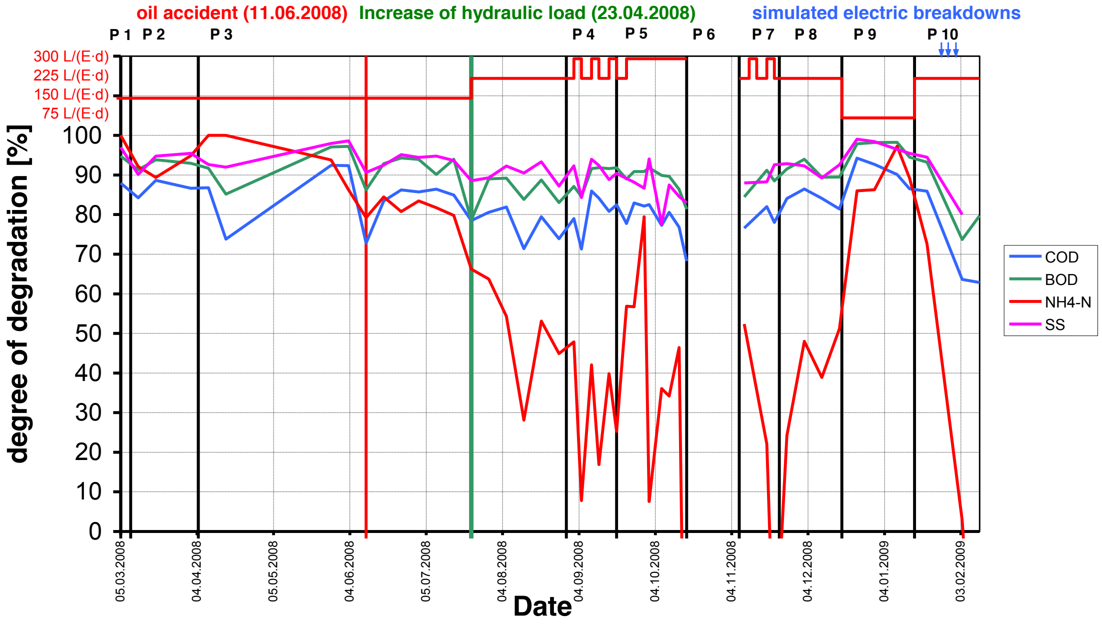

Figure 92: Klargester BioDisk BA – Degradation curves for COD, BOD_5, NH_4-N, SS

The COD degradation rate was slightly higher (83%) during nominal load testing than during the entire study period (82%). Degradation rates during the hydraulic overload phases tended to be lower. The lowest degradation rate in terms of COD elimination was observed after the simulated electric breakdowns. The degradation curves show a decline in the degradation of NH_4-N during Phase 3. Only during Phase 9, the NH_4-N degradation rate increased to above 95 % and tumbled again after the simulated electric breakdowns.

More detailed analyses of effluent values are presented in Section 7.3.4.

7.3.9 Power consumption

Power consumption (Figure 93) was classified according to the population-specific hydraulic load (no load, 75, 150, 225, 225+300, 300 L/(PE·d)); the load corresponded to the nominal population equivalent value (6 PE, see 7.3.1).

Mean power consumption values are given in kWh/(PE·a) (see 2.3). Since power consumption in Phase 6 (no load) was calculated based on the nominal pollution load (6 PE), the estimated specific power consumption may be lower under other hydraulic conditions because the values were calculated as the quotient of measured power consumption and the population equivalent of wastewater flow. At higher loads, the population equivalent is often higher than the nominal population equivalent; consequently, power consumption per inhabitant is lower.

Power consumption was measured as the total power consumed by the system. The following power consumers were included in the calculation:

- Sludge pump
- Geared motor

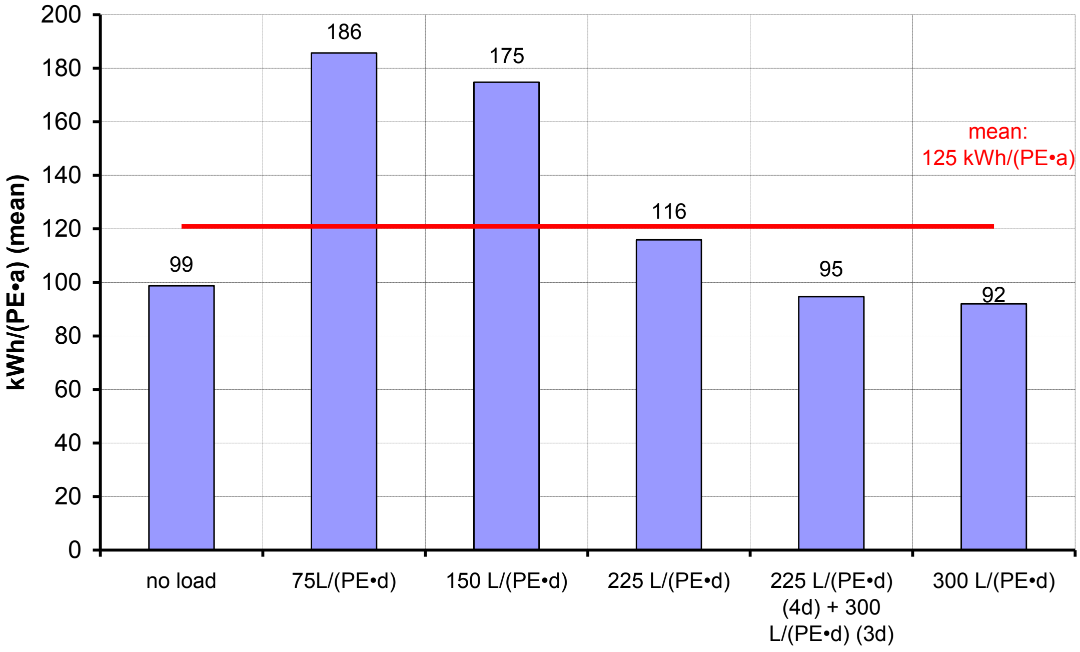

Figure 93: Klargester BioDisk BA – Power consumption

Total power consumption at the plant during the entire study period was a mean 125 kWh/(PE·a). Calculated based on the average population equivalent of 4.8 PE (based on BOD_5 (see 2.3); this corresponds to a daily power consumption of 1.6 kWh/d.

Population-independent consumption was 1.6 kWh/d, as calculated based on zero load power consumption (99 kWh/(PE·a) at 6 PE during Phase 6 (no load)

7.3.10 Sludge

The sludge volume was estimated based on the measured sludge height and the known container geometry. As such geometry-dependent estimates are relatively imprecise, their power of evidence is limited.

Overall sludge production during the entire study period was 0.89 m³. At a sludge dry matter content of 42.5 g/L (measured), this corresponds to a sludge mass of 37.8 kg.

The specific sludge volume at the calculated actual load of 4.8 PE is 21.7 gTS/E·d.

7.3.11 Operation and maintenance

Figure 94 shows all unusual events occurring over the entire study period while the system was in operation. Hydraulic loads and influent COD concentrations are also shown for better clarity. The diagram shows the course of events over time.

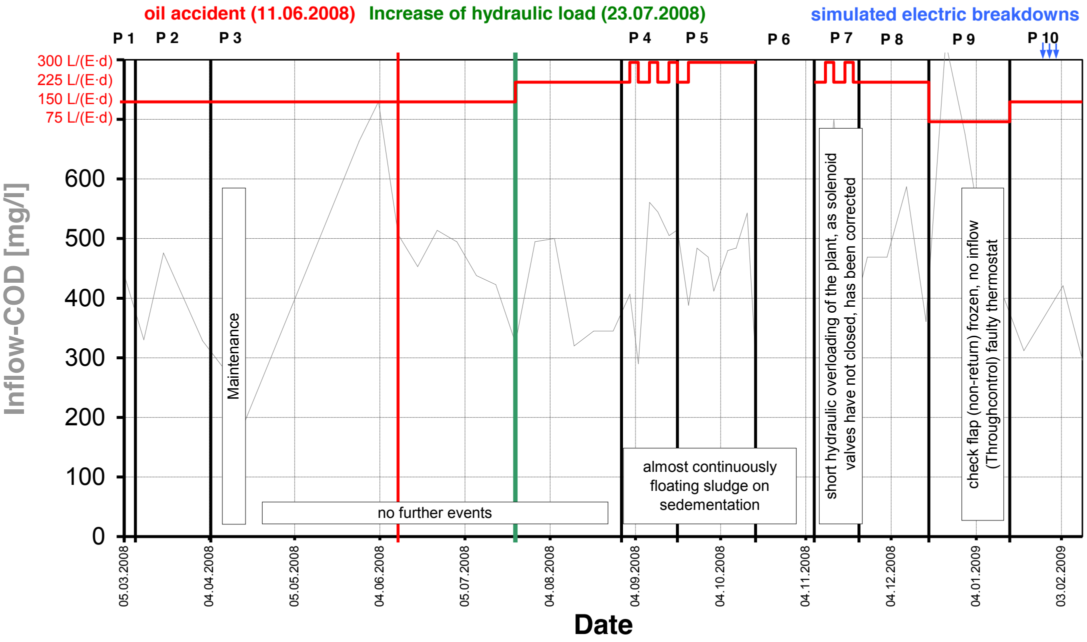

Figure 94: Klargester BioDisk BA – Maintenance log analysis

On 29 Jan (is not present on Figure 94), on 15 Apr and on 9 Oct 2008, half-hour maintenances were carried out.

From 28 Aug to 29 October 2008: almost continuously slight floating sludge on sedimentation.

On 10 Nov 2008 a brief hydraulic overload occurred, because some magnetic valves did not close. The magnetic valve was not part of the BioDisk BA system, so that Klargester was not responsible for this malfunction. The valve defect was repaired. Related measured values were not considered.

From 06 Jan 2009 08:00 hrs to 07 Jan 2009 12:00 hrs influent was obstructed due to a frozen non-return check flap. The valve was not part of the Klargester BioDisk BA system, but belonged to the test facility. Klargester was therefore not responsible for this malfunction.

7.3.12 Microbiology

Effluent water samples were collected on three consecutive days and tested for total coliform bacteria, faecal coliform bacteria, intestinal enterococci, salmonella and intestinal nematodes (see 5.4.2). The results of the microbiological analysis are presented in Table 59.

On average of three consecutive days, total coliform bacteria were reduced by 1.1 log steps, faecal coliform bacteria by 0.8 log steps, intestinal enterococci by 1.7 log steps and salmonella by around 1.5 log steps. In intestinal nematodes, there was an avarage increase of 6 eggs/L, although this may be explained by statistical uncertainty in the determination of the number. In addition, the simultaneous sampling in the influent and effluent did not consider the time lag during the system passage

It can generally be assumed that the number of faecal coliform bacteria undergoes a one- to two-log reduction per treatment stage (compare DWA, 1998). This was almost achieved by this plant with a mean of 0.8-log reduction.

As expected, effluent microbiological quality did not meet bathing water quality standard.

Table 59: Klargester - BioDisk BA – Microbiological analysis

Date		1 Dec 08			2 Dec 08			3 Dec 08			Mean
		[MPN/ mL]	[log]	Δ [log]	[MPN/ mL]	[log]	Δ [log]	[MPN/ mL]	[log]	Δ [log]	Δ [log]
Total coliform bacteria	Influent	930,000	5.97	1.67	390,000	5.59	1.41	430,000	5.63	0.66	1.1
	Effluent	20,000	4.30		15,000	4.18		93,000	4.97		
Faecal coliform bacteria	Influent	150,000	5.18	1.00	240,000	5.38	1.41	73,000	4.86	0.23	0.8
	Effluent	15,000	4.18		9,300	3.97		43,000	4.63		
Intestinal enterococci	Influent	43,000	4.63	1.31	93,000	4.97	1.59	93,000	4.97	2.34	1.7
	Effluent	2,100	3.32		2,400	3.38		430	2.63		
Salmonella	Influent	2,100	3.32	0.28	750	2.88	0.24	46,000	4.66	2.79	1.5
	Effluent	1,100	3.04		430	2.63		74	1.87		
		[Eggs/L]		Δ [Eggs]	[Eggs/L]		Δ [Eggs]	[Eggs/L]		Δ [Eggs]	Δ [Eggs]
Intestinal nematodes	Influent	<1		-9	13[1)]		-7	<1		-1	-6
	Effluent	9			20			1			

1) statistical uncertainty in determination of the egg counts

"< 1" is assumed to be zero

7.3.13 Comparison of test results with reports and literature data

Chemical oxygen demand

According to the manufacturer's specification (see 4.6.8), the system should achieve effluent COD concentrations of < 110 mg/L in 24-hour composite samples (in accordance with DIBt requirements specified in Table 2 up to 100 mg/L at the most in a 24-hour composite sample). Measured concentrations were below 110 mg/L in 90% of cases and below 100 mg/L in 88% of cases. In addition, they were below the manufacturer's specification of 110 mg/L as well as below 100 mg/L (see above) in 95% of cases during the nominal load phases 1, 2 and 3.

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008) is approx. 65 mg/L in the 100% phase, which is only slightly below the mean 78 mg/L achieved by the BioDisk BA system (despite stricter test conditions).

Considering that the average effluent concentration of rotary filter systems in practise was determined to be 144 mg/L (STRAUB 2008), the mean 78 mg/L achieved by the BioDisk BA system is much lower than the reference average.

In a test series performed in *Dorf Mecklenburg*, Germany (JIROUDI 2005), the rotary filter system used there (4 PE, 26 measurements) achieved a mean effluent COD concentration of 96 mg/L, which is higher than that achieved by the investigational system. In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 1.087 mg/L (223 mg/L - 2.128 mg/L, 135 measurements).

Biological oxygem demand

According to the manufacturer's specification (see 4.6.8), the system should achieve effluent BOD_5 concentrations of < 25 mg/L in one composite sample (in accordance with DIBt requirements specified in Table 2). Measured concentrations were below 25 mg/L in 83% of cases. In addition, they were below the manufacturer's specification of 25 mg/L in 90% of cases during the nominal load phases 1, 2 and 3.

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008) is approx. 12 mg/L in the 100% phase, which is roughly comparable to the mean 19 mg/L achieved by the BioDisk BA system during the entire study period.

Considering that the average effluent concentration of rotary filter systems in practise was determined to be 23 mg/L (STRAUB 2008), the mean 19 mg/L achieved by the BioDisk BA system is slightly lower than the reference average.

Ammonia (NH_4-N)

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008) is approx. 5 mg/L in the 100% phase. The BioDisk BA system achieved a mean effluent of 15.9 mg/L during the entire study period which is thus far above the reference average. On the other hand, during the nominal load phases 1, 2 and 3, the effluent NH_4-N concentrations were 7 mg/L, which is comparable to the reference average achieved at the PIA test facility in Aachen.

Considering that the average effluentNH_4-N concentration of rotary filter systems in practise was determined to be 24 mg/L (STRAUB 2008), the mean 15.9 mg/L achieved by the BioDisk

BA system is below the reference average, although values measured during water temperatures of below 12°C were used (cf. STRAUB 2008).

In a test series performed in *Dorf Mecklenburg*, Germany (JIROUDI 2005), the rotary filter system used there (4 PE, 20 measurements) achieved a mean effluent NH_4-N concentration of 10 mg/L, which is clearly lower than mean 15.9 mg/L achieved by the BioDisk BA system during the entire study period, but slightly more than the measured 7 mg/L of the 100% phase. In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 72 mg/L (24 mg/L - 114 mg/L, 137 measurements).

Suspended solids

According to the manufacturer's specification (see 4.6.8), the system should achieve effluent SS concentrations of < 30 mg/L in 24-hour composite samples (in accordance with DIBt requirements specified in Table 2 up to 75 mg/L at the most in a qualified sample). Measured concentrations were below 30 mg/L in 81% of cases and below 75 mg/L in 100% of cases. In addition, they were below the manufacturer's specification of 30 mg/L in 95% of cases and below 75 mg/L in 100% of cases during the nominal load phases 1, 2 and 3.

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008) is approx. 25 mg/L in the 100% phase, which is comparable to the mean 21 mg/L achieved by the BioDisk BA system during the entire study period.

Considering that the average effluent concentration of rotary filter systems in practise was determined to be 29 mg/L (STRAUB 2008), the mean 21 mg/L achieved by the BioDisk BA system is lower than the reference average.

In a test series performed in *Dorf Mecklenburg*, Germany (JIROUDI 2005), the rotary filter system used there (4 PE, 10 measurements) achieved a mean effluent SS concentration of 25 mg/L, which is roughly comparable to the mean 21 mg/L achieved by the BioDisk BA system during the entire study period.

Simulated electric breakdowns

The increase in effluent concentrations observed during the simulated electric breakdowns (Figure 87, Figure 88, Figure 89 and Figure 90) may be directly attributable to the electric breakdowns themselves independent of increased influent concentrations or the presence of persistent substances. In a comparison study carried out in Nantes (VIGNOLES, CAUCHI, 2009), similar peaks were observed during simulated electric breakdowns in almost all plants independent of whether they required electricity or not. The researchers in Nantes also could not find a plausible explanation for this phenomenon. This issue requires further research.

Power consumption

The power consumption of the investigational system was found to be 1.6 kWh/d. The reference value of 0.3 kWh/(PE·d), calculated as the average power consumption of 3 activated sludge systems with moving/fluidized bed filtration tested at the PIA test facility Aachen, Germany (DORGELOH 2008), is hardly below the mean 0.34 kWh/(PE·d) achieved by the BioDisk BA system. The consumption of the systems tested at the PIA testfield in Aachen varied from approximately 0.28 kWh/(PE·d) to 0.32 kWh/(PE·d). The power consumption of the investigational system thus slightly exceeded this range.

In a test series performed in *Dorf Mecklenburg*, Germany (JIROUDI 2005), the rotary filter system used there achieved a mean power consumption of 44 kWh/(PE·a). This corresponds to 0.5 kWh/d which is slightly above the rate of the investigational system.

Sludge

Based on the data in DWA, 2003 a total solids concentration of approximately 70 g/(PE·d) was expected. According to the measurements, the actual load was 21.52 g/(PE·d), which is clearly below the reference value. Reasons for this could be that the solids loading was lower and/or because the mineralisation rate was increased, i.e. more biomass than ususal was converted and released as CO_2.

Microbiological parameters

The investigestional system achieved effluent faecal coliform bacteria counts from 930,000 to 430,000 per 100 ml which considerably exceeded the reference average for SBR systems (STRAUB ET AL. 2008), a mean 32.000 bacteria per 100 ml with a range (minimum-maximum) of 93 to 120,000 per 100 ml (STRAUB ET AL. 2008). The investigational system had an average log reduction of 0.8 log steps. This is well below the log reduction of 1.5 log steps by STRAUB ET AL. 2008.

In a test series performed in *Dorf Mecklenburg*, Germany (JIROUDI 2005), the rotary filter system used there reduced total coliform bacteria to $1.37x10^7$/100 mL and faecal coliform bacteria to $6.8x10^6$/100mL, which is much higher than that achieved by the investigational system. The investigational system had an average log reduction of 1.1 log steps. This is well below the faecal coliforms log reduction of 3.2 log steps by JIROUDI 2005.

7.3.14 Summary

The investigational system was operated at a load of 4.8 PE over the entire study period. The effluent COD concentrations (mean 78 mg/L) could be kept below 150 mg/L also during the hydraulic overload phases (200%). Only during the electric breakdowns one elevated value was observed.

The effluent SS concentrations (mean 21 mg/L) were mainly below 35 mg/L. During the hydraulic overload phase (200%), effluent SS concentration reached however, twice the level of approx. 50 mg/L. Also during the electric breakdowns, increased effluent SS concentrations were observed.

On the whole, the treatment performance of the BioDisk BA system proved to be very stable. No malfunctions occurred during the study period. Despite the slight floating sludge on the secondary treatment tank, the treatment results were excellent.

7.4 Nordbeton – Biofilter KP253 PAL „Klärpott"

7.4.1 Loading conditions

Nordbeton GmbH installed the Biofilter KP253 PAL ("Klärpott") system which has a design capacity of 9 PE and was loaded correspondingly. The nominal BOD_5 load is 540 g/d. According to DIBt authorisation, the system is designed to handle 360 g/d.

The nominal hydraulic load was 1.350 L/d. The system was also tested with 200-litre bathtub discharges 5 times a week corresponding to approx. 114 L/d (see Chapter 5.1.2).

According to authorisation, the system should be able to handle haudraulic loads of 1.350 L/d at most.

The system was operated under the following influent loadings level:

- Befor 23 July 2008[1]: 4.9 $PE_{BOD,60}$
- 23 Jul 2008 until before 27 Aug 2008: 6.3 $PE_{BOD,60}$
- Mean load over the entire study period: 7.0 $PE_{BOD,60}$

Therefore, the system achieved a 77% capacity relative to influent BOD_5 over the entire study period.

The residence times corresponded to the volumes of the pretreatment tank, the bioreactor and the secondary treatment tank and are thus 1.6 days for the pretreatment tank, 1.0 days for the bioreactor and 1.1 days for the secondary treatment tank. The overall residence times for the entire system were therefore 3.8 days (see 2.6).

7.4.2 Statistical overview of results

Table 60 und Table 61 show the results of the statistical analysis for the entire study period, including the number of samples, the mean, median, minimum (min) and maximum (max) values, the statutory limits in France (FR and Germany (DE) (see 2.2.1.1 and 2.2.1.2) and the rates of compliance of effluent COD, BOD_5, SS, NH_4-N, N_{tot} and P_{tot}. with the statutory limits (*stay below probability*). Mean, median, minimum and maximum values as well as the statutory limits in France (FR) and Germany (DE) are expressed in mg/L. The number of samples is a dimensionless parameter. The stay probability is given in percent (%).

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[1] See Chapter 5.1.2: Due to the low influent concnetrations, testing under increased hydraulic load conditions (150%) was discontinued in order to increase the influent load.

Table 60: Nordbeton KP253 PAL – Statistical analysis for COD, BOD_5 and SS

Nordbeton, Biofilter KP253 PAL	COD		BOD			SS	
	In	Out	In	Load (real)*	Out	In	Out
	[mg/l]	[mg/l]	[mg/l]	[E]	[mg/l]	[mg/l]	[mg/l]
Number of samples	50	50	50	50	50	49	49
mean	456	92	207	7,0	25	269,0	28,7
median	469	85	215	6,4	21	260,0	22,0
min.	180	33	78	2,0	4	120,0	2,6
max.	830	334	301	12,4	101	730,0	210,0
legally binding value (DE / FR)		**150 / 125**			**40 / 25**		**-- / 35**
stay below of legally binding value (DE)		94%			86%		
stay below of legally binding value (FR)		80%			58%		69%

* Load (real) see 2.3

Table 61: Nordbeton KP253 PAL – Statistical analysis for nitrogen and phosphorus

Nordbeton, Biofilter KP253 PAL	NH_4-N		N_{tot}		P_{tot}	
	In	Out	In	Out	In	Out
	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]
Number of samples	50	50	50	50	50	50
mean	35,1	18,0	47,4	25,1	7,0	5,3
median	34,8	12,9	46,5	22,9	7,3	5,1
min.	11,6	3,6	19,8	8,8	2,9	3,0
max.	54,5	42,3	71,6	47,4	10,2	9,0
legally binding value (DE / FR)		-- / --		-- / --		-- / --
stay below of legally binding value (DE)						
stay below of legally binding value (FR)						

Chemical oxygen demand (COD)

The system achieved a mean effluent COD of 92 mg/L over the entire study period; the maximum concentration was 334 mg/L. Measured COD levels were below the German statutory limit of 150 mg/L in 94% of cases (see 2.2.1.1) and were below the French statutory limit of 125 mg/L in 80% of cases (see 2.2.1.2). In other words, the measured levels exceeded the German limit in 3 cases and exceeded the French limit in 10 cases (see 7.4.4). The system met the statutory effluent requirements for Germany and France in the vast majority of cases

Biochemical oxygen demand (BOD_5)

The system achieved a mean effluent BOD_5 concentration of 25 mg/L during the entire study period; the maximum concentration was 101 mg/L. Measured BOD_5 levels were below the German statutory limit of 40 mg/L in 86% of cases, and were below the French statutory limit of 25 mg/L in 58% of cases. In other words, the measured levels exceeded the German limit in 7 cases and exceeded the French limit in 21 cases (see 7.4.4). The system met the statutory effluent requirements for Germany in the majority of cases and for France in more than the half of all cases.

Suspended solids (SS)

The system achieved a mean effluent SS concentration of 29 mg/L during the entire study period; the maximum concentration was 210 mg/L. Measured concentrations were below the French statutory limit of 35 mg/L in 69% of cases. In other words, the measured concentrations exceeded the French limit in 14 cases (see 7.4.6). The system met the statutory effluent requirements for France in most cases. There are no statutory limits for effluent SS concentrations in Germany.

Nitrogen

- **Ammonia (NH_4-N):**
  The system achieved a mean effluent NH_4-N concentration of 18.0 mg/L over the entire study period. The maximum concentration was 42.3 mg/L (see 7.4.5).
- **Total nitrogen (N_{tot})**
  The system achieved a mean effluent N_{tot} concentration of 25.1 mg/L over the entire study period; the maximum concentration was 47.4 mg/L (see 7.4.5).

Total phosphorus (P_{tot})

The system achieved a mean effluent P_{tot} concentration of 5.3 mg/L over the entire study period; the maximum concentration was 9 mg/L (see 7.4.7).

7.4.3 Operational and process stability

Process stability was described in terms of compliance with statutory limits for target parameters (stay below probability) (Figure 95). The steeper the curve, the more stably the system is operating. A stable system maintains steady effluent concentrations in spite of changes in influent concentrations, temperatures etc. (see 2.10.9).

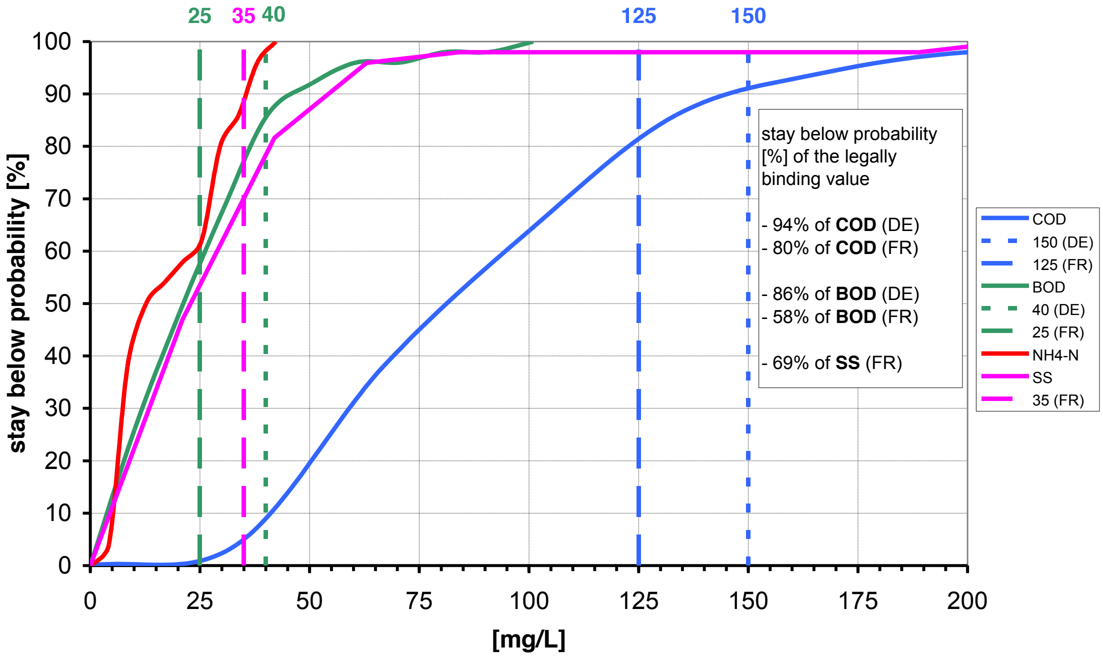

Figure 95: Nordbeton KP253 PAL – Stay below probability for COD, BOD_5, NH_4-N and SS

7.4.4 COD and BOD_5 elimination

The combined parameters for organic matter were analysed based on the COD curve over the entire study period. The horizontal lines (Figure 96) at 150 mg/L (125 mg/L) represent the German and French statutory limits.

The BOD_5 curve shown in Figure 97 is similar to the COD curve. The mean COD/ BOD_5 ratio is 3.7 to 1.

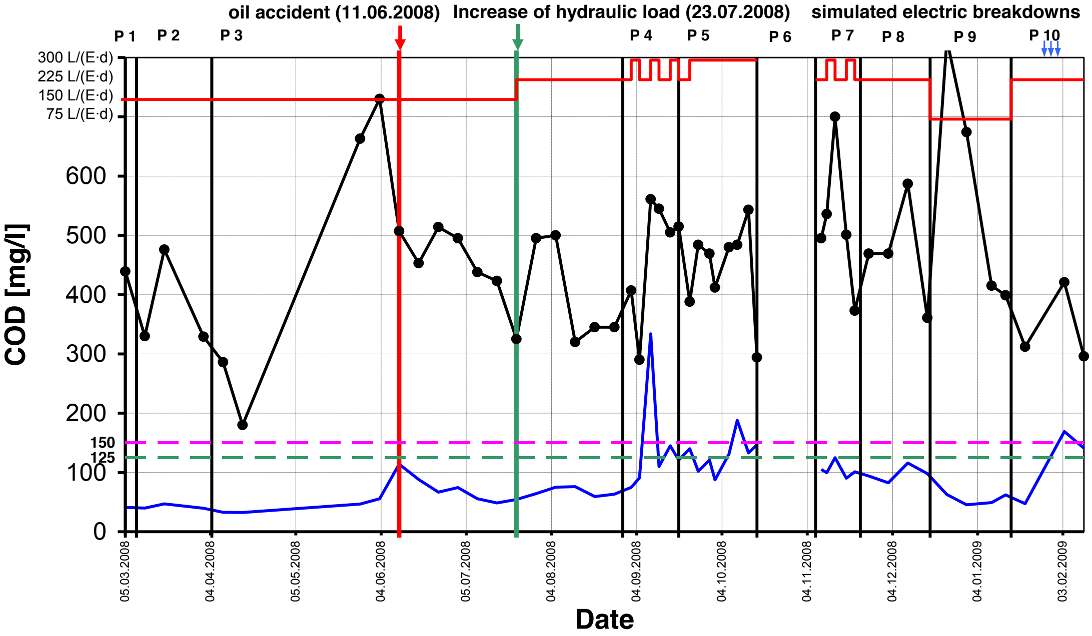

Figure 96: Nordbeton KP253 PAL – Influent and effluent COD curves

During the phases 1 to 3, the effluent COD concentrations remained below 100 mg/L with one exception (Figure 96). The oil accident resulted in elevated effluent COD concentrations. Although no countermeasures were taken apart from cleaning of the primary treatment, COD concentrations returned to baseline levels within about 14 days. The increased nominal hydraulic load during Phase 3 had only a minor influence on the effluent concentrations.

The 200% hydraulic load increases on three days per week during Phase 4 resulted in a brief but sharp rise to more than 300 mg COD/L. This very sharp rise in Phase and also the peak in Phase 5 coincided with the settling of coarse matter in the distribution channel (see 7.4.11). This indicates that the pretreatment tank had been overloaded which consequently led to a deterioration of the wastewater distribution which explains the elevated effluent concentrations

The resting peridod had a positive influence on the COD degradation. From Phase 7 on, the French statutory limit was exceeded only one more time during the simulated electric breakdowns. This could be due to a temporary increase in persistent substances in the influent, since this phenomenon was observed at the same time in nearly all SWWTPs studied (see 7.3.12).

As a consequence of the low hydraulic load during Phase 9, the effluent COD concentrations decreased to approx. 50 mg/L.

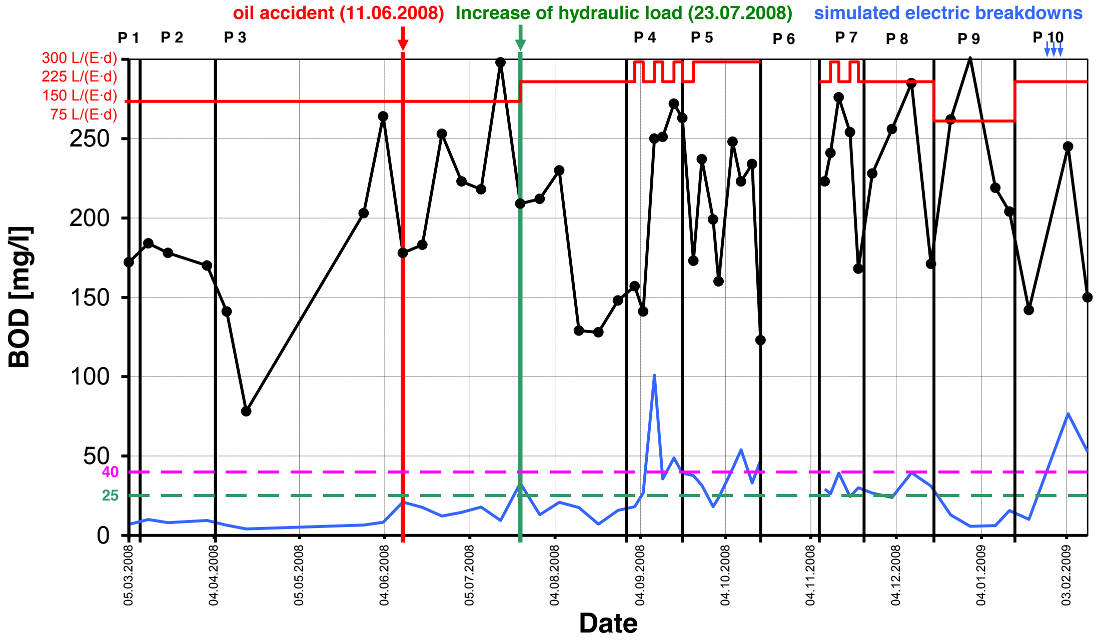

Figure 97: Nordbeton KP253 PAL – Influent and effluent BOD_5 curves

7.4.5 Nitrogen

Ammonia (NH_4-N)

The course of the NH_4-N curve reflects the course of nitrification (Figure 98). As a biological process very sensitive to changes in process control, nitrification is a useful indicator of the stability of wastewater treatment systems.

Until 23 July 2008, effluent NH_4-N concentrations remained at a very low level of approx. mean 5 mg/L. The oil accident had no significant influence on the effluent concentrations

Due to the increased hydraulic load from150 L/(PE·d) to 225 L/(PE·d) from 23 July on, the NH_4-N concentrations continuously rose from approx. 8 mg/L to more than 40 mg/L until the end of Phase 4, although the temperatures were the highest measured over the entire study period (mean 17.4°C for Phase 4 and 5). During the phases 4 and 5, the nitrification process was inhibited which can be clearly explained by the increased hydraulic load.

After the resting period, the effluent NH_4-N concentrations finally decreased to levels around 10 mg/L, but rose again to 35 mg/L thereafter.

In Phases 7 to 9, the NH_4-N concentrations continuously fell to a minimum level of below 10 mg/L in Phase 9, although during this period the wastewater temperature fell below 5°C (approx. 4.2°C on 14 Jan 2009).

In Phase 10, the concentrations rose again to more than 30 mg/L which is presumably due to the electric breakdowns.

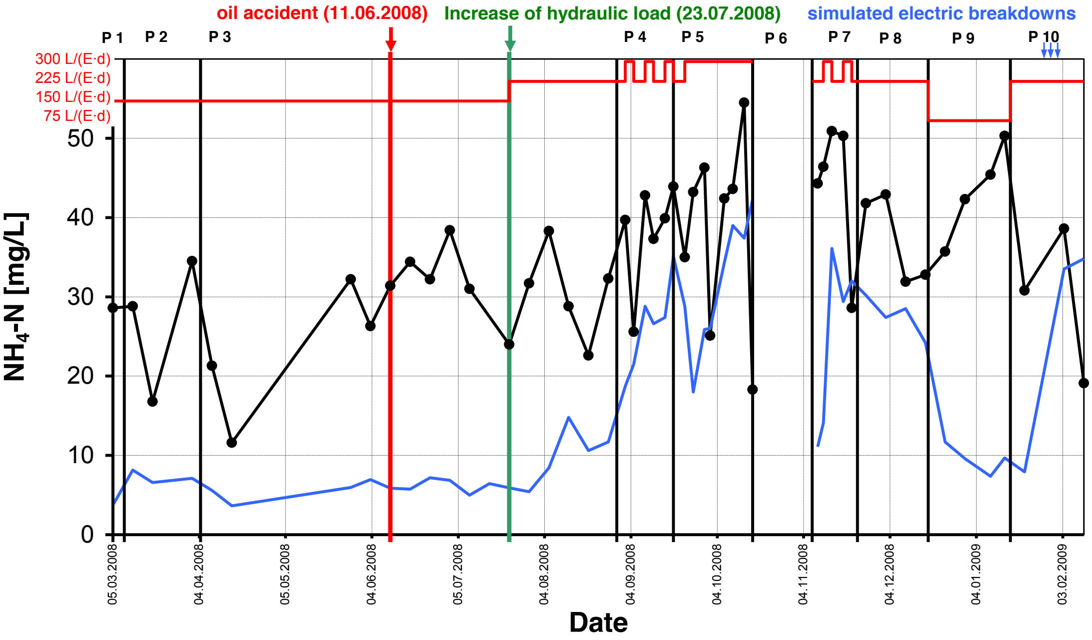

Figure 98: Nordbeton KP253 PAL – Influent and effluent NH_4-N curves

Inorganic nitrogen

The inorganic nitrogen curve is provided in the Appendix.

The inorganic nitrogen concentrations ranged from 10 to 20 mg/L, which is attributable by the denitrification process occurring either simultaneously or in the pretreatment tank.

In phases 4 and 5, the concentrations increased to more than 40 mg/L.

During the decrease of hydraulic load during phases 7 to 9, also the effluent concentrations dropped to approx. 20 mg/L, in spite of the low wastewater temperatures of below 5°C. This indicates that the denitrification process started again.

The simulated electric breakdowns induced a reincrease to more than 30 mg/L.

The oil accident had no significant influence on the effluent concentrations.

7.4.6 Suspended solids

Until the beginning of Phase 4, effluent SS concentrations (Figure 99) remained relatively constant at a low level of below 35 mg/L. In Phase 4, a peak of more than 200 mg/L was achieved. Afterwards, effluent concentrations slightly increased to a level between 30 to 60 mg/L which was due to the elevated hydraulic load from Phase 4 on (see 7.4.4).

After the resting period (Phase 6), the effluent concentrations achieved a relatively constant level of approx. 35 mg/L which then dropped due to the underload of 75 L/(PE·d) to a level between 10 to 20 mg/L. The electric breakdowns resulted again in an increase to more than 50 mg/L. This could be due to the simulated electric breakdowns themselves (see 5.1.1) or to a persistent substance leading to the death and escape of biomass, since this peak was observed at almost all systems investigated. Furthermore, the same phenomenon was noticed in the COD and BOD_5 influent (Figure 96 und Figure 97).

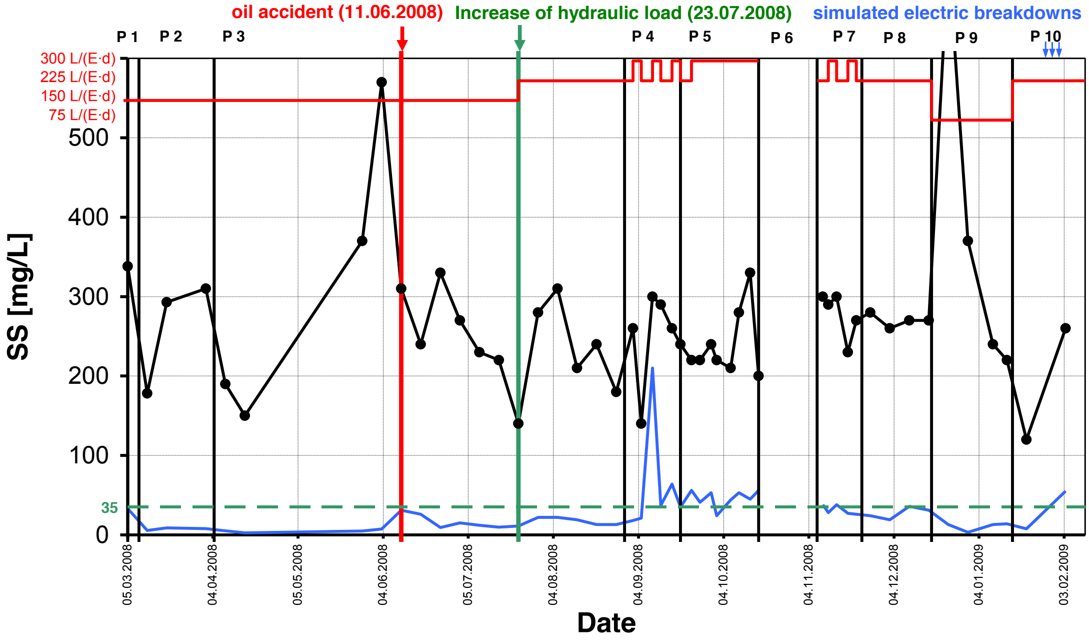

Figure 99: Nordbeton KP253 PAL – Influent and effluent SS curves

7.4.7 Phosphorus

The phosphorus elimination rate (Figure 100) was low (3 to 5 mg/L). During the increased hydraulic load phases (Phase 4, 5 and 7), the effluent phosphorus concentration slightly increased to 6 to 8 mg/L. During this phase, elimination was only poor. Effluent phosphorus concentrations ran relatively parallel to the effluent concentrations, but generally with a slight time lag. The > 9 mg/L peak induced by solids in Phase 4 decreased within 1 week to a mean effluent concentration of about 6 mg/L.

Comparison with suspended solids concentrations demonstrates that effluent phosphorus concentrations are directly proportional to SS concentrations because bound phosphorus is also eliminated with suspended solids. Therefore, phosphorus is not degraded but rather bound and removed by sludge. In addition, the effluent phosphorus concentrations are partially dependent of the influent phosphorus concentrations

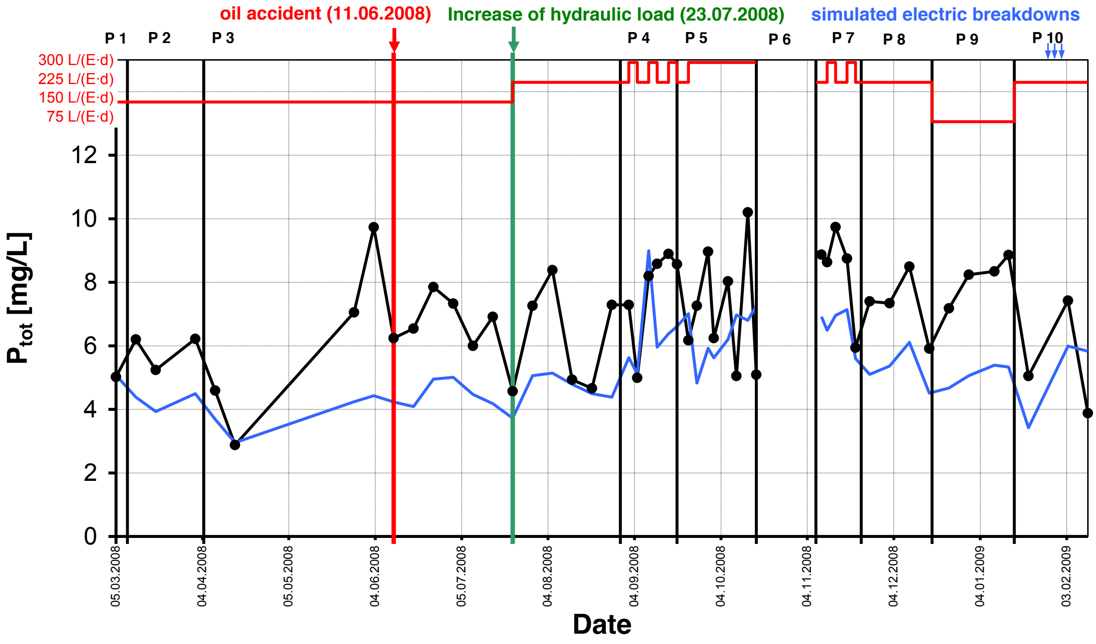

Figure 100: Nordbeton KP253 PAL – Influent and effluent P_{tot} curves

7.4.8 Degradation rate

Degradation rates for COD, BOD_5, NH_4-N, N_{tot}, P_{tot} and SS are expressed as percentage values (Table 62, Table 63 and Table 64, see 2.9). Negative values mean that influent concentrations were smaller than effluent concentrations. Potential reasons for this are redissolution, washout and (back) transformation from the biomass. Measurement error is another potential cause, but checks for measurement error were performed in the course of quality assurance. Table 63 contains data from Phases 1, 2 and 3 during which the system was tested at 100% hydraulic load, and Table 64 contains data from Phases 4, 5 and 7 during which the system was tested under hydraulic overload conditions.

Phosphorus is not eliminated. Instead, it settles in the primary treatment tank or is incorporated in the biomass, and is then returned with excess sludge to the primary treatment tank.

The mean degradation rate was 79% for COD and 88% for BOD_5. The mean elimination rates were 47% for NH_4-N, 45% for N_{tot} and 20% for P_{tot}.

Table 62: Nordbeton KP253 PAL – Degradation rates (%) for COD, BOD_5, NH_4-N, N_{tot}, SS and P during the complete period

Nordbeton, Biofilter KP253 PAL	η_{COD}	η_{BOD}	$\eta_{NH4\text{-}N}$	$\eta_{N\text{-}tot}$	η_P	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	50	50	50	50	50	49
mean	79	88	47	45	20	89
median	82	89	60	49	27	91
min.	40	60	-131	-65	-50	30
max.	93	98	87	78	54	99

Table 63: Nordbeton KP253 PAL - Degradation rates (%) for COD, BOD_5, NH_4-N, N_{tot}, SS and P during the 100% phases (Phases 1, 2 and 3)

Nordbeton, Biofilter KP253 PAL	η_{COD}	η_{BOD}	$\eta_{NH4\text{-}N}$	$\eta_{N\text{-}tot}$	η_P	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	20	20	20	20	20	20
mean	86	93	74	57	26	95
median	87	94	78	62	30	95
min.	76	84	49	18	-2	89
max.	93	97	87	81	54	99

Table 64: Nordbeton KP253 PAL - Degradation rates (%) for COD, BOD_5, NH_4-N, N_{tot}, SS and P during the overload phases (Phases 4, 5 and 7)

Nordbeton, Biofilter KP253 PAL	η_{COD}	η_{BOD}	$\eta_{NH4\text{-}N}$	$\eta_{N\text{-}tot}$	η_P	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	19	19	19	19	19	19
mean	72	82	23	20	12	81
median	76	85	29	29	23	85
min.	40	60	-131	-131	-43	30
max.	82	91	75	58	34	93

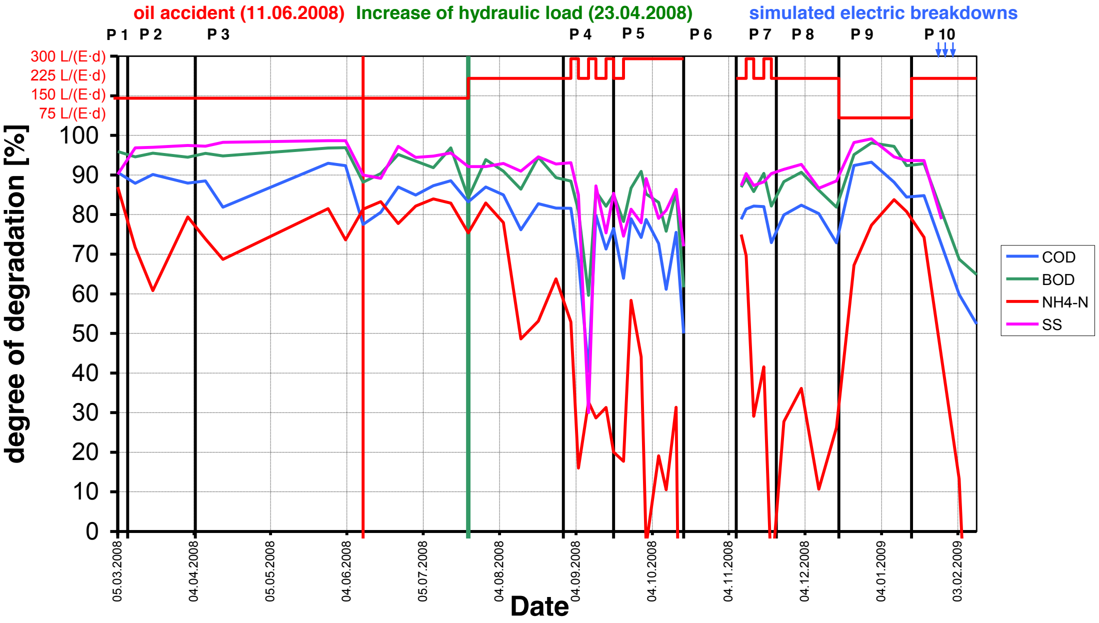

Figure 101: Nordbeton KP253 PAL – Degradation curves for COD, BOD_5, NH_4-N, SS

Due to the lower hydraulic load, the COD degradation rate was slightly higher (86%) during nominal load testing than during the entire study period (79%). Degradation rates during the hydraulic overload phases tended to be lower. The lowest COD elimination rate was observed in Phase 5 (maximum hydraulic load) and after the simulated electric breakdowns. The degradation curves (Figure 101) show a sharp drop of NH_4-N degradation rates after the nominal influent rate was increased from 150 to 225 L/(PE·d).

During the overload phases (Phase 4 and 5) as well as during the electric breakdowns all degradation rates decreased by approx. 10 to 20%, but returned to average levels within a few days. This became apparent in Phase 9 (underload) during which degradation rates re-increased to values from 80 to almost 100%.

More detailed analyses of effluent values are presented in section 7.4.4.

7.4.9 Power consumption

Power consumption (Figure 171) was classified according to the population-specific hydraulic load (no load, 75, 150, 225, 225+300, 300 L/(PE·d)); the nominal load corresponds to authorisation (9 PE).

Mean power consumption values are given in kWh/(PE·a) (see 2.3). Since power consumption in Phase 6 (no load) was calculated based on the nominal pollution load (9 PE), the estimated specific power consumption may be lower under other hydraulic conditions because the values were calculated as the quotient of measured power consumption and the population equivalent of wastewater flow. At higher loads, the population equivalent is often higher than the nominal population equivalent; consequently, power consumption per inhabitant is lower.

Power consumption was measured as the total power consumed by the system. The following power consumers were included in the calculation:

Irrigation pump	(220 W, according to manufacturer's specification)
Sludge pump	(200 W, according to manufacturer's specification)
Control system	(10 W, according to manufacturer's specification)

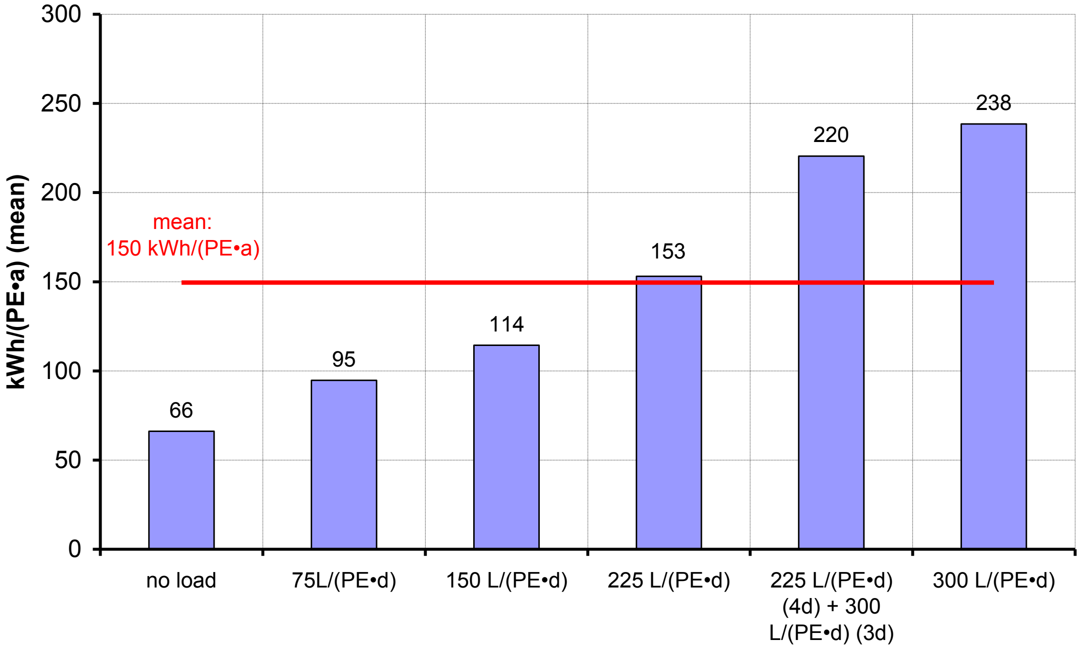

Figure 102: Nordbeton KP253 PAL – Power consumption

Total power consumption of the system during the entire study period was a mean 150 kWh/(PE·a). Calculated based on the average population equivalent of 6.9 PE (based on BOD_5) (see 2.3), this corresponds to a daily power consumption rate of 2.8 kWh/d.

Population-independent consumption was 1.6 kWh/d, as calculated based on zero load power consumption of 66 kWh/(PE·a) at 9 PE during Phase 6 (no load). .

7.4.10 Sludge

The sludge volume was estimated based on the measured sludge height and the known container geometry. As such geometry-dependent estimates are relatively imprecise, their power of evidence is limited.

Overall sludge production during the entire study period was 2.02 m³. At a sludge dry matter content of 77.1 g/L (measured), this corresponds to a sludge mass of 156 kg.

The specific sludge volume at the calculated actual load of 6.9 PE is 62 gTS/E·d.

7.4.11 Operation and maintenance

Figure 103 shows all unusual events occurring over the entire study period while the system was in operation. Hydraulic loads and influent COD concentrations are also shown for better clarity. The diagram shows the course of events over time.

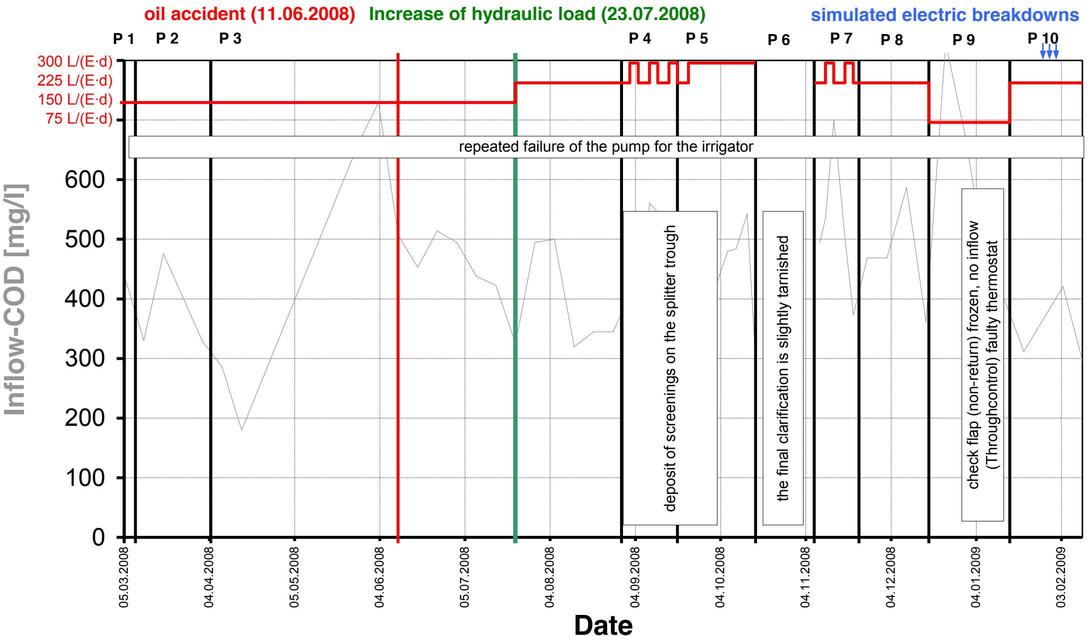

Figure 103: Nordbeton KP253 PAL – Maintenance log analysis

On 21 Jan (is not present in Figure 103), 6 May and 9 Oct 2008 maintenance were carried out.

Due to floodwaters, the irrigation pump failed several times during the entire study period. These failures mostly occurred for a short time only (10 to 15 min).

Between 28 Aug and 25 Sep 2008, coarse matter settled on the distribution channel, which might be explained by overflow due to floodwaters

On 21 and 29 Oct 2008 (Phase 6, no load) the secondary treatment tank was slightly cloudy.

From 06 Jan 2009 08:00 hrs until 07 Jan 2009 12:00 hrs, inflow was obstructed due to a frozen non-return check valve. The valve was not part of the Biofilter KP253 PAL system, but belonged to the test facility. Therefore, Nordbeton was not responsible for this malfunction.

7.4.12 Microbiology

Effluent water samples were collected on three consecutive days and tested for total coliform bacteria, faecal coliform bacteria, intestinal enterococci, salmonella and intestinal nematodes (see 5.4.2). The results of the microbiological analysis are presented in Table 65.

On average of three consecutive days, total coliform bacteria were reduced by 1.1 log steps, faecal coliform bacteria by 0.8 log steps, intestinal enterococci by 1.3 log steps and salmonella by around 0.6 log steps. In intestinal nematodes, there was no change in the number. On some days, there was an increase, although this may be explained by statistical uncertainty in the determination of the number. In addition, the simultaneous sampling in the influent and effluent did not consider the time lag during the system passage

It can generally be assumed that the number of faecal coliform bacteria undergoes a one- to two-log reduction per treatment stage (compare DWA, 1998). This was almost achieved by this plant with a mean of 0.8-log reduction.

As expected, effluent microbiological quality did not meet bathing water quality standard.

Table 65: Nordbeton KP253 PAL – Microbiological analysis

Date		1 Dec 08			2 Dec 08			3 Dec 08			Mean
		[MPN/ mL]	[log]	Δ [log]	[MPN/ mL]	[log]	Δ [log]	[MPN/ mL]	[log]	Δ [log]	Δ [log]
Total coliform bacteria	Influent	930,000	5.97	1.34	390,000	5.59	1.21	430,000	5.63	0.83	1.1
	Effluent	43,000	4.63		24,000	4.38		64,000	4.81		
Faecal coliform bacteria	Influent	150,000	5.18	1.21	240,000	5.38	1.00	73,000	4.86	0.27	0.8
	Effluent	9,300	3.97		24,000	4.38		39,000	4.59		
Intestinal enterococci	Influent	43,000	4.63	0.66	93,000	4.97	1.59	93,000	4.97	1.93	1.3
	Effluent	9,300	3.97		2,400	3.38		1,100	3.04		
Salmonella	Influent	2,100	3.32	0.28	750	2.88	1.55	46,000	4.66	0.58	0.6
	Effluent	1,100	3.04		21	1.32		12,000	4.08		
		[Eggs/L]		Δ [Eggs]	[Eggs/L]		Δ [Eggs]	[Eggs/L]		Δ [Eggs]	Δ [Eggs]
Intestinal nematodes	Influent	<1		-9	13 1)		10	<1		-1	0
	Effluent	9			3 1)			1			

1) statistical uncertainty in determination of the egg counts

"< 1" is assumed to be zero

7.4.13 Comparison of test results with reports and literature data

Chemical oxygen demand

According to the manufacturer's specification (see 4.6.9), the system should achieve effluent COD concentrations of < 100 mg/L in 24-hour composite samples, in accordance with DIBt effluent class C requirements (Table 2). Measured concentrations were below 100 mg/L in 64% of cases. Related to the nominal load phases 1, 2 and 3, they were below the manufacturer's specification of 100 mg/L in 95% of cases.

The reference value calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approx. 65 mg/L in the 100% phases, which is comparable to the mean 59 mg/L achieved by the Biofilter KP253 PAL system. Over the entire study period however, the mean was 92 mg/L due to the stricter test conditions and was thus higher than the reference average yielded at the PIA test facility.

The average effluent COD concentration of trickling filter systems in practice was determined to be 108 mg/L (STRAUB 2008). This roughly corresponds to the mean 92 mg/L achieved by the Biofilter KP253 PAL system.

In a test series in *Dorf Mecklenburg*, Germany (JIROUDI 2005), the trickling filter systems used there (5 PE, 26 measurements) achieved a mean effluent COD concentration of 207 mg/L, which is more as twice as high as the values achieved by the Biofilter KP253 PAL system (92 mg/L). In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 1.087 mg/L (223 mg/L - 2.128 mg/L, 135 measurements).

According to FLASCHE 2002, 5 trickling filter systems achieved a mean effluent COD concentration of 69.9 mg/L, which is slighty below the mean 92 mg/L achieved by the Biofilter KP253 PAL system.

According to BOLLER 2004, 121 trickling filter systems systems yielding 486 measurement values achieved a mean effluent COD concentration of 160 mg/L, which is far higher than the mean 92 mg/L achieved by the Biofilter KP253 PAL system.

Biological oxygen demand in five days

According to the manufacturer's specification (see 4.6.9), the system should achieve effluent BOD_5 concentrations of < 25 mg/L in a composite samples, in accordance with DIBt effluent class C requirements (Table 2). Measured concentrations were below 25 mg/L in 58% of cases. Related to the nominal load phases 1, 2 and 3, they were below the manufacturer's specification of 25 mg/L in 95% of cases.

The reference value calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approx. 12 mg/L in the 100% phases, which is comparable to the mean 13 mg/L achieved by the Biofilter KP253 PAL system. Over the entire study period however, the mean was 25 mg/L due to the stricter test conditions and was thus considerably higher than the reference average yielded at the PIA test facility.

The average effluent BOD_5 concentration of trickling filter systems in practice was determined to be 21 mg/L (STRAUB 2008). The mean 25 mg/L achieved by the Biofilter KP253 PAL system was thus slightly above the reference average yielded at the PIA test facility.

In a test series in *Dorf Mecklenburg*, Germany (JIROUDI 2005), trickling filter systems used there (5 PE, 26 measurements) achieved a mean effluent BOD_5 concentration of 27 mg/L, which roughly corresponds to the mean 25 mg/L achieved by the Biofilter KP253 PAL system. In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 598 mg/L (160 mg/L - 960 mg/L, 136 measurements).

According to FLASCHE 2002, 5 trickling filter systems achieved a mean effluent BOD_5 concentration of 6.7 mg/L, which is clearly below the mean 92 mg/L achieved by the Biofilter KP253 PAL system.

Ammonia NH_4-N

The reference value calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approx. 5 mg/L in the 100% phases, which is comparable to the values achieved by the Biofilter KP253 PAL system during phases 1 to 3 until 23 Jul 2008. Over the entire study period however, the mean was 18.0 mg/L which is far above the reference average yielded at the PIA test facility.

The average effluent NH_4-N concentrations of trickling filter systems in practice were determined to be 19 mg/L (STRAUB 2008). The mean 18.0 mg/L achieved by the Biofilter KP253 PAL system was thus slightly below the reference average, although values measured during water temperatures of below 12°C were used (cf. STRAUB 2008).

In a test series in *Dorf Mecklenburg*, Germany (JIROUDI 2005), the trickling filter systems used there (5 PE, 20 measurements) achieved a mean effluent NH_4-N concentration of 13 mg/L, which is lower than the mean 18 mg/L achieved by the Biofilter KP253 PAL system. During the 100% phases (phases 1 to 3) however, the Biofilter KP253 PAL system achieved a mean effluent NH_4-N concentration of 7 mg/L which is only half of the value obtained in Mecklenburg. In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 72 mg/L (24 mg/L - 114 mg/L, 137 measurements).

According to FLASCHE 2002, 5 trickling filter systems achieved a mean effluent NH_4-N concentration of 9.1 mg/L, which is clearly below the mean 18 mg/L achieved by the Biofilter KP253 PAL system.

Suspended solids

According to the manufacturer's specification (see 4.6.9), the system should achieve effluent SS concentrations of < 75 mg/L in one sample, in accordance with DIBt effluent class C requirements (Table 2). The concentrations measured from one composite sample were below 75 mg/L in 98% of cases.

The reference value calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approx. 25 mg/L in the 100% phases, which is only slightly below the mean 28.7 mg/L achieved by the Biofilter KP253 PAL system over the entire study period.

The average effluent SS concentrations of trickling filter systems in practice was determined to be 47 mg/L (STRAUB 2008). The mean 28.7 mg/L achieved by the Biofilter KP253 PAL system was thus far below the reference average.

In a test series in *Dorf Mecklenburg*, Germany (JIROUDI 2005), the trickling filter systems used there (5 PE, 10 measurements) achieved a mean effluent SS concentration of 45 mg/L, which is considerably higher than the mean 28.7 mg/L achieved by the Biofilter KP253 PAL system.

Simulated electric breakdowns

The increase in effluent concentrations observed during the simulated electric breakdowns (Figure 96, Figure 97, Figure 98 and Figure 99) may be directly attributable to the electric breakdowns themselves independent of increased influent concentrations or the presence of persistent substances. In a comparison study carried out in Nantes (VIGNOLES, CAUCHI, 2009), similar peaks were observed during simulated electric breakdowns in almost all plants independent of whether they required electricity or not. The researchers in Nantes also could not find a plausible explanation for this phenomenon. This issue requires further research.

Power consumption

The power consumption of the investigational system was found to be 2.8 kWh/d and is thus three times higher than the mean 0.9 kWh/d specified by the manufacturer (see 4.6.9). The average power consumption of 5 trickling filter systems tested at the PIA test facility Aachen, Germany (DORGELOH 2008), is 0.05 kWh/(PE d) which is far below the mean 0.4 kWh/(PE·d) achieved by the Biofilter KP253 PAL system. The consumption of the systems tested at the PIA testfield in Aachen varied from approximately 0.01 kWh/(PE·d) to 0.1 kWh/(PE·d). The power consumption of the investigational system thus clearly exceeded this range.

In a test series performed in *Dorf Mecklenburg*, Germany (JIROUDI 2005), the power consumption of biofilter system used there (5 PE) ranged between 131 to 152 kWh/(PE·a). This corresponds to a range between 1.8 to 2.1 kWh/d which is slightly below the rate of the investigational system, although increased backflows were set over a longer period of time.

Sludge

Based on the data from DWA, 2003 a total solids concentration of approx. 70 g/(PE·d) was expected. According to the measurements, the actual load was 62 g/(PE·d).

Microbiological parameters

The investigestional system achieved effluent faecal coliform bacteria counts from 24,000 to 64,000 per 100 ml which is comparable to the reference average for SBR systems (STRAUB ET AL. 2008), a mean 32.000 bacteria per 100 ml with a range (minimum-maximum) of 93 to 120,000 per 100 ml (STRAUB ET AL. 2008). The investigational system had an average log reduction of 0.8 log steps. This is well below the log reduction of 1.5 log steps by STRAUB ET AL. 2008.

In a test series performed in *Dorf Mecklenburg*, Germany (JIROUDI 2005), the biofilter system used there reduced total coliform bacteria to 7,23x10^4/100 mL and faecal coliform bacteria to 4,1x10^4/100ml, which is insignificantly higher than the values achieved by the investigational system. The investigational system had an average log reduction of 1.1 log steps. This is well below the faecal coliforms log reduction of 3.2 log steps by JIROUDI 2005.

7.4.14 Summary

The investigational system was operated at a load of 6.9 PE over the entire study period. Effluent COD concentrations achieved a mean 92 mg/L and could mainly be kept under 150 mg/L even during the 200% hydraulic load phases.

The mean effluent SS concentrations of19.9 mg/L were predominantly less than 35 m/L. During the 200 % hydraulic load phases and also after the electric breakdowns in Phase 10, increased effluent SS concentrations were however, observed several times.

On the whole, the treatment performance proved to be very stable

During the overload phases, some problems occurred due to repeated failure of the irrigation pump caused by floodwaters.

The power consumption was substantially higher than indicated by the manufacturer. Also the sludge production was strikingly high.

7.5 PREMIER TECH - Ecoflex^{TM}

7.5.1 Loading conditions

PREMIER TECH installed the Ecoflex^{TM} system which has a design capacity of 5 PE, but was initially tested at a load of 6 PE due to the system group classification used in this study (4 PE, 6 PE und 9 PE). After the start of increased hydraulic loading in Phase 4, the nominal load was reduced to 4 PE on 10 Oct 2008 at the request of the manufacturer because the effluent quality results decreased..

Thus, the nominal influent load used for testing was 360 g BOD_5/d before 10 Oct 2008 and 240 g BOD_5/d from 10 Oct 2008 on. According to the manufacturer's specification, the system should be able to handle influent loads up to 300 g BOD_5/d.

Likewise, the nominal hydraulic load was 900 L/d before 10 Oct 2008 and 600 L/d from 10 Oct 2008 on. The system was also tested with a 200-litre bathtub discharge 5 times a week which corresponding to approx. 114 l/d (see 5.1.2). According to the manufacturer's specification, the maximum permissible load for this system is 750 L/d.

Due to the clogging occurred in the distribution system (see 7.5.11), which were caused by the overflow of some coarse matters into the balance tank, the measured values obtained in the period from 30 Jul to 17 Oct 2008 were not used for interpretation purposes. This has to be taken into consideration on the evaluation of this system.

The system was operated under the following influent loadings level:

Before 23 Jul 2008[1]:	3.6 $PE_{BOD,60}$
From 23 Jul 2008 until 17 Oct 2008	no values, see above
Overall average for entire study period:	3.6 $PE_{BOD,60}$

Therefore the system achieved a 61% capacity at a nominal load of 6 PE relative to influent BOD_5 before 23 Jul 2008, which corresponds to a 73% at a load of 5 PE. From 17 Oct 2008 on, the system worked at a capacity of 90% at a nominal load of 4 PE relative to influent BOD_5.

The residence times corresponded to the volumes of the pretreatment tank, the balancing tank and the dosage tank are 3.6 days for the pretreatment tank and 0.5 days for the balancing tank at a load of 6 PE. The specific load of the filters and the filter surfaces results in a hydraulic retention time of 1.3 days. At a load of 4 PE, the retention times were 4.1 days for the pretreatment tank and 0.5 days for the balancing tank. The hydraulic retention time was 1.3 days. Consequently, for the entire system the residence times were 5.5 days at 6 PE and PE 5.9 days at 4 (mean 5.7 days)) (see 2.6).

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[1] See Chapter 5.1.2: Due to the low influent concentrations, testing under increased hydraulic load conditions (auf 150%) was discontinued in order to increase the influent load.

7.5.2 Statistical overview of results

Table 66 and Table 67 show the results of the statistical analysis for the entire study period, including the number of samples, the mean, median, minimum (min) and maximum (max) values, the statutory limits in France (FR and Germany (DE) (see 2.2.1.1 and 2.2.1.2) and the rates of compliance of effluent COD, BOD_5, SS, NH_4-N, N_{tot} and P_{tot}. with the statutory limits (*stay below probability*). Mean, median, minimum and maximum values as well as the statutory limits in France (FR) and Germany (DE) are expressed in mg/L. The number of samples is a dimensionless parameter. The stay probability is given in percent (%).

Table 66: PREMIER TECH - Ecoflex^{TM} – Statistical analysis of COD, BOD_5 and SS

PREMIER TECH LTEE - Ecoflex	COD		BOD			SS	
	In	Out	In	Load (real)*	Out	In	Out
	[mg/l]	[mg/l]	[mg/l]	[E]	[mg/l]	[mg/l]	[mg/l]
Number of samples	50	31	50	31	31	49	31
mean	456	45	207	3,6	9	269,0	9
median	469	44	215	3,4	6	260,0	6
min.	180	21	78	1,5	< 3	120,0	2
max.	830	91	301	5,6	24	730,0	26
legally binding value (DE / FR)		**150 / 125**			**40 / 25**		**-- / 35**
stay below of legally binding value (DE)		100%			100%		
stay below of legally binding value (FR)		100%			100%		100%

* Load (real) see 2.3

Table 67: PREMIER TECH - Ecoflex^{TM} - Statistical analysis of nitrogen and phosphorus

PREMIER TECH LTEE - Ecoflex	NH_4-N		N_{tot}		P_{tot}	
	In	Out	In	Out	In	Out
	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]
Number of samples	50	31	50	31	50	31
mean	35,1	8	47,4	38	7,0	5
median	34,8	6	46,5	40	7,3	5
min.	11,6	< 0,5	19,8	12	2,9	2
max.	54,5	35	71,6	69	10,2	7
legally binding value (DE / FR)		**-- / --**		**-- / --**		**-- / --**
stay below of legally binding value (DE)						
stay below of legally binding value (FR)						

Chemical oxygen demand (COD)

The system achieved a mean effluent COD of 45 mg/L over the entire study period: the maximum concentration was 91 mg/L. Measured levels were below the German statutory limit of 150 mg/L (see 2.2.1.1) and below the French statutory limit of 125 mg/L in 100% of cases (see 2.2.1.2). The system thus met the statutory effluent requirement for both Germany and France in all cases (see 7.5.4), but could however, temporarily not be loaded.

Biological oxygen demand (BOD_5)

The system achieved a mean effluent BOD_5 of 9 mg/L over the entire study period; the maximum concentration was 24 mg/L. Measured levels were below the German statutory limit of 40 mg/L (see 2.2.1.1) and below the French statutory limit of 25 mg/L (see 2.2.1.2) in 100% of cases. The system met the statutory effluent requirements for Germany and France in all cases (see 7.5.4), but could however, temporarily not be loaded.

Suspended Solids (SS)

The system achieved a mean effluent SS concentration of 9 mg/L over the entire study period; the maximum concentration was 26 mg/L. Measured levels were below the French statutory limit of 35 mg/L in 100% of cases. The system met the statutory effluent requirements for France in all cases. There are no statutory limits for effluent SS concentrations in Germany (see 7.5.6).

Nitrogen

- **Ammonia (NH_4-N):**
  The system achieved a mean effluent NH_4-N concentration of 8 mg/L over the entire study period; the maximum concentration was 35 mg/L (see 7.5.5).
- **Total nitrogen (N_{tot})**
  The system achieved a mean effluent N_{tot} concentration of 38 mg/L over the entire study period; the maximum concentration was 69 mg/L (see 7.5.5).

Total phosphorus (P_{tot})

The system achieved a mean effluent P_{tot} concentration of 4.5 mg/L over the entire study period, the maximum concentration was 11 mg/L (see 7.5.7).

7.5.3 Operation and process stability

Process stability was described in terms of compliance with statutory limits for target parameters (stay below probability) (Figure 104). The steeper the curve, the more stably the system is operating. A stable system maintains steady effluent concentrations in spite of changes in influent concentrations, temperatures etc. (see 2.10.9).

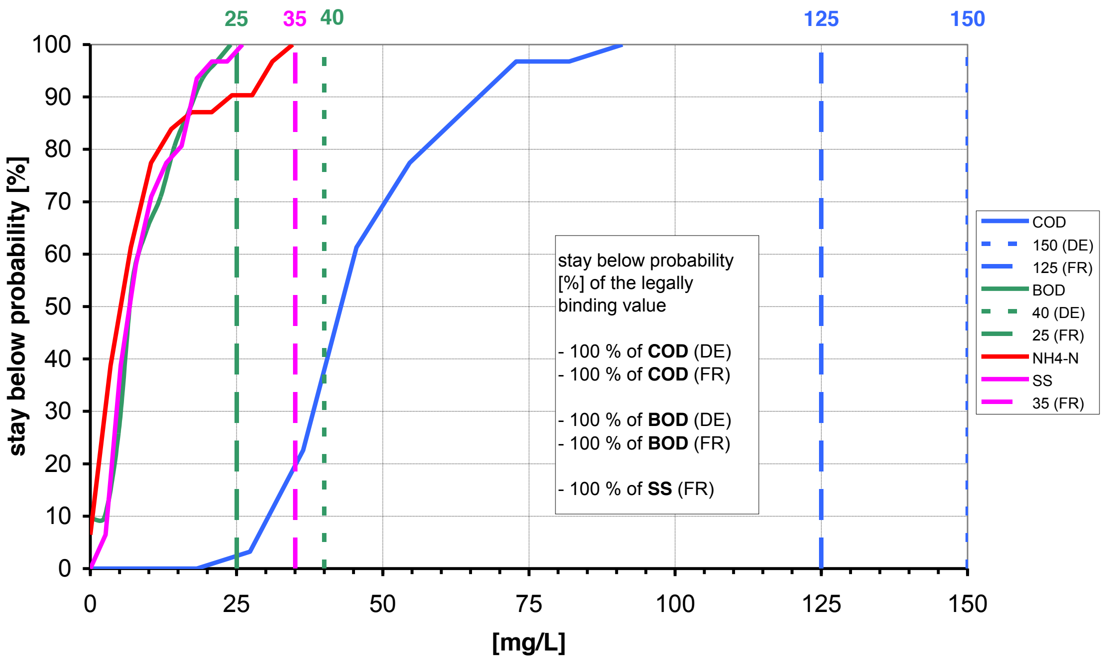

Figure 104: PREMIER TECH - Ecoflex^{TM} – Stay below probability for COD, BOD$_5$, NH$_4$-N and SS

7.5.4 COD and BOD$_5$ elimination

The combined parameters for organic matter were analysed based on the COD curve over the entire study period. The horizontal lines (Figure 105) at 150 mg/L (125 mg/L) represent the German and French statutory limits. The vertical broken line (30 Sep 2008) represents the switch from 9 PE to 4 PE, including the changed hydraulic loading conditions.

The BOD$_5$ curve shown in Figure 106 is similar to the COD curve. The mean COD/ BOD$_5$ ratio is 5 to 1.

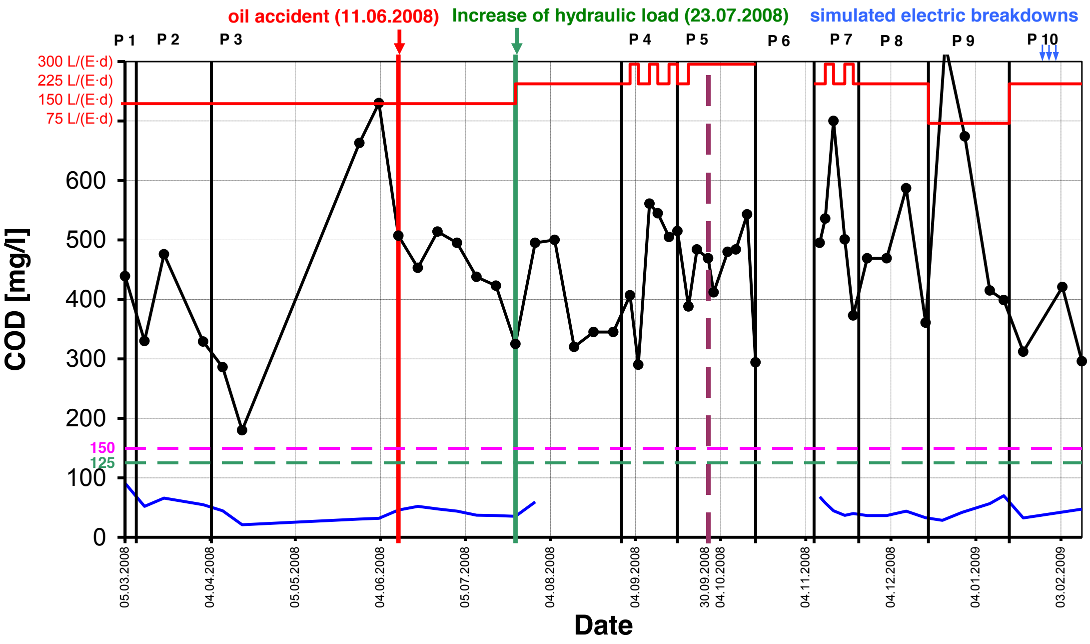

Figure 105: PREMIER TECH - Ecoflex^{TM} – Influent and effluent COD curves

Effluent COD concentrations remained below 100 mg/L without exception (Figure 105). The oil accident caused only a very slight and asynchronous increase in effluent COD levels. COD concentrations returned to baseline levels within about 14 days, although no countermeasures were taken apart from the cleaning of the pretreatment tank. The increased hydraulic load in Phase 3 led to elevated effluent concentrations. Due to the clogging of the distribution lines, this matter was however, not further investigated (see 7.5.11).

After the termination of Phase 6 (3 weeks no load), a very slight increase of the COD concentration was detected.

The simulated electric breakdowns had obviously no impact on the treatment performance.

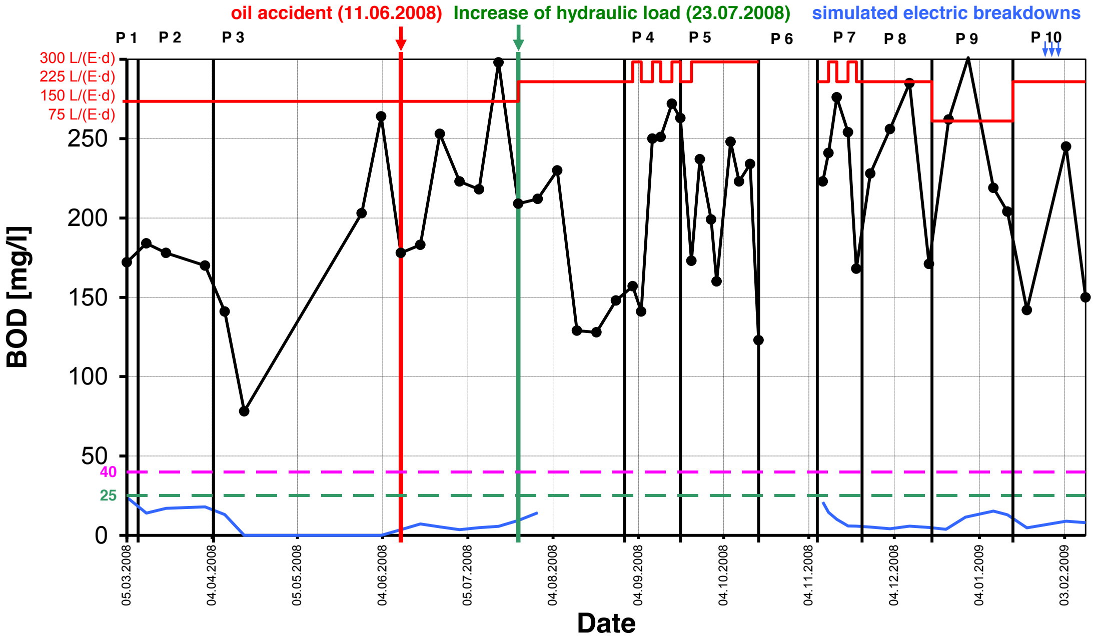

Figure 106: PREMIER TECH - Ecoflex^{TM} – Influent and effluent BOD_5 curves

7.5.5 Nitrogen

<u>Ammonia (NH_4-N)</u>

The course of the ammonia curve reflects the course of nitrification (Figure 107). As a biological process very sensitive to changes in process control, nitrification is a useful indicator of the stability of wastewater treatment systems.

During phases 1 and 2, no significant nitrification was observed. This suggests that the nitrifying population on the filter material was still insufficient until then. Furthermore, the very low wastewater temperature of 8.8 °C had an unfavourable effect on the nitrification process. The oil accident had no measurable influence on the effluent NH_4-N concentration.

From the beginning of Phase 4 until 30 Jul 2008 (see 7.5.11), the effluent NH_4-N concentrations were below 2 mg/L, which indicates a very good nitrification at a mean wastewater temperature of 18°C

From Phase 7 on, the effluent NH_4-N concentration twice increased to just above 12 mg/L which exactly coincided with the elevated influent concentration of more than 50 mg/L, but was independent from the hydraulic load. The second peak can be explained by the very low wastewater temperature of 3°C at this time. Apart from that, the effluent NH_4-N concentrations during these phases remained below 10 mg/L, partially even almost above 1 mg/L (also during the simulated electric breakdowns).

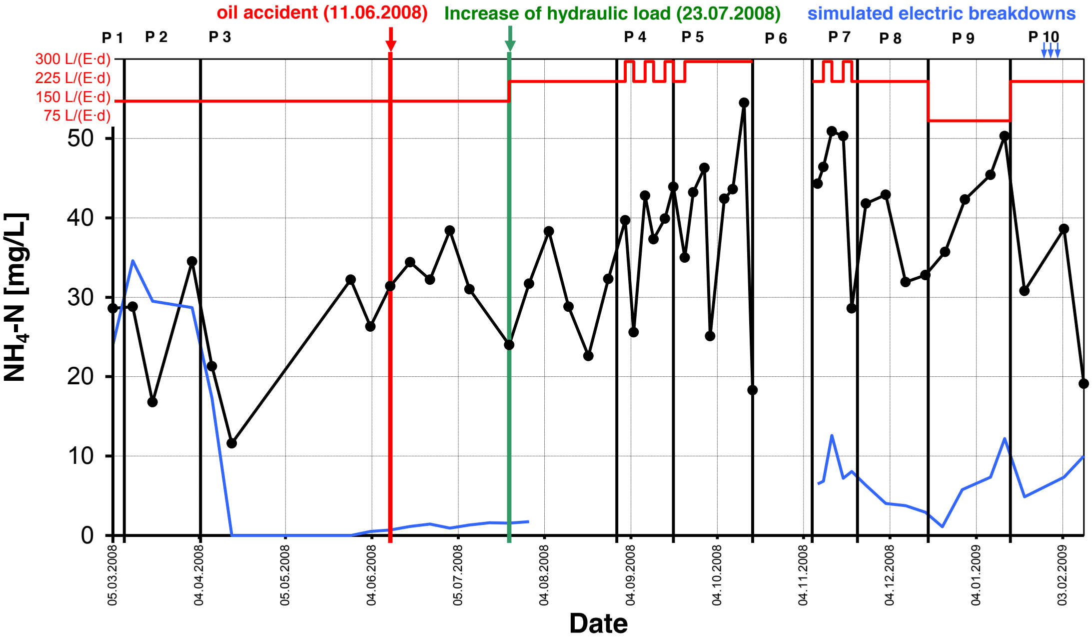

Figure 107: PREMIER TECH - Ecoflex^{TM} – Influent and effluent NH_4-N curves

Inorganic nitrogen

The inorganic nitrogen curve is provided in the Appendix.

Due to minor nitrification, no denitrification occurred until 16 Apr 2008. From this moment on (corresponds to the start of good nitrification), partial denitrification up to 50% to 60% was observed until 30 Jul 2008 (see 7.5.11).

From Phase 7 on, no appreciable denitrification occurred which might be caused by the increased hydraulic load during Phase 7 and by the sharp drop of wastewater temperatures from 12 °C to 3.8 °C afterwards.

7.5.6 Suspended solids

The suspended solids concentration (see Figure 108) generally remained relatively constant at very low levels less than 26 mg/L. The oil accident caused only a very slight and asynchronous increase of effluent SS concentrations (8.4 mg/L at most). Effluent concentrations returned to baseline levels of approx. 4 mg/L within about 14 days, although no countermeasures were taken apart from the cleaning of the pretreatment tank. The increased hydraulic load in Phase 3 led to elevated effluent concentrations. Due to the clogging of the distribution lines, this matter was however, not further investigated (see 7.5.11).

After the resting phase (Phase 6), the maximum concentration of 26 mg/L fell to the normal level of just above 5 mg/L. within 7 days. The initially increased value can be explained by the partial washout of biomass after the resting phase.

The simulated electric breakdowns had no further impact on the effluent SS concentrations.

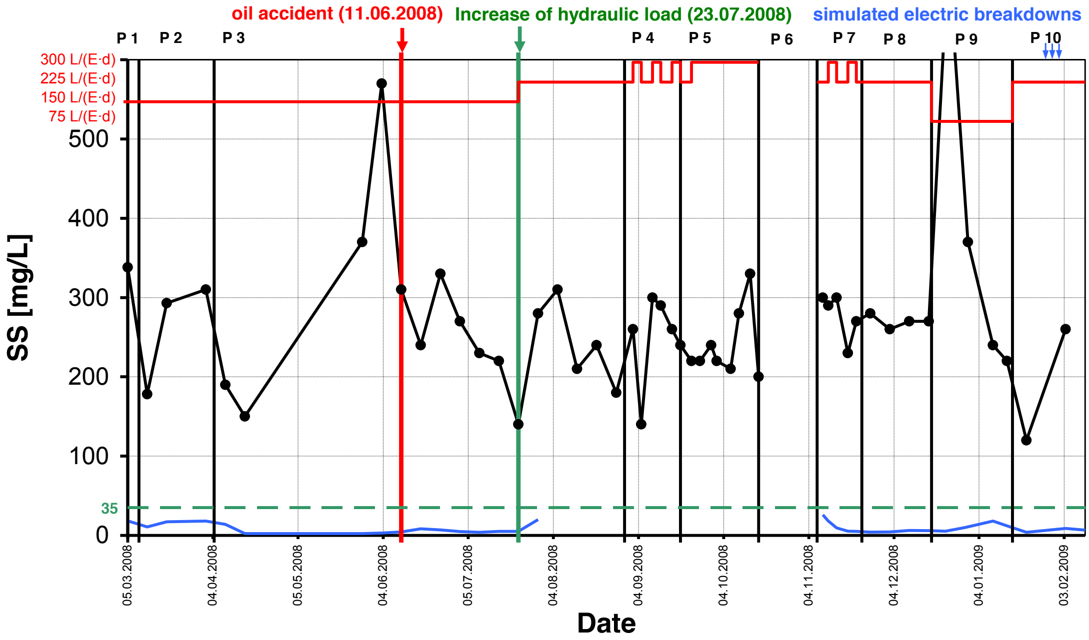

Figure 108: PREMIER TECH - Ecoflex^{TM} – Influent and effluent SS curves

7.5.7 Phosphorus

During the entire study period, the phosphorus elimination rate was mostly low (Figure 109) and hydraulic load-independent. Effluent phosphorus concentrations ran parallel to the influent concentrations, but generally with a slight time lag.

Due to the very low effluent SS concentration (Figure 108), no direct relation to suspended solids and phosphorus is detectable, although phosphorus is not degraded but rather bound and removed by sludge. The effluent phosphorus concentration is thus almost exclusively related to the influent concentrations.

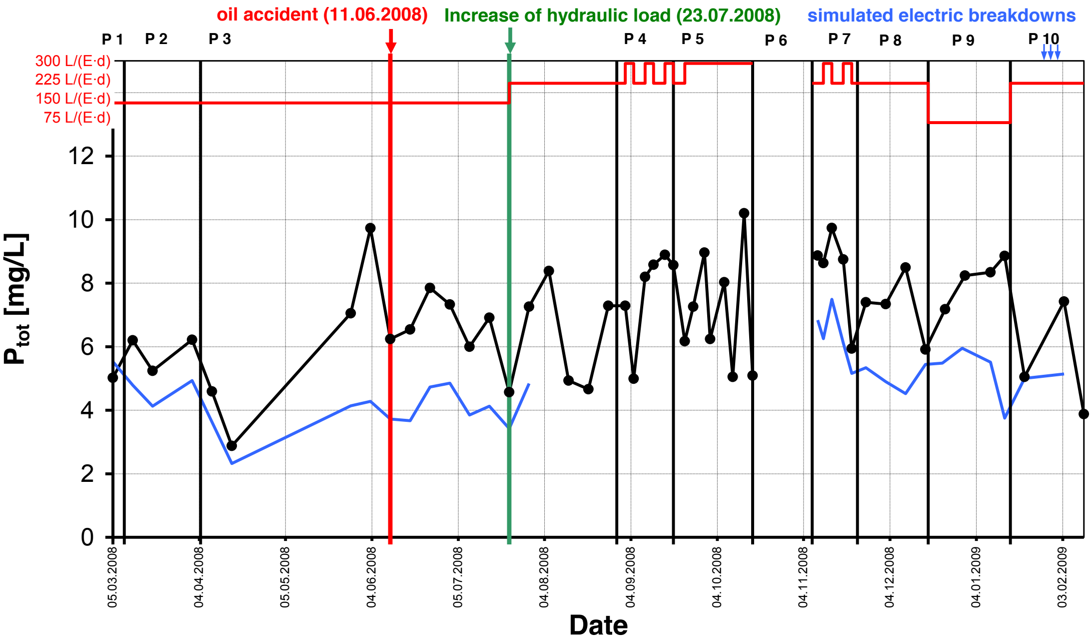

Figure 109: PREMIER TECH - Ecoflex^{TM} – Influent and effluent P_{tot} curves

7.5.8 Degradation rate

Degradation rates for COD, BOD_5, NH_4-N, N_{tot}, P_{tot} and SS are expressed as percentage values (Table 68, Table 69 and Table 70, see 2.9). Negative values mean that influent concentrations were smaller than effluent concentrations. Potential reasons for this are redissolution, washout and (back) transformation from the biomass. Measurement error is another potential cause, but checks for measurement error were performed in the course of quality assurance. Table 69 contains data from Phases 1, 2 and 3 during which the system was tested at 100% hydraulic load, and Table 70 contains data from Phases 4, 5 and 7 during which the system was tested under hydraulic overload conditions.

Phosphorus is not eliminated. Instead, it settles in the primary treatment tank or is incorporated in the biomass, and is then returned with excess sludge to the primary treatment tank.

The mean degradation rate was 89% for COD and 96% for BOD_5. The mean elimination rates were 72% for NH_4-N, 21% for N_{tot} and 26% for P_{tot}.

Table 68: PREMIER TECH - Ecoflex^{TM} - Degradation rates (%) for COD, BOD$_5$, NH$_4$-N, N$_{tot}$, SS and P during the entire study period

PREMIER TECH LTEE - Ecoflex	η_{COD}	η_{BOD}	$\eta_{NH4\text{-}N}$	η_{tot}	η_P	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	31	31	31	31	31	30
mean	89	96	72	21	26	97
median	90	97	86	15	27	97
min.	79	86	-76	-56	-32	91
max.	97	100	100	69	56	99

Table 69: PREMIER TECH - Ecoflex^{TM} - Degradation rates (%) for COD, BOD$_5$, NH$_4$-N, N$_{tot}$, SS and P during the 100% phases (Phases 1, 2 and 3)

PREMIER TECH LTEE - Ecoflex	η_{COD}	η_{BOD}	$\eta_{NH4\text{-}N}$	$\eta_{N\text{-}tot}$	η_P	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	20	20	20	20	20	20
mean	89	95	67	34	30	96
median	89	96	95	46	34	97
min.	79	86	-76	-80	-10	92
max.	96	100	100	71	56	99

Table 70: PREMIER TECH - Ecoflex^{TM} - Degradation rates (%) for COD, BOD$_5$, NH$_4$-N, N$_{tot}$, SS and P during the overload phases (Phases 4, 5 and 7)

PREMIER TECH LTEE - Ecoflex	η_{COD}	η_{BOD}	$\eta_{NH4\text{-}N}$	$\eta_{N\text{-}tot}$	η_P	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	17	17	17	17	17	17
mean	85	92	71	19	19	91
median	86	92	75	30	18	94
min.	69	80	29	-53	-34	65
max.	94	98	94	61	47	98

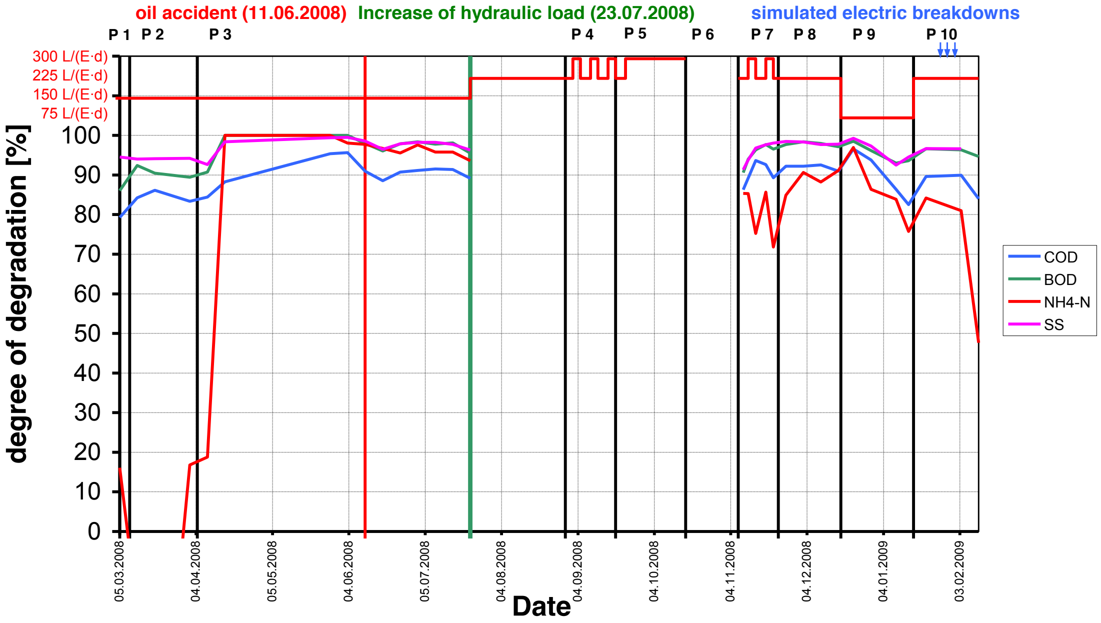

Figure 110: PREMIER TECH - Ecoflex™ – Degradation curves for COD, BOD_5, NH4-N, and SS

In terms of the nominal load, the COD degradation rate did not exceed the 89% level which was achieved during the entire study period. The degradation rates during the hydraulic overload phases (only Phase 7) tend to be lower. The lowest COD elimination rate was observed at the beginning of the study period (Phase 1) and at its end (Phases 9 and 10). The degradation curves (Figure 110) show a sharp decrease of the NH_4-N degradation rate during Phases 1 and 2 as well as at the end of Phase 10.

More detailed analyses of the effluent values are presented in section 7.5.4.

7.5.9 Power consumption

Power consumption (Figure 111) was classified according to the population-specific hydraulic load (no load, 75, 150, 225, 225+300, 300 L/(PE·d)); the nominal load corresponds to the manufacturer's specification (until 10 Oct 2008 = 6 PE, from 10 Oct 2008 = 4 PE).

Mean power consumption values are given in kWh/(PE·a) (see 2.3). Since power consumption in Phase 6 (no load) was calculated based on the nominal pollution load (4 PE), the estimated specific power consumption may be lower under other hydraulic conditions because the values were calculated as the quotient of measured power consumption and the population equivalent of wastewater flow. At higher loads, the population equivalent is often higher than the nominal population equivalent; consequently, power consumption per inhabitant is lower.

Power consumption was measured as the total power consumed by the system. The following power consumers were included in the calculation:

- Feed pump (0.3 kW)

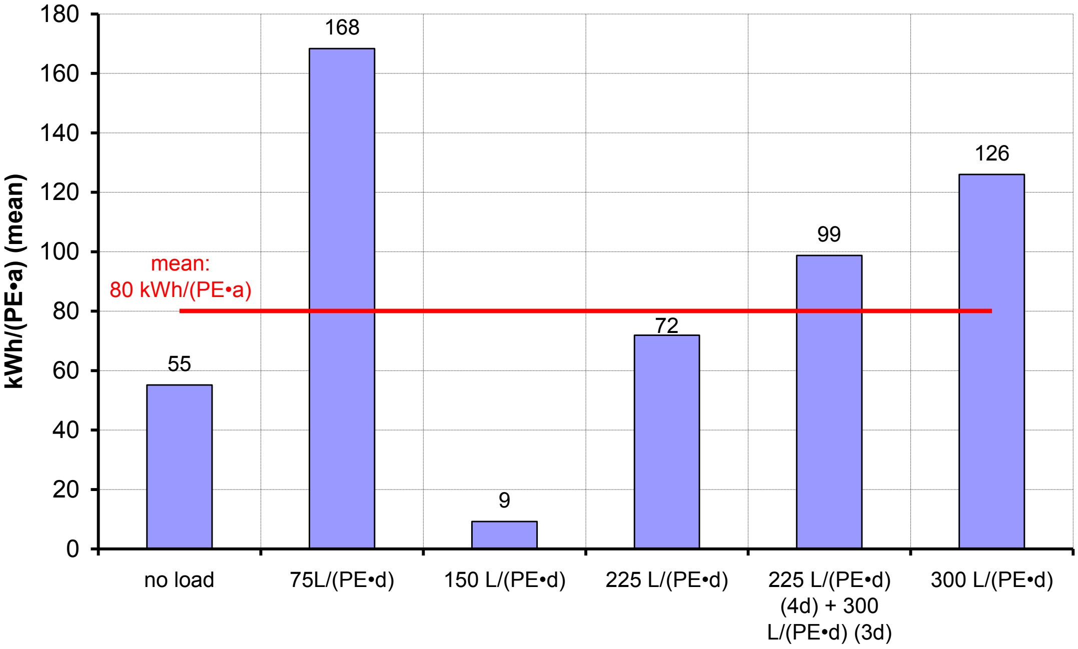

Figure 111: PREMIER TECH - Ecoflex^{TM} – Power consumption

The total power consumption of the system over the entire study period was 80 kWh/(PE·a). Calculated based on the average population equivalent of 3.6 PE (based on BOD_5) (see 2.3), this corresponds to a daily power consumption of 0.8 kWh/d.

Population-independent consumption was 0.6 kWh/d, as calculated based on zero load power consumption of 55 kWh/(PE·a) at 4 PE during phase 6 (no load).

7.5.10 Sludge

The sludge volume was estimated based on the measured sludge height and the known container geometry. As such geometry-dependent estimates are relatively imprecise, their power of evidence is limited.

Overall sludge production during the entire study period was 0.63 m³. At a sludge dry matter content of 46.9 g/L (measured), this corresponds to a sludge mass of 61.73 kg.

The specific sludge volume at the calculated actual load of 3.6 PE is 47.0 gTS/E·d.

7.5.11 Operation and maintenance

Figure 112 shows all unusual events occurring over the entire study period while the system was in operation. Hydraulic loads and influent COD concentrations are also shown for better clarity. The diagram shows the course of events over time.

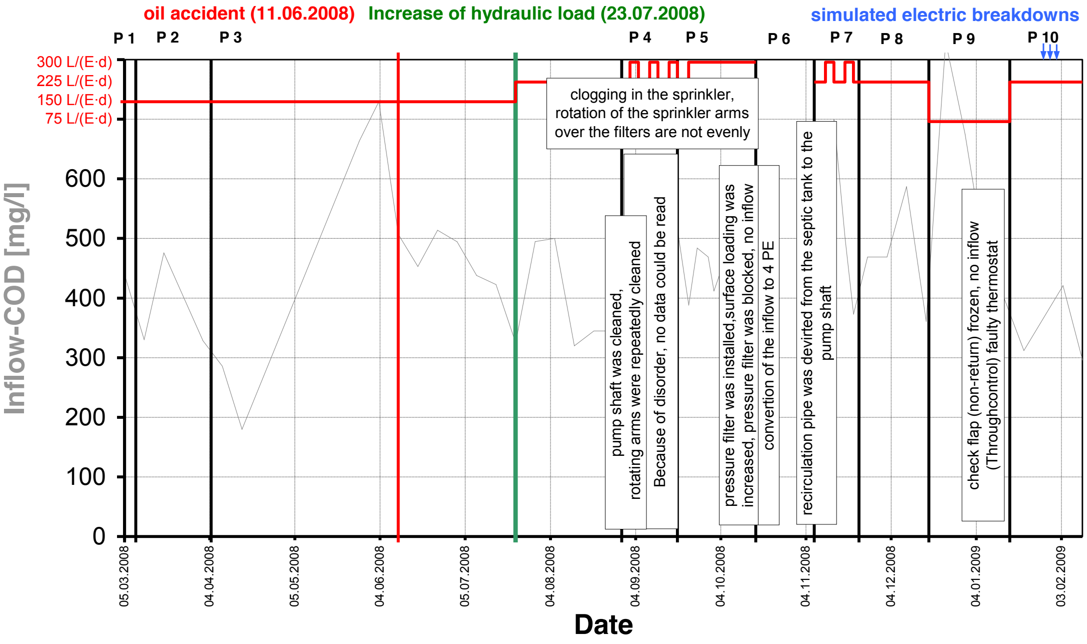

Figure 112: PREMIER TECH - Ecoflex^{TM} – Maintenance log analysis

From 30 Jul to 17 Oct 2008: The distribution arms rotated irregularly and were partially clogged, so that only one filter module was charged and the wastewater trickled on the same spot of the filter respectively. The manufacturer tried to balance this behaviour by inserting a screening device, but did not succeed. Regular operation continued only after 17 Oct 2008.

Between 28 Aug and 17 Sep 2008: due to a failure, data readout was interrupted.

On 3 Sep 2008: the pump shaft was cleaned by means of a sludge vacuum cleaner, and also the rotary distributors were repeatedly cleaned.

The following changes were made in calendar week 39:

a. Installation of a new control PCB

b. Installation of press filter ahead the rotary distributors to avoid clogging

c. Increase of load quantities (according to manufacturer to 50L/15min)

d. Failure “Floodwater“

e. Due to the clogging of the rotary distributer, the pump had no flow capacity anymore

f. Influent was stopped

From 2 Oct until 8 Oct 2008: the system was decommissioned due to a malfunction of the pressure filter facility, which was eliminated by the manufacturer on 8 Oct 2008.

On 13 Oct 2008: the influent was altered from 6 PE to 4 PE.

On 6 Nov 2008: the recirculating duct was redirected from the pretreatment tank to the pump shaft.

From 06 Jan 2009 08:00 hrs until 07 Jan 2009 12:00 hrs, inflow was obstructed due to a frozen non-return check valve. The valve was not part of the PREMIER TECH Ecoflex^{TM} system, but belonged to the test facility. Therefore, PREMIER TECH was not responsible for this malfunction.

7.5.12 Microbiology

The microbiological analysis is presented in Section 6.2.

Effluent water samples were collected on three consecutive days and tested for total coliform bacteria, faecal coliform bacteria, intestinal enterococci, salmonella and intestinal nematodes (see 5.4.2). The results of the microbiological analysis are presented in It can generally be assumed that the number of faecal coliform bacteria undergoes a one- to two-log reduction per treatment stage (compare DWA, 1998). This was almost achieved by this plant with a mean of 0.9-log reduction.

Table 71.

On average of three consecutive days, total coliform bacteria were reduced by 1.5 log steps, faecal coliform bacteria by 0.9 log steps, intestinal enterococci by 1.8 log steps and salmonella by around 1.5 log steps. In intestinal nematodes, there was an avarage increase of 1 egg/L, although this may be explained by statistical uncertainty in the determination of the number. In addition, the simultaneous sampling in the influent and effluent did not consider the time lag during the system passage

It can generally be assumed that the number of faecal coliform bacteria undergoes a one- to two-log reduction per treatment stage (compare DWA, 1998). This was almost achieved by this plant with a mean of 0.9-log reduction.

Table 71: PREMIER TECH - Ecoflex™ – Microbiological analysis

Date		1 Dec 08			2 Dec 08			3 Dec 08			Mean
		[MPN/ mL]	[log]	Δ [log]	[MPN/ mL]	[log]	Δ [log]	[MPN/ mL]	[log]	Δ [log]	Δ [log]
Total coliform bacteria	Influent	930,000	5.97	2.79	390,000	5.59	1.62	430,000	5.63	1.00	1.5
	Effluent	1,500	3.18		9,300	3.97		43,000	4.63		
Faecal coliform bacteria	Influent	150,000	5.18	2.30	240,000	5.38	1.41	73,000	4.86	0.23	0.9
	Effluent	750	2.88		9,300	3.97		43,000	4.63		
Intestinal enterococci	Influent	43,000	4.63	3.25	93,000	4.97	2.00	93,000	4.97	1.59	1.8
	Effluent	24	1.38		930	2.97		2,400	3.38		
Salmonella	Influent	2,100	3.32	0.28	750	2.88	3.40	46,000	4.66	2.03	1.5
	Effluent	> 1,100	3.04		< 0.3	-0.52		430	2.63		
		[Eggs/L]		Δ [Eggs]	[Eggs/L]		Δ [Eggs]	[Eggs/L]		Δ [Eggs]	Δ [Eggs]
Intestinal nematodes	Influent	<1		-2	13 1)		2	<1		-3	-1
	Effluent	2 1)			11			3 1)			

1) statistical uncertainty in determination of the egg counts
2) 0 MPN/ml in effluent, no log reduction determined
"< 1" is assumed to be zero
"<0.3" is assumed to be zero
"> 1,100" is assumed to be 1,100

7.5.13 Comparison of test results with reports and literature data

In terms of the evaluation of the Ecoflex™ system it has to be taken into account that, due to the clogging problems of the rotary distributors, the system did not function properly, in particular during the hydraulic overload phases. For this reason, measured values collected in these most difficult phases are not included in the evaluation.

Chemical oxygen demand

The system should achieve effluent COD concentrations of < 100 mg/L in 24-hour composite samples, in accordance with DIBt effluent class C requirements (Table 2). Measured concentrations were below 100 mg/L in 100% of cases which applies also to the nominal load phases 1, 2 and 3.

The reference value calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (Dorgeloh 2008), is approx. 65 mg/L in the 100% phases, which is above the mean 45 mg/L achieved by the Ecoflex™ system over the entire study period and during the 100% phases 1, 2 and 3, respectively (46 mg/L).

The average effluent COD concentration of trickling filter systems, which are the most similar to the Ecoflex™ system, was determined in practice to be 108 mg/L (Straub 2008). The mean 45 mg/L achieved by the Ecoflex™ system is far below this average reference

In a test series performed in *Dorf Mecklenburg*, Germany (Jiroudi 2005), the trickling filter systems used there (5 PE, 26 measurements) achieved a mean effluent COD concentration of 207 mg/L, which is considerably higher than the mean 45 mg/L achieved by the Ecoflex™

system over the entire study period. In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 1.087 mg/L (223 mg/L - 2.128 mg/L, 135 measurements).

According to FLASCHE 2002, 5 trickling filter systems achieved a mean effluent COD concentration of 69.9 mg/L, which is slighty higher the mean 45 mg/L achieved by the Ecoflex^{TM} system.

According to BOLLER 2004, 121 trickling filter systems systems yielding 486 measurement values achieved a mean effluent COD concentration of 160 mg/L, which is far higher than the mean 45 mg/L achieved by the Ecoflex^{TM} system.

Biological oxygen demand in five days

The system should achieve effluent BOD_5 concentrations of < 25 mg/L in 24-hour composite samples, in accordance with DIBt effluent class C requirements (Table 2). Measured concentrations were below 25 mg/L in 100% of cases which applies also to the nominal load phases 1, 2 and 3.

The reference value calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approx. 12 mg/L in the 100% phases, which is slightly above the mean 9 mg/L achieved by the Ecoflex^{TM} system over the entire study period and during the 100% phases 1, 2 and 3, respectively (8 mg/L).

The average effluent BOD_5 concentration of trickling filter systems , which are the most similar to the Ecoflex^{TM} system, was determined in practice to be 21 mg/L (STRAUB 2008). The mean 9 mg/L achieved by the Ecoflex^{TM} system is far below this average reference

In a test series performed in *Dorf Mecklenburg*, Germany (JIROUDI 2005), the trickling filter systems used there (5 PE, 6 measurements) achieved a mean effluent BOD_5 concentration of 27 mg/L, which is considerably higher than the mean 9 mg/L achieved by the Ecoflex^{TM} system over the entire study period. In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 598 mg/L (160 mg/L - 960 mg/L, 136 measurements).

According to FLASCHE 2002, 5 trickling filter systems achieved a mean effluent COD concentration of 6.7 mg/L, which is slighty below the mean 9 mg/L achieved by the Ecoflex^{TM} system.

Ammonia (NH_4-N)

The reference value for NH_4-N elimination calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approx. 5 mg/L in the 100% phases. The mean effluent NH_4-N concentration of 10 mg/L achieved by the Ecoflex^{TM} system during this stage (Phases 1 to 3, until 23 Jul 2008), is twice as much. Considering the entire study period, the mean effluent NH_4-N concentration of 8.1 mg/L is still far above the reference average.

The average effluent NH_4-N concentration of trickling filter systems, in practice was determined to be 21 mg/L (STRAUB 2008). The mean 8.1 mg/L achieved by the Ecoflex^{TM} system is far below this average reference, although also values measured during water temperatures of below 12°C (cf. STRAUB 2008).

In a test series performed in *Dorf Mecklenburg*, Germany (JIROUDI 2005), the trickling filter systems used there (5 PE, 20 measurements) achieved a mean effluent NH_4-N concentration of 13 mg/L, which is above the mean 8.1 mg/L achieved by the Ecoflex^{TM} system over the entire study period. In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 72 mg/L (24 mg/L - 114 mg/L, 137 measurements).

According to FLASCHE 2002, 5 trickling filter systems achieved a mean effluent COD concentration of 9.1 mg/L, which is roughly corresponds the mean 10 mg/L achieved by the Ecoflex^{TM} system.

Suspended Solids

The system should achieve effluent SS concentrations of < 75 mg/L in one sample, in accordance with DIBt effluent class C requirements (Table 2). Measured concentrations (taken from composite sample) were below 75 mg/L in 100% of cases.

The reference value calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approx. 25 mg/L in the 100% phases, which is clearly above the mean 9 mg/L achieved by the Ecoflex^{TM} system over the entire study period and during the 100% phases 1, 2 and 3, respectively (8 mg/L).

The average effluent SS concentration of trickling filter systems, in practice was determined to be 47 mg/L (STRAUB 2008). The mean 9 mg/L achieved by the Ecoflex^{TM} system is far below this average reference.

In a test series performed in *Dorf Mecklenburg*, Germany (JIROUDI 2005), the trickling filter system used there (5 PE, 10 measurements) achieved a mean effluent SS concentration of 45 mg/L, which is clearly above the mean 9 mg/L achieved by the Ecoflex^{TM} system over the entire study period.

Simulated electric breakdowns

With regard to the parameters COD, BOD_5 and SS (Figure 105, Figure 106 and Figure 108), the simulated electric breakdowns had no influence on the treatment capacity of the system. Only the effluent NH_4-N concentrations (Figure 107) slightly increased, which can also be explained by the lower temperatures.

Power consumption

The power consumption of the investigational system was found to be 0.8 kWh/d which corresponds to the manufacturer's specification. The reference value of 0.05 kWh/(PE·d), calculated as the average power consumption of 5 trickling filter systems tested at the PIA test facility Aachen, Germany (DORGELOH 2008), is clearly below the mean 0.22 kWh/(PE·d) achieved by the Ecoflex^{TM} system. The consumption of the systems tested at the PIA testfield in Aachen varied from approximately 0.01 kWh/(PE·d) to 0.1 kWh/(PE·d). The power consumption of the investigational system thus clearly exceeded this range.

Sludge

Based on the data from DWA, 2003 a total solids concentration of approx. 70 g/(PE·d) was expected. According to the measurements, the actual load was 22.4 g/(PE·d) which was far below the expected value. This might be due to an increase in mineralisation, i.e. more biomass than usual was transformed and released as $CO_{2.}$ Another reason for the poor sludge quantity could be the uncertainty of the measurement method: despite the two-compartment tank only one value was taken.

Microbiological parameters

The investigestional system achieved effluent faecal coliform bacteria counts from 1,500 to 43,000 per 100 ml which is comparable to the reference average for SBR systems (STRAUB ET AL. 2008), a mean 32.000 bacteria per 100 ml with a range (minimum-maximum) of 93 to 120,000 per 100 ml (STRAUB ET AL. 2008). The investigational system had an average log reduction of 0.9 log steps. This is well below the log reduction of 1.5 log steps by STRAUB ET AL. 2008.

In a test series performed in *Dorf Mecklenburg*, Germany (JIROUDI 2005), the biofilter system used there (5 PE) reduced total coliform bacteria to 7,23x10^{7}/100 mL which is clearly higher than the values achieved by the Ecoflex^{TM} system. Faecal coliform bacteria were reduced to 4,1x10^{4}/100ml, which roughly corresponds to the level achieved by the investigational system. The investigational system had an average log reduction of 1.5 log steps. This is well below the faecal coliforms log reduction of 3.2 log steps by JIROUDI 2005.

7.5.14 Summary

The investigational system was operated at a load of 6 PE before 10 Oct 2008. From 10 Oct on, the system was operated at 4 PE at the request of the manufacturer due to the occurrence of overflow.

Due to the fact that failures occurred related to the distribution of wastewater to the filters from the 20 Jul to the 17 Oct 2008 (see 7.5.11), the according values were removed from the data analysis. This interferes with the general view of the system, since during this stage it was operated at the maximum hydraulic load. This fact has to be taken into account on the evaluation of the system.

During its normal operation, the Ecoflex^{TM} system mostly achieved excellent effluent concentrations in terms of COD, BOD_5, SS und NH_4-N. All values were below the German and French statutory limits.

Apart from the clogging problems during the hydraulic overload phases, the treatment efficiency proved to be very stable.

The measured power consumption was higher than the reference values taken from literature data.

7.6 HUBER - 3K PLUS®

7.6.1 Loading conditions

The HUBER - 3K PLUS® was installed by the manufacturer (HUBER DeWaTec). The system has a design caoacity of 4 PE and was tested accordingly. The design organic load is equivalent to 240 g BOD_5/d, which is consistent with the influent load specified in the DIBt approval.

The design hydraulic load is 600 L/day. The system was also stressed with 200-litre bath water loads (bathtub tests) 5 times a week, corresponding to approximately 114 L/d (see 5.1.2). According to the authorisation, the maximum permissible hydraulic load for this system is 600 L/d.

The system was operated under the following influent loadings level:

Before 23 Jul 2008[*]:	2.6 $PE_{BOD,60}$
From 23 Jul 2008 until 17 Oct 2008:	3.1 $PE_{BOD,60}$
Overall mean (across entire study period):	3.4 $PE_{BOD,60}$

Therefore the system achieved a 86% capacity relative to influent BOD_5 over the entire study period.

The primary clarifier and sludge accumulation volumes were taken from the manufacturer's specifications. Using these volumes, we calculated a residence time of 2.7 to 3.3 days for the primary clarifier, 1.7 to days for the bioreactor, and 1.7 to days for the secondary clarifier, yielding a total residence time of 6.1 to 6.7 days (mean 6.4. days) in the treatment plant (see Section 2.6).

7.6.2 Statistical overview of results

The results of the statistical analysis for the entire study period, including the number of samples, the mean, median, minimum and maximum values, the statutory limits in France and Germany (see Sections 2.2.1.1 and 2.2.1.2), and the rates of compliance of effluent COD, BOD_5, SS, NH_4-N, N_{tot} and P_{tot} with the statutory limits (stay below probability) are shown in below (Table 72 and Table 73). Mean, median, minimum and maximum values as well as the statutory limits in France (FR) and Germany (DE) are expressed in units of mg/L. The number of samples is a dimensionless parameter. The stay below probability is given in percent (%).

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[*] See Section 5.1.2: A higher hydraulic load (150% design load) was used at the later date in order to compensate for the low influent concentrations at design load.

Table 72: Huber - 3K Plus: Statistical analysis of COD, BOD_5 and SS

Huber - 3K Plus®	COD		BOD			SS	
	In	Out	In	Load (real)*	Out	In	Out
	[mg/l]	[mg/l]	[mg/l]	[E]	[mg/l]	[mg/l]	[mg/l]
Number of samples	50	49	50	50	49	49	49
mean	456	56	207	3,4	11	269,0	11,2
median	469	52	215	3,2	8	260,0	8,4
min.	180	25	78	1,0	0	120,0	2,8
max.	830	144	301	5,8	52	730,0	44,0
legally binding value (DE / FR)		**150 / 125**			**40 / 25**		**-- / 35**
stay below of legally binding value (DE)		100%			96%		
stay below of legally binding value (FR)		98%			92%		96%

* Load (real); see Section 2.3

Table 73: Huber - 3K Plus: Statistical analysis of nitrogen and phosphorus

Huber - 3K Plus®	NH_4-N		N_{tot}		P_{tot}	
	In	Out	In	Out	In	Out
	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]
Number of samples	50	49	50	49	50	49
mean	35,1	19,5	47,4	28,9	7,0	4,9
median	34,8	21,4	46,5	28,0	7,3	4,7
min.	11,6	< 0,5	19,8	9,7	2,9	2,8
max.	54,5	47,9	71,6	56,4	10,2	7,4
legally binding value (DE / FR)		-- / --		-- / --		-- / --
stay below of legally binding value (DE)						
stay below of legally binding value (FR)						

Chemical oxygen demand (COD)

The system achieved a mean effluent COD of 56 mg/L over the entire study period; the maximum was 144 mg/L. Measured COD levels were below the German statutory limit of 150 mg/L (see Section 2.2.1.1) in 100% of cases, and were below the French statutory limit of 125 mg/L (see Section 2.2.1.2) in 98%. In other words, the measured values exceeded the German limit in 0 cases and exceeded the French limit in 1 case (see Section 7.6.4). Hence, the system met the statutory effluent requirements for Germany in all cases and met the French statutory effluent requirements in all but one case.

Biochemical oxygen demand (BOD_5)

The system achieved a mean effluent BOD_5 of 11 mg/L over the entire study period; the maximum was 52 mg/L. Measured BOD_5 levels remained below the German statutory limit of 40 mg/L in 96% of cases, and were below the French statutory limit of 25 mg/L in 92%. In other words, the measured values exceeded the German limit in 2 cases and exceeded the

French limit in 4 cases (see Section 7.6.4). Hence, the system met the statutory effluent requirements for Germany and France in the vast majority of cases.

Suspended solids (SS)

The system achieved a mean effluent SS concentration of 11.2 mg/L over the entire study period; the maximum was 44 mg/L. Measured SS concentrations were below the French statutory limit of 35 mg/L in 96% of cases. In other words, the measured values exceeded the French limit in 2 cases (see Section 7.6.6). Hence, the system met the statutory effluent requirements for France in the majority of cases. There are no statutory limits for suspended solids in Germany.

Nitrogen (NH_4-N and N_{tot})

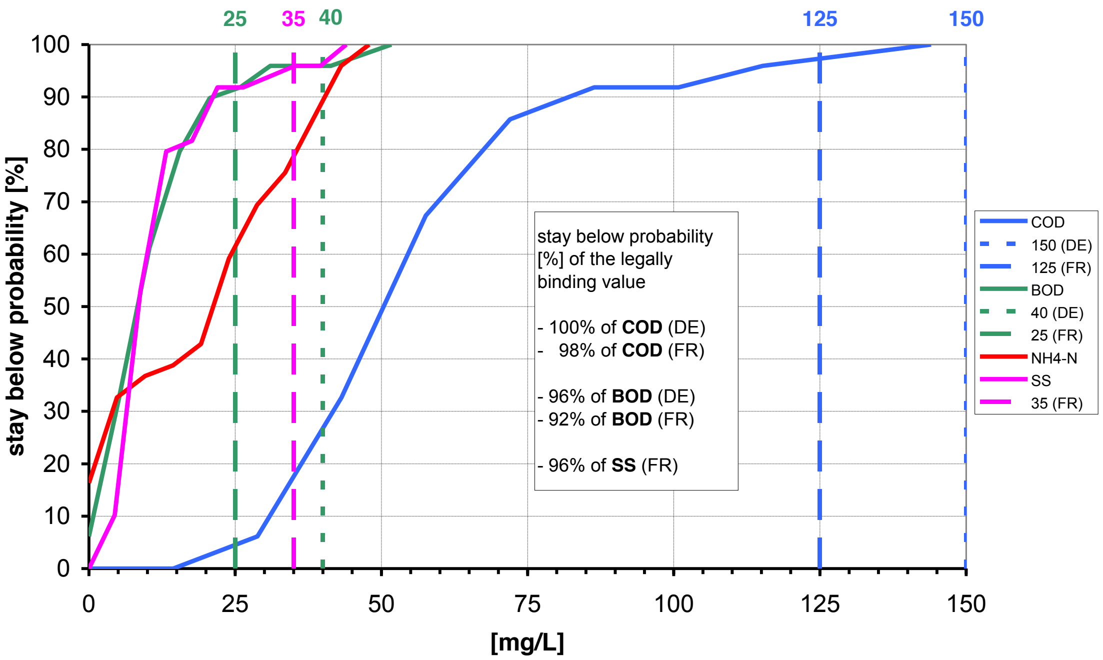
- **Ammonia (NH_4-N):**
  The system achieved a mean effluent NH_4-N concentration of 19.5 mg/L over the entire study period; the maximum was 47.9 mg/L (see Section 7.6.5).
- **Total nitrogen (N_{tot}):**
  The system achieved a mean effluent N_{tot} concentration of 28.9 mg/L over the entire study period; the maximum was 56.4 mg/L (see Section 7.6.5).

Total phosphorus (P_{tot})

The system achieved a mean effluent P_{tot} concentration of 4.9 mg/L over the entire study period; the maximum was 7.4 mg/L (see Section 7.6.7).

7.6.3 Operational and process stability

Process stability was described in terms of compliance with statutory limits for target parameters (stay below probability) as shown in Figure 113. The steeper the curve, the more "stably" the system is operating. A stable system maintains steady effluent concentrations in spite of changes in influent concentration and temperature, etc. (see Section 2.10.9).



stay below probability [%] of the legally binding value

- 100% of **COD** (DE)
- 98% of **COD** (FR)

- 96% of **BOD** (DE)
- 92% of **BOD** (FR)

- 96% of **SS** (FR)

Figure 113: Huber - 3K Plus: Stay below probability for COD, BOD$_5$, NH$_4$-N and SS

7.6.4 COD and BOD$_5$ elimination

The combined parameters for organic matter were analysed based on the COD curve across the entire study period. In Figure 114, the horizontal lines at 150 mg/L and 125 mg/L, respectively, represent the German and French maximum limits.

The course of the BOD$_5$ curve (Figure 115) is similar to that of the COD curve. The mean effluent COD/ BOD$_5$ ratio is 5 to 1.

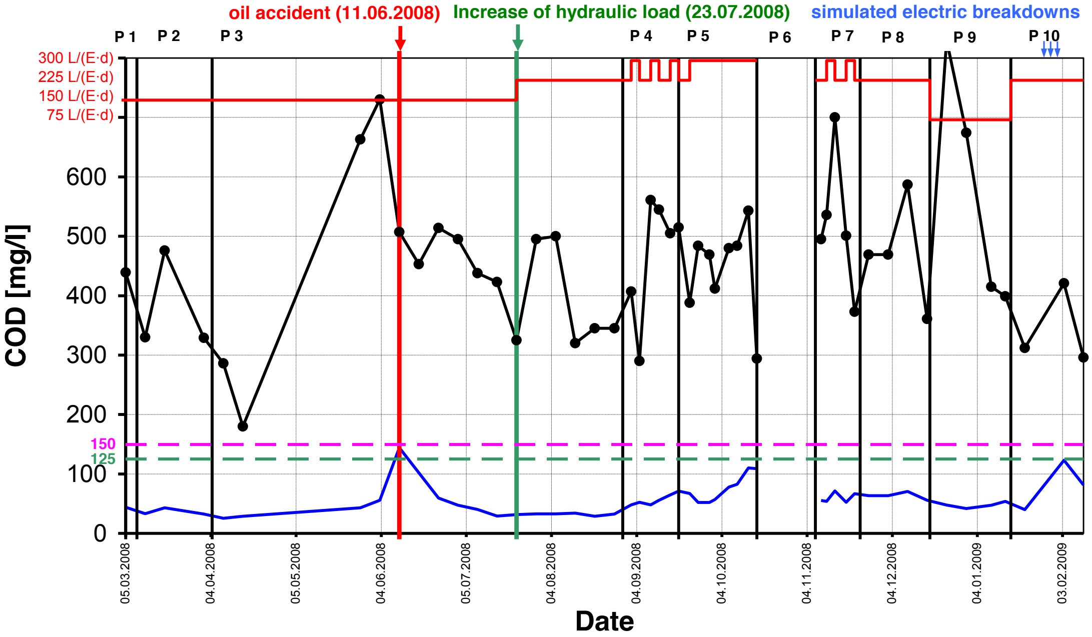


Figure 114: Huber - 3K Plus: Influent and effluent COD curves

Effluent COD levels remained below 100 mg/L with few exceptions (Figure 114). The oil accident resulted in a very sharp rise in COD to levels above 125 mg/L. After the primary clarifier was cleaned and the fixed bed reactor thoroughly hosed down on 17 June 2008 (see Section 7.6.11), effluent concentrations stabilised to baseline levels within about 14 days. The increase in design hydraulic load in Phase 3 had no measurable effect on COD concentrations. Periodic 200% hydraulic loading on 3 days per week (Phase 4) increased effluent COD concentrations to approximately 50 mg/L. This rise continued during Phase 5 and reached a level of about 110 mg/L by the beginning of Phase 6. As the oxygen content (mean 5.4 mg/L during Phase 5) and wastewater temperatures (mean 16°C during Phase 5) at that time were sufficient, one must assumed that the high hydraulic load must have been the reason for the rise in effluent concentration.

No increase was detected after completion of Phase 6 (3 weeks with no load). Effluent COD concentrations remained at around 50 mg/L until the middle of Phase 10. The only rise was a brief one observed during the simulated electrical breakdowns, where levels rose to roughly 125 mg/L. A temporary increase in influent concentrations of hard-to-degrade substances could be the cause of this phenomenon because it was observed at the same time in nearly all of the SWWTPs studied (see Section 7.6.13).

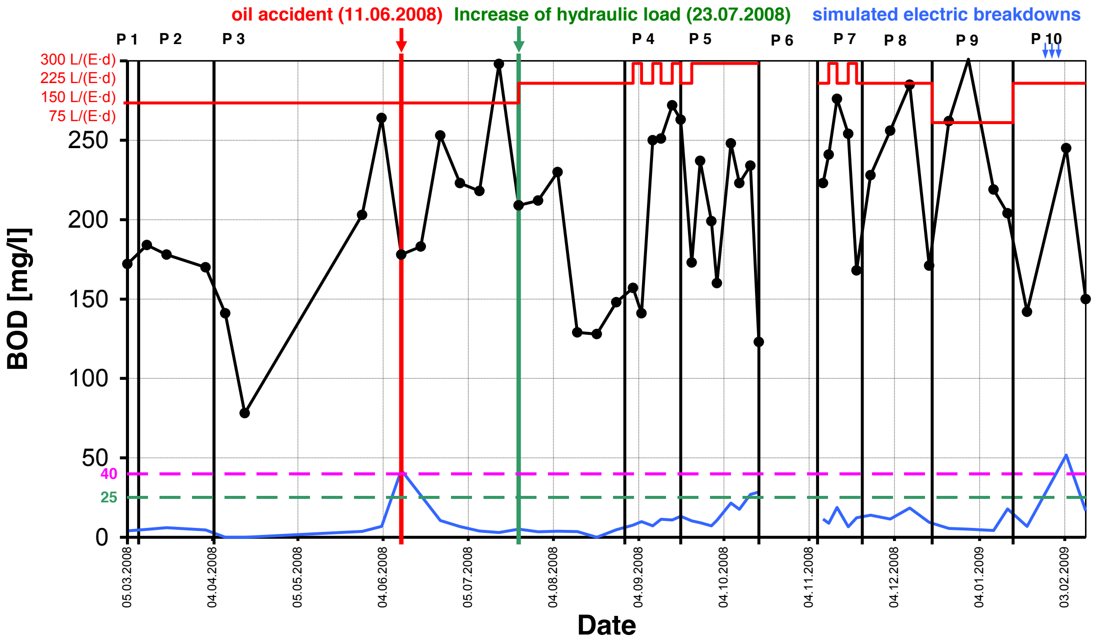


Figure 115: Huber - 3K Plus: Influent and effluent BOD_5 curves

7.6.5 Nitrogen

Ammonia (NH_4-N)

The course of ammonia concentration (Figure 116) reflects the course of nitrification. As a biological process very sensitive to changes in process control, nitrification can be used as an indicator of changes in wastewater treatment systems.

Nitrification collapsed completely during the oil accident but recovered within about 14 day after thorough cleaning of the fixed bed reactor on 17 June 2008 (see Section 7.6.11)

From 23 July 2008 on, effluent NH_4-N concentrations rose sharply (from approx. 0 mg/L to 45 mg/L) and continuously in response to the increase in hydraulic load from 150 L/(PE·d) to 225 L/(PE·d) although temperatures were in the highest range observed during the entire test period (mean 17°C during Phases 4 and 5). Oxygen concentrations of 6.2 mg O_2/L, which is more than sufficient for biological processes, were detected during this time.

During the remaining test period, no significant nitrification occurred except at the beginning of Phase 7 and at the end of Phase 9. The low hydraulic load could be a potential reason for the improvement in effluent concentration during Phase 9. The simulated electrical breakdowns can also prevent nitrification, in which case the effluent concentration would be even higher than the influent concentration. The fact that nitrification was at times poor from Phase 7 on therefore could be attributable to the low temperatures, ranging from 5°C to 12°C, and the increased hydraulic load.

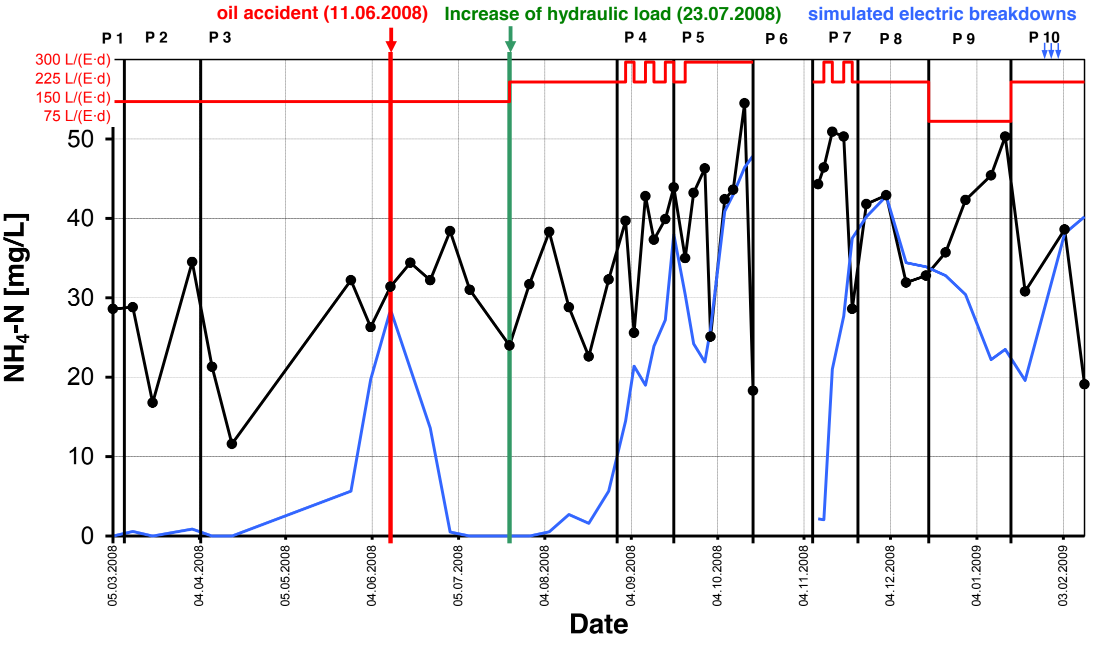


Figure 116: Huber - 3K Plus: Influent and effluent NH_4-N curves

Inorganic nitrogen

The inorganic nitrogen curve can be found in the Appendix.

Inorganic nitrogen concentrations increased by around 10 mg/L by the end of Phase 3. As these concentrations were 5 to 10 mg/L lower than the influent concentrations and because the NH_4-N concentrations were predominantly low, the occurrence of partial denitrification (approx. 30-60%) can be assumed. The oil accident was the only thing preventing denitrification. Inorganic nitrogen concentrations did not rise until Phase 4. From then on, they rose to a peak 50 mg/L and later remained at a mean concentration of about 40 mg/L, which was approximately equal to the effluent NH_4-N concentrations. Consequently, no further significant denitrification occurred. Brief, approximately 60% denitrification was observed between Phases 9 and 10 in spite of the low temperatures.

7.6.6 Suspended solids

Effluent SS concentrations (Figure 117) generally remained relatively constant at very low levels (usually below 10 mg/L). The oil accident briefly increased the effluent concentration to 44 mg/L. After thorough cleaning of the FBR on 17 June 2008 (see Section 7.6.11), concentrations decreased to baseline levels within about 14 days. During Phase 5 (300 L/[PE·d]), the concentration rose continuously to 34 mg/L up until the beginning of Phase 6. This can be attributed to the high hydraulic load: The residence time during secondary treatment was thereby reduced and the settling process had a limiting effect. The maximum surface flow rate was 0.049 m/h at the design load of 150 L/(PE·d) and Q_d/10 (DIBt authorisation specification), 0.1 m/h at a load of 300 L/(PE·d) (Q_d/10), and 0.11 m/h with the additional bath water loads.

From Phase 7 on, effluent levels remained constant at less than 10 mg/L and increased only once, and briefly, to a peak 43 mg/L in response to the simulated electrical breakdowns. We believe that this could have occurred due to either the simulated electrical breakdowns (see Section 5.1.1) or to the presence of a hard-to-degrade substance in the influent resulting in the death and loss of biomass because a similar peak occurred at nearly all of the SWWTPs and was also reflected in the influent COD and BOD_5 concentrations (Figure 114 and Figure 115).

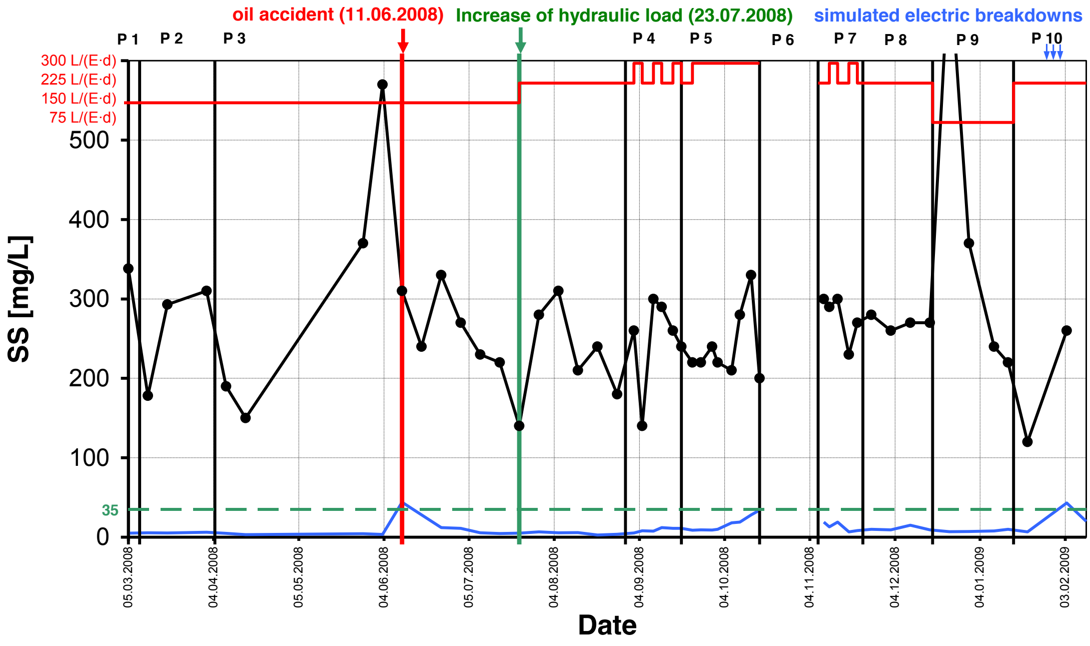


Figure 117: Huber - 3K Plus: Influent and effluent SS curves

7.6.7 Phosphorus

Phosphorus elimination (Figure 118) was low and hydraulic load-independent during the entire study period. Effluent concentrations ran parallel to influent concentrations, but generally exhibited a slight time lag. The peak of over 6 mg/L induced by suspended solids during the oil accident decreased within 2 weeks of the incident, and a mean effluent concentration of about 4 mg/L was achieved.

Comparison shows that effluent phosphorus concentrations are directly related to effluent SS concentrations because bound phosphorous is eliminated together with suspended solids. Phosphorus is not degraded, but rather is "bound" and removed by sludge.

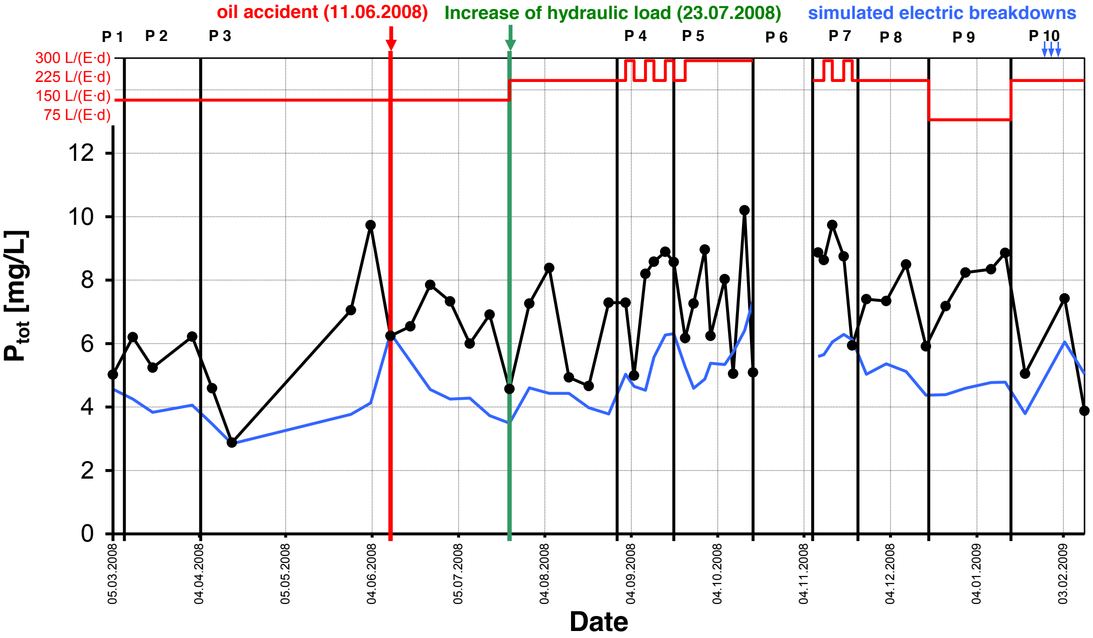


Figure 118: Huber - 3K Plus: Influent and effluent P_{tot} curves

7.6.8 Degradation rate

Degradation rates for COD, BOD_5, NH_4-N, N_{tot}, P_{tot} and SS are expressed as percentage values (Table 74, Table 75 and Table 76; cf. Section 2.9). Negative values imply that influent concentrations were smaller than effluent concentrations. In this case, redissolution, washout and conversion (or re-conversion) from the biomass could have occurred. Measurement error is also possible, but was tested for in the scope of quality assurance. The data for Phases 1, 2 and 3, during which the system was tested at 100% hydraulic load, are presented in Table 75, and those for Phases 4, 5 and 7, during which the system was tested during under hydraulic overload conditions, are shown in Table 76.

Phosphorus is not eliminated. Instead, a fraction either settles in the primary clarifier or is incorporated in the biomass and transported with excess sludge back to the primary clarifier.

The mean degradation rate was 87% for COD and 95% for BOD_5. Mean elimination rates were 44% for NH_4-N, 37% for N_{tot}, and 27% for P_{tot}.

Table 74: Huber - 3K Plus: Degradation rates (%) for COD, BOD_5, NH_4-N, N_{tot}, SS and P (overall for entire study period)

Huber - 3K Plus®	η_{COD}	η_{BOD}	η_{NH4-N}	η_{N-tot}	η_{P}	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	49	49	49	49	49	48
mean	87	95	44	37	27	96
median	89	96	51	41	31	96
min.	63	76	-162	-78	-44	83

Table 75: Huber - 3K Plus: Degradation rates (%) for COD, BOD_5, NH_4-N, N_{tot}, SS and P during 100% loading (Phases 1, 2 and 3)

Huber - 3K Plus®	η_{COD}	η_{BOD}	η_{NH4-N}	η_{N-tot}	η_{P}	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	19	19	19	19	19	19
mean	90	97	86	53	30	97
median	91	98	99	58	31	98
min.	72	76	9	19	-1	86
max.	94	100	100	79	58	99

Table 76: Huber - 3K Plus: Degradation rates (%) for COD, BOD$_5$, NH$_4$-N, N$_{tot}$, SS and P during overload periods (Phases 4, 5 and 7)

Huber - 3K Plus®	η_{COD}	η_{BOD}	η_{NH4-N}	η_{N-tot}	η_P	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	19	19	19	19	19	19
mean	85	93	23	31	23	95
median	87	95	32	35	31	96
min.	63	77	-162	-78	-44	83
max.	91	97	96	60	46	98

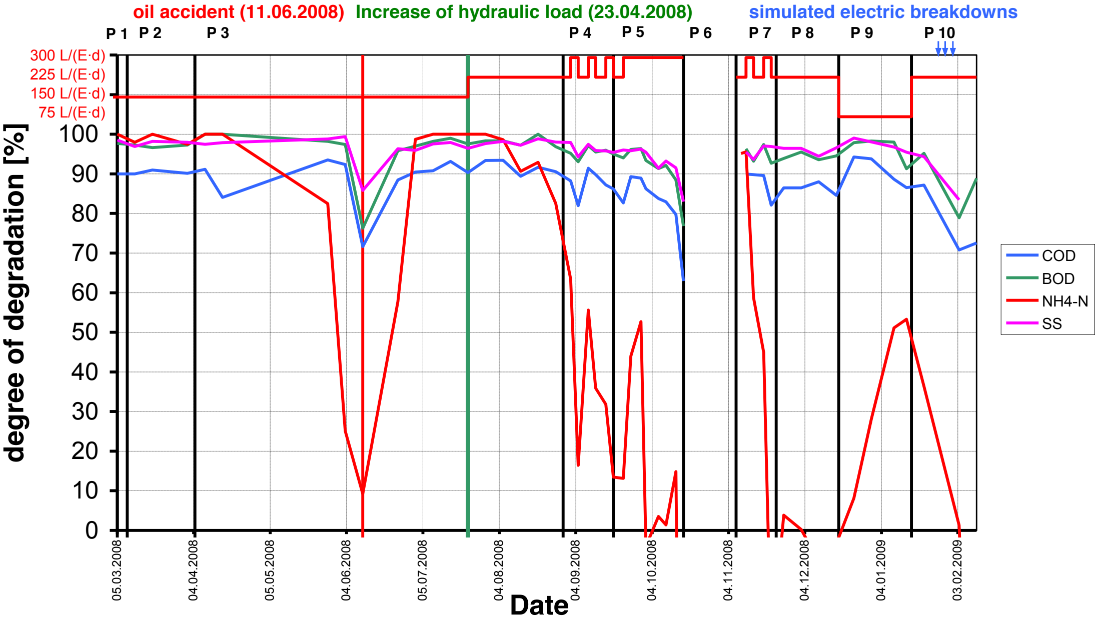


Figure 119: Huber - 3K Plus: Degradation curves for COD, BOD$_5$, NH$_4$-N and SS

The COD degradation rate at 100% design load (90%) was slightly higher than the overall rate (87%) during the entire study period. Degradation rates achieved during the hydraulic overloading phases tended to be lower. The lowest rate (ca. 60%) of COD elimination efficacy was observed at the end of Phase 5 (300 L/[PE·d]). The degradation curves (Figure 119) show that the increase in design flow from 150 L/(PE·d) to 225 L/(PE·d) resulted in a decrease in NH$_4$-N degradation.

Degradation rates for all parameters decreased by about 20 percentage points during hydraulic overloading (Phase 5) and interruptions (simulated electrical breakdowns in Phase 10), but returned to average levels within a few days. More detailed analyses of effluent values are presented in Section 7.6.4.

7.6.9 Power consumption

Power consumption (Figure 120) was classified according to the PE-specific hydraulic load of the individual SWWTPs (no load and 75, 150, 225, 225+300 or 300 L/[PE·d]) using the design population equivalent specified in the approval (4 PE).

Mean power consumption values are expressed in units of kWh/(PE·a) (see Section 2.3). Since power consumption in Phase 6 (no load) was calculated based on the design population equivalent (4 PE), specific power consumption values estimated under other hydraulic loading conditions may be lower because they were calculated as the quotient of the measured power consumption and the actual population equivalent. At higher loads, the actual population equivalent is often higher than the design population equivalent, resulting in a lower power consumption rate per inhabitant.

Only total power consumption (sum of all power consumed by the system) was assessed. The system contains the following power-consuming units:

- Air compressor engine (0.13 kWh)

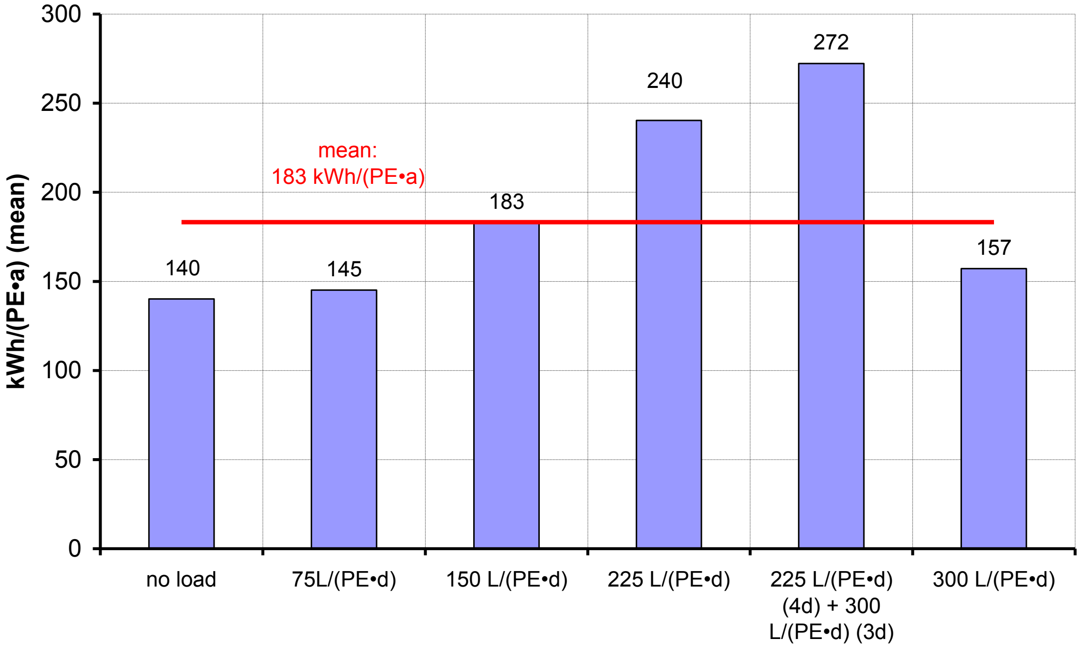


Figure 120: Huber - 3K Plus: Power consumption

Total power consumption of the investigational system across the entire study period was a mean 183 kWh/(PE·a). Calculated based on the mean population equivalent of 3.4 PE relative to BOD_5 (see Section 2.3), this corresponds to a daily power consumption rate of 1.7 kWh/d.

Population-independent consumption, calculated based on power consumption at 4 PE during Phase 6 (no load), was 140 kWh/(PE·a) or 1.7 kWh/d.

7.6.10 Sludge

Sludge production was estimated based on the measured sludge height and the known container geometry. Such geometry-dependent estimates are relatively imprecise and of limited value.

Total sludge production for the entire study period was estimated to be 2.02 m³. At a sludge dry matter content of 28.4 g/L (measured), this corresponds to a sludge mass of 57.51 kg.

At the calculated actual load of 3.4 PE, this yields a specific sludge production of 47 g dry matter/(PE·d).

7.6.11 Operation and maintenance

Figure 121 shows all unusual incidents occurring while the system was in operation during the study. Hydraulic loads and influent COD concentrations are also shown for better clarity. The diagram shows the temporal sequence of events over time.

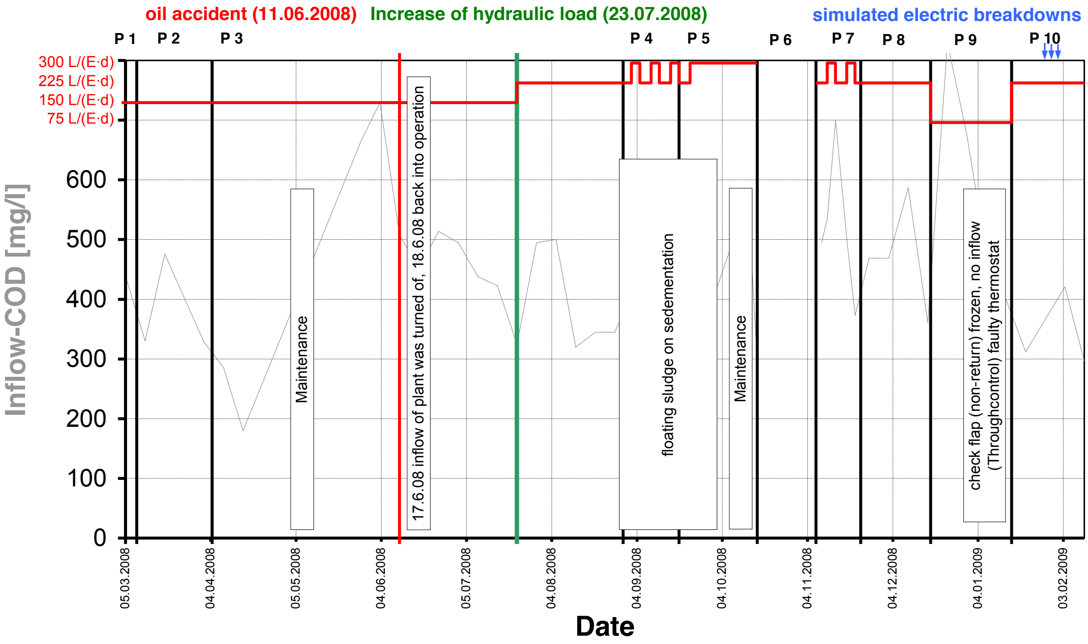


Figure 121: Huber - 3K Plus: Maintenance log analysis

Maintenance was performed on 29 Jan (not shown in Figure 121), 6 May and 9 Oct 2008.

17 Jun 2008: After the oil accident, inflow to the system was switched off at 0910 hrs. The whole system was emptied, the fixed bed reactor removed and cleaned, and the membrane pipe aerator exchanged.

18 Jun 2008: The primary clarifier was filled with wastewater, the biological reactor and secondary clarifier were filled with clear water, and the system was re-started at 0920 hrs.

28 Aug to 25 Sep 2008: Slight scum accumulation was detectable in the secondary clarifier.

06 Jan 2009 (08:00 hrs) to 07 Jan 2009 (12:00 hrs): Inflow was obstructed due to a frozen non-return check flap. The valve was not part of the standard system equipment but rather, an experimental device. Therefore, the manufacturer (Huber) was not responsible for this malfunction. On the whole, the system ran without internal malfunctions.

7.6.12 Microbiological parameters

Effluent water samples were collected on three consecutive days and tested for total coliform bacteria, faecal coliform bacteria, intestinal enterococci, salmonella and intestinal nematodes (see Section 5.4.2). The results of the microbiological analysis are presented in Table 77.

On average of three consecutive days, total coliform bacteria were reduced by 1.3 log steps, faecal coliform bacteria by 1.2 log steps, intestinal enterococci by 1.7 log steps and salmonella by around 1.9 log steps. In intestinal nematodes, there was an avarage reduction of 2 eggs/L. On some days, there was an increase, although this may be explained by statistical uncertainty in the determination of the number. In addition, the simultaneous sampling in the influent and effluent did not consider the time lag during the system passage.

It can generally be assumed that the number of faecal coliform bacteria undergoes a one- to two-log reduction per treatment stage (compare DWA, 1998). This range of performance was realized by this plant with a mean of 1.2-log reduction.

As expected, effluent microbiological quality did not meet the requirements for bathing water quality.

Table 77: Huber - 3K Plus: Microbiological analysis

Date		**1 Dec 08**			**2 Dec 08**			**3 Dec 08**			**Mean**
		[MPN/ mL]	[log]	Δ [log]	[MPN/ mL]	[log]	Δ [log]	[MPN/ mL]	[log]	Δ [log]	Δ [log]
Total coliform bacteria	Influent	930,000	5.97	1.34	390,000	5.59	1.62	430,000	5.63	1.04	1.3
	Effluent	43,000	4.63		9,300	3.97		39,000	4.59		
Faecal coliform bacteria	Influent	150,000	5.18	1.00	240,000	5.38	2.00	73,000	4.86	0.72	1.2
	Effluent	15,000	4.18		2,400	3.38		14,000	4.15		
Intestinal enterococci	Influent	43,000	4.63	1.66	93,000	4.97	1.59	93,000	4.97	2.00	1.7
	Effluent	930	2.97		2,400	3.38		930	2.97		
Salmonella	Influent	2,100	3.32	0.69	750	2.88	1.43	46,000	4.66	2.52	1.9
	Effluent	430	2.63		28	1.45		140	2.15		
		[Eggs/L]		Δ [Eggs]	[Eggs/L]		Δ [Eggs]	[Eggs/L]		Δ [Eggs]	Δ [Eggs]
Intestinal nematodes	Influent	<1		-3	13[1)]		12	<1		-2	2
	Effluent	3[1)]			1			2			

1) statistical uncertainty in determination of the egg counts

"< 1" is assumed to be zero

7.6.13 Comparison of test results with reports and literature data

Chemical oxygen demand

According to DIBt Class C specifications (Table 2), effluent COD in composite samples must not exceed 100 mg/L. Measured concentrations were below the 100 mg/L limit in 92% of cases. In addition, they were below the manufacturer's target value of 100 mg/L in 95% of cases during testing at 100% design load (Phases 1, 2, and 3).

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 65 mg/L during 100% loading, which is comparable to the overall mean 56 mg/L achieved by the investigational system during the entire study period (in spite of the stricter test conditions).

Considering that the mean effluent concentration for aerated submerged fixed bed reactor systems in practice was determined to be 139 mg/L (STRAUB 2008), the mean 56 mg/L achieved by the investigational system is higher than the reference average.

The fixed bed reactor system (4 PE) used in a test series in *Dorf Mecklenburg*, Germany (JIROUDI 2005) achieved a mean effluent concentration of 106 mg/L (n=26), which is much higher than that achieved by the investigational system. In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 1.087 mg/L (223 mg/L - 2.128 mg/L, 135 measurements).

The 5 fixed bed reactor systems studied by BOLLER (2004) achieved a mean effluent COD of 69.8 mg/L, which is slightly higher than the mean 56 mg/L achieved by this system.

The 35 fixed/fluidised bed reactor systems investigated by FLASCHE (2002) achieved a mean effluent COD concentration of 147 mg/L (n=62), which is far higher than the 56 mg/L achieved by the investigational system.

Biochemical oxygen demand (BOD_5)

According DIBt Class C specifications (Table 2), effluent BOD_5 concentrations in composite samples must not exceed 25 mg/L. Measured concentrations were below the 25 mg/L limit in 92% of cases. In addition, they were below the manufacturer's target value of 25 mg/L in 95% of cases during testing at 100% design load (Phases 1, 2, and 3).

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 12 mg/L during 100% loading, which is comparable to the overall mean 11 mg/L achieved by the investigational system across the entire study period.

Considering that the mean effluent concentration in aerated submerged fixed bed reactor systems in practice was determined to be 33 mg/L (STRAUB 2008), the mean 11 mg/L achieved by the investigational system is only one-third the reference average.

The fixed bed reactor system (4 PE) used in the test series in *Dorf Mecklenburg* (JIROUDI 2005) achieved a mean effluent BOD_5 concentration of 27 mg/L (n=10), which is higher than the mean 11 mg/L achieved by the investigational system. In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 598 mg/L (160 mg/L - 960 mg/L, 136 measurements).

The 5 fixed bed reactor systems investigated by FLASCHE (2002) achieved a mean effluent BOD_5 concentration of 8.6 mg/L, which is slightly lower than the mean 11 mg/L achieved by the investigational system.

Ammonia (NH_4-N)

The reference value, calculated as the average of 51 SWWTPs with nitrogen elimination tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 5 mg/L during 100% loading. During 100% loading (Phases 1 to 3, until 23 July 2008), the investigational system achieved a mean effluent concentration of approximately 4 mg/L, which was lower than the reference average. However, the overall mean for the entire test period (19.5 mg/L) was far higher than the reference average.

Considering that the mean effluent NH_4-N concentration in aerated submerged fixed bed reactor systems in practice was determined to be 68 mg/L (STRAUB 2008), the mean 19.5 mg/L achieved by the investigational system is higher than the reference average.

The fixed bed reactor system (4 PE) used in the test series in *Dorf Mecklenburg* (JIROUDI 2005) achieved a mean effluent concentration of 27 mg/L (n=20), which is slightly higher than that achieved by the investigational system (19.5 mg/L). In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 72 mg/L (24 mg/L - 114 mg/L, 137 measurements).

The 5 fixed bed reactors tested by FLASCHE (2002) achieved a mean effluent concentration of 10.5 mg/L, which is far lower than the overall mean 19.5 mg/L achieved by this system but approximately equal to the 6 mg/L achieved during the 100% loading phases.

Suspended solids (SS)

According DIBt Class C specifications (Table 2), effluent SS concentrations in random samples must not exceed 75 mg/L. Measured concentrations were below the 75 mg/L limit in composite samples in 100% of all cases. In addition, the observed concentrations were below the manufacturer's target value of 75 mg/L in 100% of cases during testing at 100% design load (Phases 1, 2, and 3).

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 25 mg/L during 100% loading, which is higher than the overall mean 11.2 mg/L achieved by the investigational system across the entire study period. During 100% loading (Phases 1-3), the investigational system achieved a mean effluent concentration of 8 mg/L.

Considering that the mean effluent SS concentration in aerated submerged fixed bed reactor systems in practice was determined to be 33 mg/L (STRAUB 2008), the mean 11.2 mg/L achieved by the investigational system is far lower than the reference average.

The fixed bed reactor system (4 PE) used in the test series in *Dorf Mecklenburg* (JIROUDI 1005) achieved a mean effluent value of 13 mg/L (n=20), which is slightly higher than the overall mean achieved by the investigational system across the entire study period.

Simulated electrical breakdowns

Increases in effluent concentrations of the target parameters during the simulated power outages (Figure 114, Figure 115, Figure 116 and Figure 117) can be attributed to the power outages themselves or to the presence of hard-to-degrade substances in the influent. In the study in Nantes (VIGNOLES, CAUCHI, 2009), however, similar peaks were observed during simulated electrical breakdowns in almost all WWTPs independent of whether they operated using electricity or not. The researchers in Nantes also could not find a plausible explanation for this phenomenon. This issue requires further investigation.

Power consumption

The investigational system achieved a power consumption rate of 1.7 kWh/d, which is consistent with the average power consumption rate specified by the manufacturer (1.5 kWh/d). The reference value, 0.25 kWh/(PE·d), calculated as the overall mean power consumption of 9 aerated fixed bed reactor systems tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is slightly lower than the mean 0.5 kWh/(PE·d) achieved by the investigational system. Power consumption rates for the wastewater systems tested at the PIA test facility in Aachen ranged from approximately 0.18 kWh/(PE·d) to 0.39 kWh/(PE·d). Power consumption by the investigational system was slightly higher.

The fixed bed reactor system (4 PE) used in the test series in *Dorf Mecklenburg* (JIROUDI 2005) achieved power consumption rates of 173 to 370 kWh/(PE·a), equivalent to 1.9 to 4 kWh/d. These power consumption rates are much higher than those achieved by the investigational system.

Sludge

Based on the reference values (DWA 2003), a specific sludge accumulation rate of roughly 70 g dry matter/(PE·d) was expected. The actual measured value was 47 g/(PE·d) was much lower than the expected value, suggesting that increased mineralization (i.e. increased conversion and discharge of biomass as CO_2) may have occurred.

Microbiological parameters

The investigational system reduced faecal coliform bacteria counts to roughly 10,000 to 43,000 per 100 ml. This is comparable to the reference average for fixed bed reactors, a mean 8,400 per 100 ml within a minimum-maximum range of 570 ml to 120,000 per 100 ml (STRAUB et al. 2008). The investigational system had an average log reduction of 1.2 log steps. This This corresponds roughly the log reduction of 1.1 log steps by STRAUB ET AL. 2008.

The fixed bed reactor system (4 PE) used in the test series in *Dorf Mecklenburg* (JIROUDI 2005) achieved mean counts of 1.04×10^8/100 mL for total coliform bacteria and 4.05×10^7/100mL for faecal coliform bacteria. These levels are much higher than those achieved by the investigational system. The investigational system had an average total coliform log reduction of 1.3 log steps. This is well above the faecal coliforms log reduction of 0.1 log steps by JIROUDI 2005.

7.6.14 Summary

The investigational system operated at a mean load of 3.4 PE across the entire study period. Effluent COD concentrations (mean 56 mg/L) remained below 125 mg/L during the entire study period, even during 200% hydraulic loading periods.

Effluent SS concentrations predominantly remained below the 35 mg/L limit (mean 19.9 mg/L). Higher levels were observed only during phases associated with the oil accident and simulated electrical breakdowns.

Overall, the investigational system achieved very stable treatment performance. No system malfunctions occurred during the study period.

The measured power consumption was approximately equivalent to the rate specified by the manufacturer.

7.7 Lauterbach-Kießling – BKF 4 DN2000 Z1

7.7.1 Loading conditions

The BKF 4 DN2000 Z1 was installed by the manufacturer (Lauterbach-Kießling). The system has a design capacity of 4 PE and was loaded accordingly. The design organic load is equivalent to 240 g BOD_5/d, which is consistent with the influent load specified in the DIBt approval.

The design hydraulic load is 600 L/day. The system was also stressed with 200-litre bath water loads (bathtub tests) 5 times a week, corresponding to approximately 114 L/d (see Section 5.1.2). According to the approval, the maximum permissible hydraulic load for this system is 600 L/d.

The system was operated under the following influent loadings level:

Before 23 Jul 2008[*]:	2.6 $PE_{BOD,60}$
From 23 Jul 2008 until 17 Oct 2008:	3.1 $PE_{BOD,60}$
Overall mean (across entire study period):	3.4 $PE_{BOD,60}$

Therefore the system achieved a 86% capacity relative to influent BOD_5 over the entire study period.

The manufacturer specifies a primary clarifier volume of 6 m³ (SWWTP according to the manufacturer). Residence time in the primary clarifier was therefore estimated to be 6 days (see Section 2.6). Based on the area of the filter basins (1.88 m²) and the average influent volume of 1.0 m³/d, the trickling rate was estimated to be 1.88 m/d or 7.9 cm/h, corresponding to a flow rate of approximately 1.1 m in 14 h or 0.58 days. Accordingly, the total residence time in the system was approximately 6.58 days.

7.7.2 Statistical overview of results

The results of the statistical analysis for the entire study period, including the number of samples, the mean, median, minimum and maximum values, the statutory limits in France and Germany (see Sections 2.2.1.1 and 2.2.1.2), and the rates of compliance of effluent COD, BOD_5, SS, NH_4-N, N_{tot} and P_{tot} with the statutory limits (stay below probability) are shown below (Table 78 and Table 79). Mean, median, minimum and maximum values as well as the statutory limits in France (FR) and Germany (DE) are expressed in mg/L. The number of samples is a dimensionless parameter. The stay below probability is given in percent (%).

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[*] See Section 5.1.2: A higher hydraulic load (150% design load) was used at the later date in order to compensate for the low influent concentrations at design load.

Table 78: Lauterbach-Kießling - BKF 4 DN2000 Z1: Statistical analysis of COD, BOD_5 and SS

Lauterbach-Kießling, BKF 4 DN2000 Z1	COD		BOD			SS	
	In	Out	In	Load (real)*	Out	In	Out
	[mg/l]	[mg/l]	[mg/l]	[E]	[mg/l]	[mg/l]	[mg/l]
Number of samples	50	50	50	50	50	49	50
mean	456	60	207	3,4	15	269,0	13,7
median	469	55	215	3,2	11	260,0	8,5
min.	180	29	78	1,0	4	120,0	2,0
max.	830	171	301	5,8	71	730,0	62,0
legally binding value (DE / FR)		**150 / 125**			**40 / 25**		**-- / 35**
stay below of legally binding value (DE)		98%			94%		
stay below of legally binding value (FR)		94%			86%		90%

* Load (real); see Section 2.3

Table 79: Lauterbach-Kießling - BKF 4 DN2000 Z1: Statistical analysis of nitrogen and phosphorus

Lauterbach-Kießling, BKF 4 DN2000 Z1	NH_4-N		N_{tot}		P_{tot}	
	In	Out	In	Out	In	Out
	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]
Number of samples	50	50	50	50	50	50
mean	35,1	17,1	47,4	37,2	7,0	4,9
median	34,8	12,6	46,5	35,2	7,3	4,6
min.	11,6	5,8	19,8	21,1	2,9	2,8
max.	54,5	43,9	71,6	65,4	10,2	6,7
legally binding value (DE / FR)		**-- / --**		**-- / --**		**-- / --**
stay below of legally binding value (DE)						
stay below of legally binding value (FR)						

Chemical oxygen demand (COD)

The system achieved a mean effluent COD of 60 mg/L over the entire study period; the maximum was 171 mg/L. Measured COD levels were below the German statutory limit of 150 mg/L in 98% of cases (see Section 2.2.1.1), and were below the French statutory limit of 125 mg/L in 94% (see Section 2.2.1.2). In other words, the measured values exceeded the German limit in 1 case and exceeded the French limit in 3 cases (see Section 7.7.4). Hence, the system met the statutory effluent requirements for Germany and France in the vast majority of cases.

Biochemical oxygen demand (BOD_5)

The system achieved a mean effluent BOD_5 of 15 mg/L over the entire study period; the maximum was 71 mg/L. Measured BOD_5 levels were below the German statutory limit of 40 mg/L in 94% of cases, and were below the French statutory limit of 25 mg/L in 86%. In other words, the measured values exceeded the German limit in 3 cases and exceeded the French limit in 7 cases (see Section 7.7.4). Hence, the system met the statutory effluent requirements for Germany and France in the majority of cases.

Suspended solids (SS)

The system achieved a mean effluent SS concentration of 13.7 mg/L over the entire study period; the maximum was 62 mg/L. Measured SS concentrations were below the French statutory limit of 35 mg/L in 90% of cases. In other words, the measured values exceeded the French limit in 5 cases (see Section 7.7.6). Hence, the system met the statutory effluent requirements for France in the majority of cases. There are no statutory limits for suspended solids in Germany.

Nitrogen

- **Ammonia (NH_4-N):**
  The system achieved a mean effluent NH_4-N concentration of 17.1 mg/L over the entire study period; the maximum was 43.9 mg/L (see Section 7.7.5).
- **Total nitrogen (N_{tot}):**
  The system achieved a mean effluent N_{tot} concentration of 37.2 mg/L over the entire study period; the maximum was 65.4 mg/L (see Section 7.7.5).

Total phosphorus (P_{tot})

The system achieved a mean effluent P_{tot} concentration of 4.9 mg/L over the entire study period; the maximum was 6.7 mg/L (see Section 7.7.7).

7.7.3 Operational and process stability

Process stability was described in terms of compliance with statutory limits for target parameters (stay below probability) as shown in Figure 122. The steeper the curve, the more "stably" the system is operating. A stable system maintains steady effluent concentrations in spite of changes in influent concentrations, temperature etc. (see Section 2.10.9).

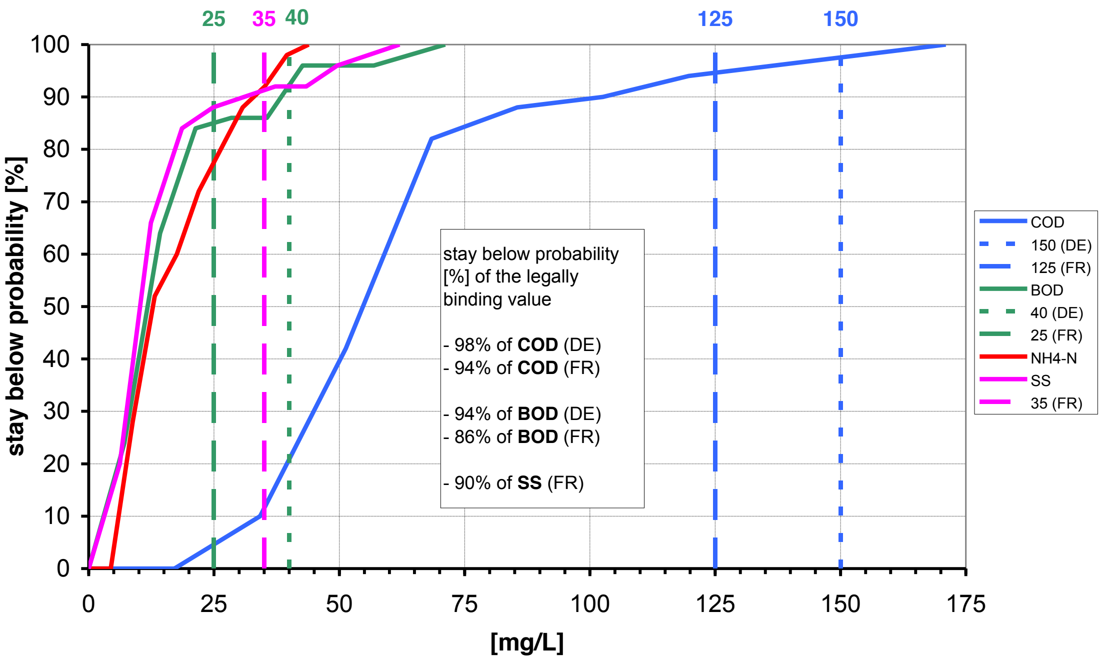

Figure 122: Lauterbach-Kießling - BKF 4 DN2000 Z1: Stay below probability for COD, BOD$_5$, NH$_4$-N and SS

7.7.4 COD and BOD$_5$ elimination

The combined parameters for organic matter were analysed based on the COD curve across the entire study period. In Figure 123, the horizontal lines at 150 mg/L and 125 mg/L, respectively, represent the German and French maximum limits.

The course of the BOD$_5$ curve (Figure 125) is similar to that of the COD curve. The mean effluent COD/ BOD$_5$ ratio is 4 to 1.

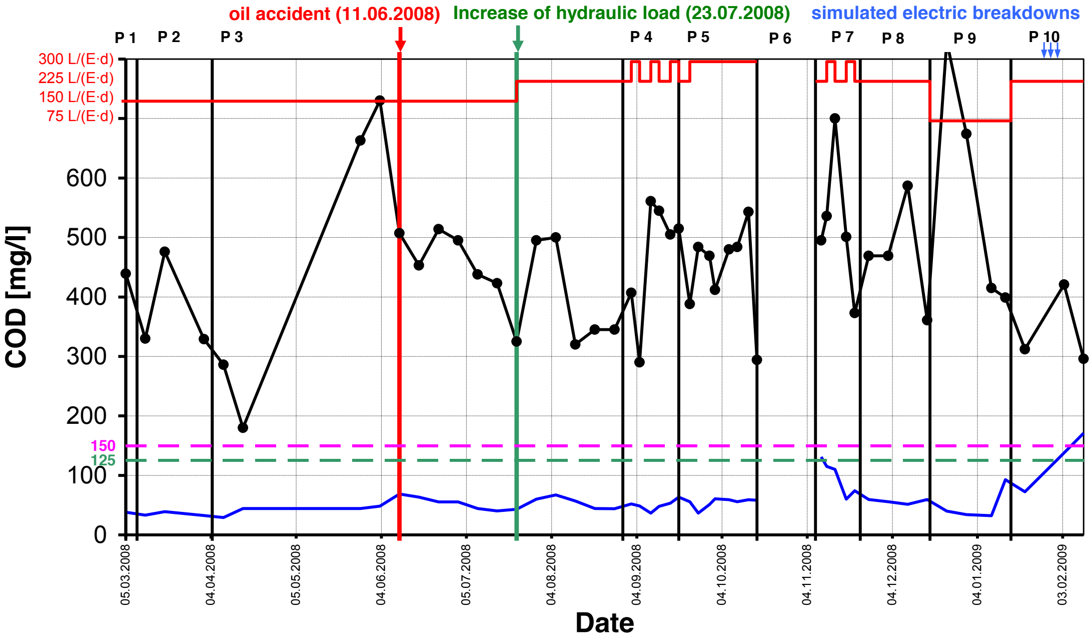

Figure 123: Lauterbach-Kießling - BKF 4 DN2000 Z1: Influent and effluent COD curves

Effluent COD levels remained below 100 mg/L with only 2 exceptions (Figure 123). The oil accident resulted in a very slight rise in COD concentration. Although the only action taken was to clean the primary clarifier, COD concentrations returned to baseline levels within about 14 days of the oil accident. The switch to a higher design hydraulic load in Phase 3 had a very slight effect, which also could have been a result of the higher influent concentration. Intermittent 200% hydraulic loading on 3 days per week (Phase 4) and continuous 200% hydraulic loading for 4 weeks (Phase 5) did not result in any significant rise in effluent COD concentrations.

COD concentrations rose to the highest level (131 mg/L) after completion of Phase 6 (3 weeks with no load), but normalized (to about 60-70 mg/L) by the middle of Phase 7. This could be due to an increased loss of dead biomass after the system was restarted.

The short-term increase in effluent COD levels observed after the re-start following simulated power outages could be due to a temporary increase in hard-to-degrade substances in the influent because this phenomenon was observed at the same time in nearly all of the SWWTPs studied (see Section 7.7.13).

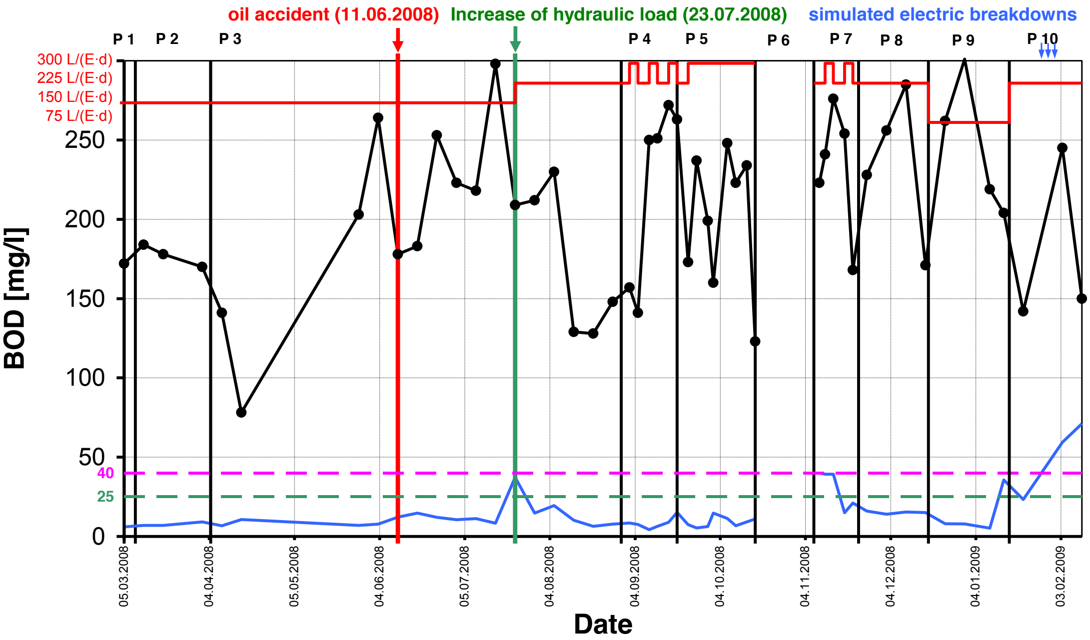

Figure 124: Lauterbach-Kießling - BKF 4 DN2000 Z1: Influent and effluent BOD$_5$ curves

7.7.5 Nitrogen

Ammonia (NH_4-N)

The course of ammonia concentration (Figure 125) reflects the course of nitrification. As a biological process very sensitive to changes in process control, nitrification can be used as an indicator of changes in wastewater treatment systems.

Effluent NH_4-N concentrations remained below 10 mg/L until Phase 4. The oil accident also did not have any significant effect on effluent NH_4-N concentrations, although the only action taken was to clean the primary clarifier.

In response to hydraulic overloading during Phase 4, effluent NH_4-N concentrations rose slowly and discontinuously to about 28 mg/L, although temperatures were in the highest range observed during the entire test period (mean 17.1°C for Phases 4 and 5).

After Phase 6, concentrations decreased to levels below 10 mg/L until the middle of Phase 9; this decrease can be attributed to the reduction of hydraulic and organic load. From Phase 9 on, the presumed reasons for the decrease were the low wastewater temperatures (ca. 5.8 °C in Phases 9 and 10) and, in Phase 10, the simulated electrical breakdowns.

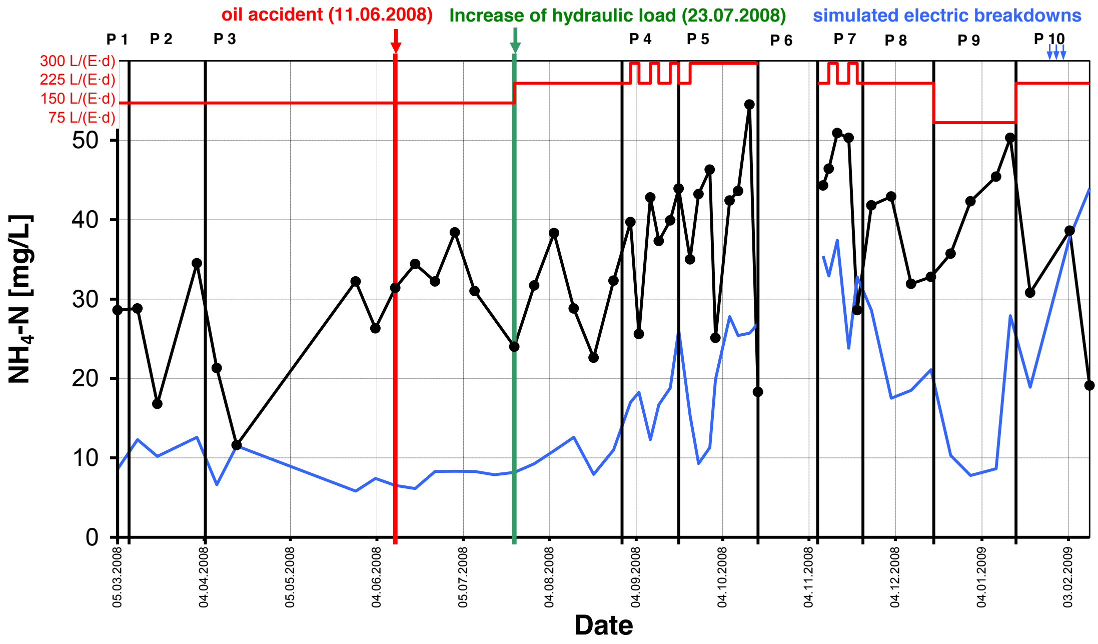

Figure 125: Lauterbach-Kießling - BKF 4 DN2000 Z1:

Influent and effluent NH_4-N curves

Inorganic nitrogen

The inorganic nitrogen curve can be found in the Appendix.

Inorganic nitrogen concentrations in the effluent were almost always identical to those in the influent. In the entire study period, no significant denitrification was observed except for partial denitrification (30% maximum) in the middle of Phase 3.

7.7.6 Suspended solids

Effluent SS concentrations (Figure 126) generally remained relatively constant at very low levels (below 15 mg/L), even during hydraulic overloading (Phases 4 and 5). After Phase 6, an elevated SS concentration (62 mg/L) was observed due, presumably, to a loss of dead biomass during the no-load phase.

In Phase 10, another brief rise to levels above the 35 mg/L limit occurred due, presumably, to either the simulated electrical breakdowns (see Section 5.1.1) or to the presence of a hard-to-degrade substance in the influent resulting in biomass death and loss; this is suspected because the same peak occurred at almost all of the SWWTPs and was also reflected in the influent COD and BOD_5 concentrations (Figure 123 and Figure 124).

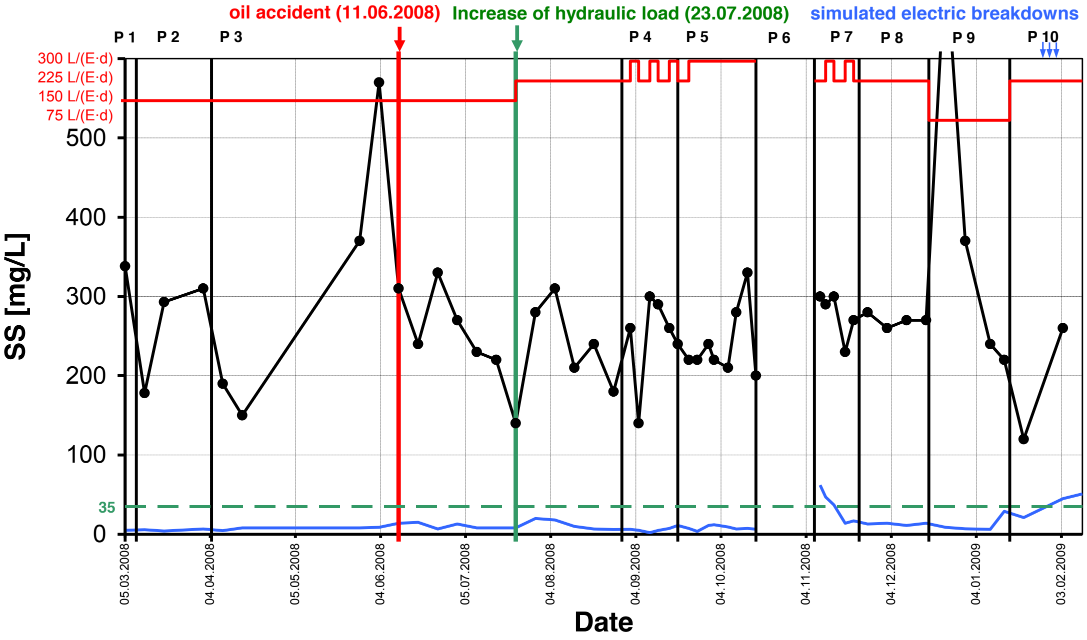

Figure 126: Lauterbach-Kießling - BKF 4 DN2000 Z1: Influent and effluent SS curves

7.7.7 Phosphorus

Phosphorus elimination (Figure 127) was low and hydraulic load-independent during the entire study period. Effluent concentrations ran relatively parallel to influent concentrations, but generally exhibited a slight time lag.

Because of the very low level of suspended solids discharge (Figure 126), no direct correlation between suspended solids and phosphorus could be detected, although phosphorous is not degraded, but rather is "bound" and removed by sludge. Thus, the effluent phosphorus concentration is almost totally dependent on the influent phosphorus concentration.

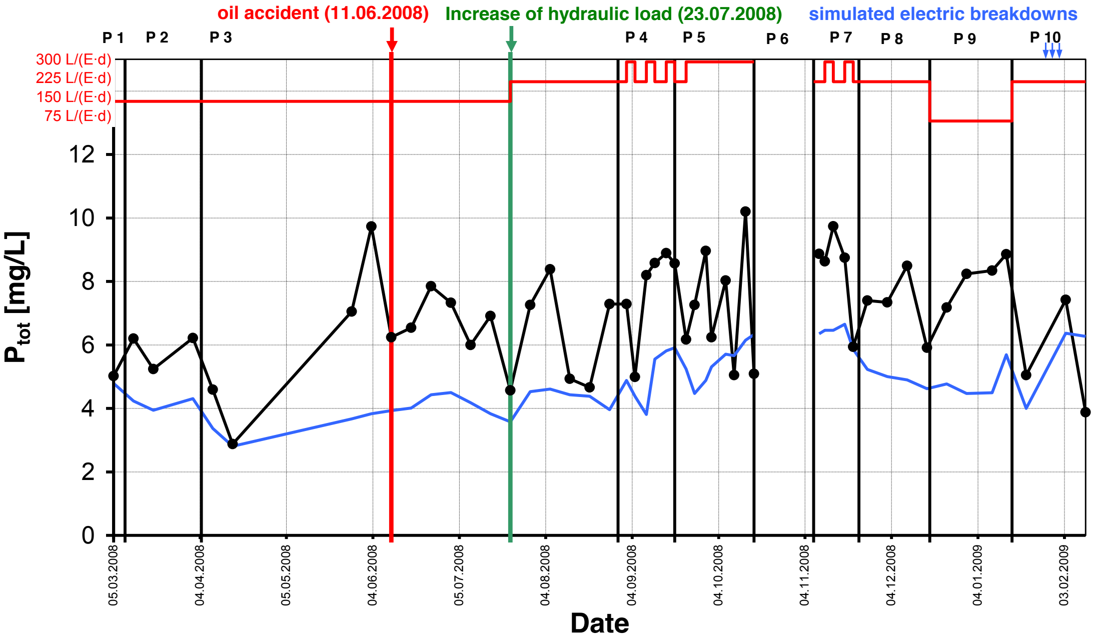

Figure 127: Lauterbach-Kießling - BKF 4 DN2000 Z1: Influent and effluent P_{tot} curves

7.7.8 Degradation rate

Degradation rates for COD, BOD_5, NH_4-N, N_{tot}, P_{tot} and SS are expressed as percentage values (Table 80, Table 81 and Table 82; cf. Section 2.9). Negative values imply that influent concentrations were smaller than effluent concentrations. In this case, redissolution, wash-out or conversion/re-conversion from the biomass could have occurred. Measurement error is also possible, but was tested for in the scope of quality assurance. The data for Phases 1, 2 and 3, during which the system was tested at 100% hydraulic load, are presented in Table 81, and those for Phases 4, 5 and 7, during which the system was tested under hydraulic overload conditions, are shown in Table 82.

Phosphorus is not eliminated. Instead, a fraction either settles in the primary clarifier or is incorporated in the biomass and transported with excess sludge back to the primary clarifier.

The mean degradation rate was 84% for COD and 93% for BOD_5. Mean elimination rates were 34% for NH_4-N, 26% for N_{tot}, and 35% for P_{tot}.

Table 80: Lauterbach-Kießling - BKF 4 DN2000 Z1: Degradation rates (%) for COD, BOD_5, NH_4-N, N_{tot}, SS and P (overall for entire study period)

Lauterbach-Kießling, BKF 4 DN2000 Z1	η_{COD}	η_{BOD}	η_{NH4-N}	η_{Ntot}	η_{P}	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	50	50	50	50	50	49
mean	86	92	48	18	27	95
median	88	95	57	22	31	96
min.	42	53	-130	-83	-62	79
max.	95	98	82	44	61	99

Table 81: Lauterbach-Kießling - BKF 4 DN2000 Z1: Degradation rates (%) for COD, BOD_5, NH_4-N, N_{tot}, SS and P during 100% loading (Phases 1, 2 and 3)

Lauterbach-Kießling, BKF 4 DN2000 Z1	η_{COD}	η_{BOD}	η_{NH4-N}	η_{N-tot}	η_{P}	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	20	20	20	20	20	20
mean	88	94	66	22	31	96
median	89	95	70	24	34	97
min.	76	82	1	-29	2	93
max.	93	97	82	44	61	99

Table 82: Lauterbach-Kießling - BKF 4 DN2000 Z1: Degradation rates (%) for COD, BOD_5, NH_4-N, N_{tot}, SS and P during overload periods (Phases 4, 5 and 7)

Lauterbach-Kießling, BKF 4 DN2000 Z1	η_{COD}	η_{BOD}	η_{NH4-N}	η_{N-tot}	η_{P}	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	19	19	19	19	19	19
mean	86	93	39	18	24	94
median	88	95	42	22	29	96
min.	74	82	-47	-56	-24	79
max.	93	98	79	44	54	99

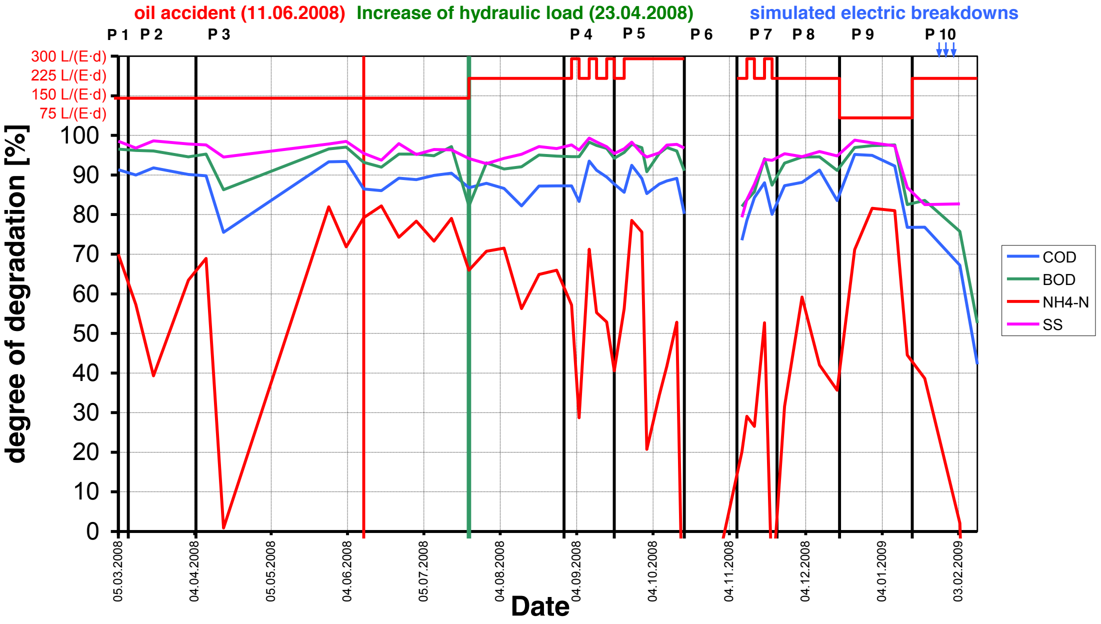

Figure 128: Lauterbach-Kießling - BKF 4 DN2000 Z1: Degradation curves for COD, BOD_5, NH_4-N and SS

The COD degradation rate at 100% design load (88%) was slightly better than the overall rate (86%) during the entire study period because the hydraulic load was lower. Degradation rates achieved during the hydraulic overloading phases tended to be slightly lower. In terms of COD elimination, the lowest treatment efficacy was observed after the simulated electrical breakdowns. The degradation curves (Figure 128) show a discontinuous decrease in NH_4-N degradation after the oil accident. During the underloading phase, a brief increase in NH_4-N degradation was observed although the lowest temperatures occurred at that time.

After Phase 6, COD degradation rates decreased but normalised again within a week. From the middle of Phase 9 on, a sharp decrease occurred due, presumably, to the very low wastewater temperatures and, perhaps, also as a result of the simulated electrical breakdowns.

More detailed analyses of effluent values were presented in Section 7.7.4.

7.7.9 Power consumption

This system does not need electrical power if installed conventionally. This system requires electrical power only if installed under adverse slope conditions where the treated wastewater must be pumped. In that case, the amount of pump energy required depends on the specific local conditions. At the BDZ facility, power was needed solely due to the fact that the treated wastewater had to be pumped from the sample collection shaft to the level of the discharge channel

Therefore, total power consumption for the entire study period was assigned a value of 0 kWh/d.

7.7.10 Sludge

Sludge production was estimated based on the measured sludge height and the known container geometry. Such geometry-dependent estimates are relatively imprecise and of limited value.

Total sludge production for the entire study period was estimated to be 1.1 m^3. At a sludge dry matter content of 49.7 g/L (measured), this corresponds to a sludge mass of 54.65 kg.

At the calculated actual load of 3.4 PE, this yields a specific sludge production of 44.7 g dry matter/(PE·d).

7.7.11 Operation and maintenance

Figure 129 shows all unusual incidents occurring while the system was in operation during the study. Hydraulic loads and influent COD concentrations are also shown for better clarity. The diagram shows the temporal sequence of events over time.

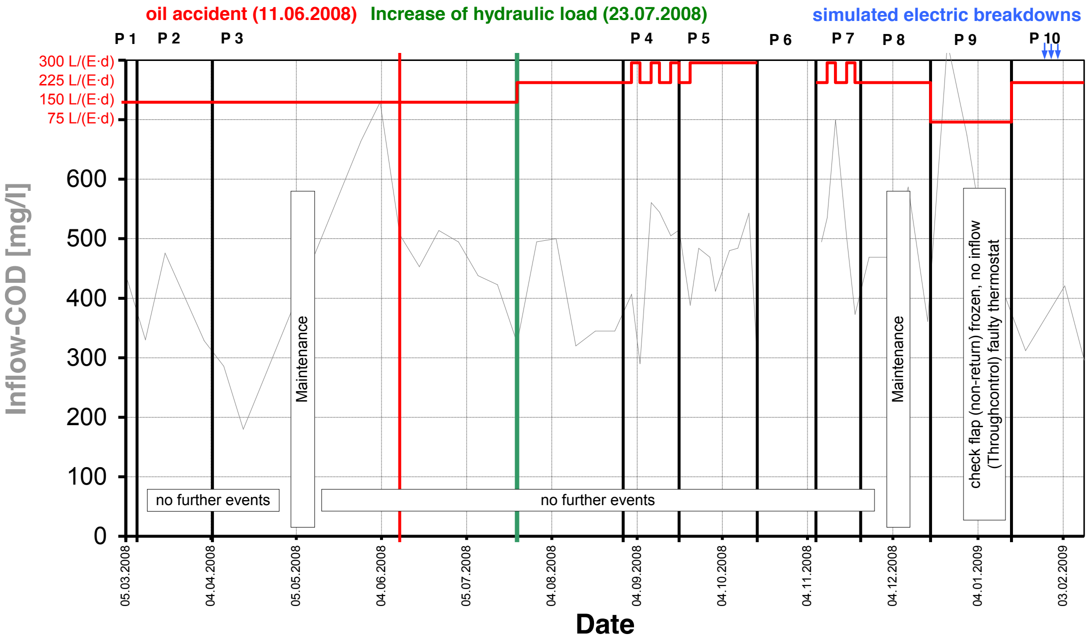

Figure 129: Lauterbach-Kießling - BKF 4 DN2000 Z1: Maintenance log analysis

09 May 2008 and 10 Dec 2008: System maintenance was performed by the manufacturer.

06 Jan 2009 (0800 hrs) to 07 Jan 2009 (1200 hrs): Inflow was obstructed due to a frozen non-return check flap. The valve was not part of the standard system equipment but rather, an experimental device. Therefore, the manufacturer (Lauterbach) was not responsible for this malfunction.

7.7.12 Microbiological parameters

Effluent water samples were collected on three consecutive days and tested for total coliform bacteria, faecal coliform bacteria, intestinal enterococci, salmonella and intestinal nematodes (see Section 5.4.2). The results of the microbiological analysis are presented in Table 83.

On average of three consecutive days, total coliform bacteria were reduced by 1.4 log steps, faecal coliform bacteria by 1.1 log steps, intestinal enterococci by 1.6 log steps and salmonella by around 1.1 log steps. An increase in influent and effluent salmonella counts was observed on 2 Dec 2008. However, because influent and effluent samples were collected simultaneously, the time required for wastewater to flow from one point of the system to another was not taken into account. This may have been a factor. In intestinal nematodes, there was an avarage reduction of 2 eggs/L. On some days, there was an increase, although this may be explained by statistical uncertainty in the determination of the number. In addition, the simultaneous sampling in the influent and effluent did not consider the time lag during the system passage

It can generally be assumed that the number of faecal coliform bacteria undergoes a one- to two-log reduction per treatment stage (compare DWA, 1998). This range was met by this plant with a mean of 1.1-log reduction.

As expected, effluent microbiological quality did not meet the requirements for bathing water quality.

Table 83: Lauterbach-Kießling - BKF 4 DN2000 Z1: Microbiological analysis

Date		**1 Dec 08**			**2 Dec 08**			**3 Dec 08**			**Mean**
		[MPN/ mL]	[log]	Δ [log]	[MPN/ mL]	[log]	Δ [log]	[MPN/ mL]	[log]	Δ [log]	Δ [log]
Total coliform bacteria	Influent	930,000	5.97	2.00	390,000	5.59	0.96	430,000	5.63	1.46	1.4
	Effluent	9,300	3.97		43,000	4.63		15,000	4.18		
Faecal coliform bacteria	Influent	150,000	5.18	1.21	240,000	5.38	1.20	73,000	4.86	0.69	1.1
	Effluent	9,300	3.97		15,000	4.18		15,000	4.18		
Intestinal enterococci	Influent	43,000	4.63	1.25	93,000	4.97	1.59	93,000	4.97	2.00	1.6
	Effluent	2,400	3.38		2,400	3.38		930	2.97		
Salmonella	Influent	2,100	3.32	0.28	750	2.88	-0.09	46,000	4.66	1.34	1.1
	Effluent	> 1,100	3.04		930	2.97		2,100	3.32		
		[Eggs/L]		Δ [Eggs]	[Eggs/L]		Δ [Eggs]	[Eggs/L]		Δ [Eggs]	Δ [Eggs]
Intestinal nematodes	Influent	<1		-6	13 1)		12	<1		-1	2
	Effluent	6 1)			1			1			

1) statistical uncertainty in determination of the egg counts

"< 1" is assumed to be zero

">1,100" is assumed to be 1,100

7.7.13 Comparison of test results with reports and literature data

<u>Chemical oxygen demand</u>

According to the manufacturer's specifications (Section 4.9.9), the system achieves effluent COD concentrations of < 75 mg/L in random samples, in conformity with DIBt requirements (Table 2). Measured concentrations were below the 75 mg/L limit in 88% of all cases. In addition, they were below the manufacturer's target value of 75 mg/L in 100% of cases during testing at 100% design load (Phases 1, 2, and 3).

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 65 mg/L during 100% loading, which is comparable to the overall mean 60 mg/L achieved by the investigational system during the entire study period (in spite of the stricter test conditions).

Considering that the average effluent concentration of trickling filter systems was determined to be 107 mg/L (STRAUB 2008), the mean 60 mg/L achieved by the investigational system is much lower than the reference average.

The vertical flow constructed wetland (6 PE) used in the test series in *Dorf Mecklenburg* (JIROUDI 2605), the system that most closely resembles the investigational system, achieved a mean effluent concentration of 107 mg/L (n=26), which is much higher than the mean achieved by the investigational system. In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 1.087 mg/L (223 mg/L - 2.128 mg/L, 135 measurements).

The 14 filter systems tested by FLASCHE (2002) achieved a mean effluent concentration of 54.9 mg/L, which is comparable to the mean 60 mg/L achieved by the investigational system.

The 12 biological filter systems studied by BOLLER (2004) achieved a mean effluent COD of 71 mg/L, which is slightly higher than the mean 60 mg/L achieved by the investigational system.

Biochemical oxygen demand (BOD_5)

According to the manufacturer's specifications (Section 4.9.9), the system should achieve a BOD_5 concentration of < 15 mg/L in composite samples, in conformity with DIBt requirements (Table 2). Measured concentrations were below the 15 mg/L limit in 72% of all cases. In addition, they were below the manufacturer's target value of 15 mg/L in 90% of cases during testing at 100% design load (Phases 1, 2, and 3).

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 12 mg/L during 100% loading, which is comparable to the overall mean 15 mg/L achieved by the investigational system across the entire study period.

Considering that the average effluent concentration of trickling filter systems was determined to be 46 mg/L (STRAUB 2008), the mean 15 mg/L achieved by the investigational system is much lower than the reference average.

The vertical flow constructed wetland (6 PE) used in the test series in *Dorf Mecklenburg* (JIROUDI 205), the system that most closely resembles the investigational system, achieved a mean effluent concentration of 47 mg/L (n=2), which is much higher than the mean achieved by the investigational system. In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 598 mg/L (160 mg/L - 960 mg/L, 136 measurements).

The 14 filter systems tested by FLASCHE (2002) achieved a mean effluent concentration of 4.4 mg/L, which is much lower than the overall mean of 15 mg/L or the 100% loading phase mean of 11 mg/L achieved by the investigational system.

Ammonia (NH_4-N)

According to the manufacturer's specifications (Section 4.9.9), the system should achieve an NH_4-N concentration of < 10 mg/L in composite samples, in conformity with DIBt requirements (Table 2). Measured concentrations were below the 10 mg/L limit in 32% of all cases.

In addition, they were below the manufacturer's target value of 10 mg/L in 65% of cases during testing at 100% design load (Phases 1, 2, and 3).

The reference value, calculated as the average of 51 SWWTPs with nitrogen elimination tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 5 mg/L during 100% loading. During 100% loading (Phases 1 to 3, until 23 July 2008), the investigational system achieved a mean effluent concentration of approximately 9 mg/L. However, the overall mean for the entire test period (17.1 mg/L) was far higher than the reference average.

Considering that the average effluent concentration of trickling filter systems was determined to be 15 mg/L (STRAUB 2008), the mean 17.1 mg/L achieved by the investigational system is comparable to the reference average. During 100% loading (Phases 1-3), the investigational system achieved a mean of 9 mg/L, which is better than the reference average (STRAUB 2008).

The vertical flow constructed wetland (6 PE) used in the test series in *Dorf Mecklenburg* (JIROUDI 2005), the system that most closely resembles the investigational system, achieved a mean effluent concentration of 17 mg/L (n=20), which is comparable to the mean achieved by the investigational system. In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 72 mg/L (24 mg/L - 114 mg/L, 137 measurements).

The 14 filter systems tested by FLASCHE (2002) achieved a mean effluent concentration of 6.5 mg/L, which is much lower than the overall mean of 17.1 mg/L and slightly lower than the 100% loading phase mean of 11 mg/L achieved by the investigational system.

Suspended solids (SS)

According to the manufacturer's specifications (Section 4.9.9), the system achieves effluent SS concentrations of < 50 mg/L in random samples, in conformity with DIBt requirements (Table 2). Measured SS concentrations were below the 50 mg/L limit in 96% of all cases. In addition, they were below the manufacturer's target value of 50 mg/L in 100% of cases during testing at 100% design load (Phases 1, 2, and 3).

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 25 mg/L during 100% loading, which is higher than the overall mean 13.7 mg/L achieved by the investigational system across the entire study period. During 100% loading (Phases 1-3), the investigational system achieved a mean effluent concentration of 9 mg/L.

The vertical flow constructed wetland (6 PE) used in the test series in *Dorf Mecklenburg* (JIROUDI 1005), the system that most closely resembles the investigational system, achieved a mean effluent concentration of 12 mg/L (n=10), which is comparable to the mean achieved by the investigational system.

Simulated electrical breakdowns

Increases in effluent concentrations of the target parameters during the simulated power outages (Figure 123, Figure 124, Figure 125 and Figure 126) can be attributed to the power outages themselves or to the presence of hard-to-degrade substances in the influent. In the study in Nantes (VIGNOLES, CAUCHI, 2009), however, similar peaks were observed during simulated electrical breakdowns in almost all WWTPs independent of whether they operated using electricity or not. The researchers in Nantes also could not find a plausible explanation for this phenomenon. This issue requires further investigation.

Power consumption

This SWWTP is designed in such a way that it normally does not need electrical power. The reference value, calculated as the average power consumption of 5 trickling filter systems tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is 0 to 0.1 kWh/(PE·d), which is comparable to the zero energy requirement of the investigational system.

The vertical flow constructed wetland (6 PE) used in the test series in *Dorf Mecklenburg* (JIROUDI 2605), the system that most closely resembles the investigational system, achieved power consumption rates of 0.05 to 0.06 kWh/(PE·d),

Sludge

Based on the reference values (DWA 2003), a specific sludge accumulation rate of approximately 70 g dry matter/(PE·d) was expected. The actual measured value of 44.7 g dry matter/(PE·d) was lower than the expected value, suggesting that the solids load of the raw sewage was below the expected value because the investigational system operates using primary sludge only.

Microbiological parameters

The investigational system reduced faecal coliform bacteria counts to roughly 9,300 to 43,000 per 100 ml. This is comparable to the reference average for trickling filter systems (the types most similar to the investigational system), a mean 35,000 per 100 ml within a minimum-maximum range of 93 ml to 200,000 per 100 ml (STRAUB ET AL. 2008). The investigational system had an average log reduction of 1.1 log steps. This corresponds roughly the log reduction of 1.2 log steps by STRAUB ET AL. 2008.

The vertical flow constructed wetland used in the test series in *Dorf Mecklenburg* (JIROUDI 2605), the system that most closely resembles the investigational system, reduced total coliform bacteria counts to 5.6×10^4/100 mL and faecal coliform bacteria counts to 3.49×10^4/100ml; these concentrations were much higher than those achieved by the investigational system. The investigational system had an average total coliform log reduction of 1.4 log steps. This is well below the faecal coliforms log reduction of 3.3 log steps by JIROUDI 2005.

7.7.14 Summary

The investigational system operated at a mean load of 3.4 PE across the entire study period. Effluent COD concentrations (mean 60 mg/L) remained below 100 mg/L during the entire study period, even during 200% hydraulic loading periods. Higher concentrations did not occur except when restarting the system after the no-load phase and simulated electrical breakdowns.

Effluent SS concentrations predominantly remained below the 35 mg/L limit (mean 13.7 mg/L). However, increased effluent SS concentrations were observed after restarting the system after the no-load phase and after the simulated electrical breakdowns.

Overall, the investigational system achieved very stable treatment performance. No system malfunctions occurred during the study period.

The system does not require electrical power.

7.8 UFZ C+H 4 E Constructed Wetland

7.8.1 Loading conditions

The UFZ C+H 4 E constructed wetland was installed by the manufacturer (ÖKOTEC). According to the DIBt criteria for small wastewater treatment plants, this system is designed for a capacity of 3 PE. The manufacturer, however, specifies a design capacity of 4 PE (see Section 4.10.3), and the system was tested accordingly. The design organic load is equivalent to 240 g BOD_5/d, which is consistent with the influent load specified by the manufacturer.

The design hydraulic load is 600 L/day. The system was also stressed with 200-litre bath water loads (bathtub tests) 5 times a week, corresponding to approximately 114 L/d (see Section 5.1.2). According to the manufacturer's specifications, the maximum permissible hydraulic load for this system is 600 L/d. The primary clarifier was rated at 900 L/PE (see Section 4.10.3).

The system was operated under the following influent loadings level:

- Befor 23 July 2008[*]: 2.6 $PE_{BOD,60}$
- From 23 Jul 2008 until 17 Oct 2008: 3.1 $PE_{BOD,60}$
- Overall mean (across entire study period): 3.5 $PE_{BOD,60}$

Therefore the system achieved a 86% capacity relative to influent BOD_5 over the entire study period.

According to the manufacturer's specification, the volume of the primary clarifier is 3.7 m³, and that of the two filter basins was 12 m² and 6 m², respectively. In addition to these areas, the height (1 m) of the filter basins must be considered. The calculated residence times were therefore 3.7 for primary clarifier, 12 days for the vertical soil filter, and 3 days for the horizontal filter, yielding a total residence time of 21.7 days in the system (see Section 2.6). The theoretical calculation is very inaccurate for the unsaturated vertical soil filter. Therefore the average residence time of the wastewater in the whole treatment plant was determinded by means of two tracer tests with NaCl with 5.25 and 6.3 days.

7.8.2 Statistical overview of results

The results of the statistical analysis for the entire study period, including the number of samples, the mean, median, minimum and maximum values, the statutory limits in France and Germany (see Sections 2.2.1.1 and 2.2.1.2), and the rates of compliance of effluent COD, BOD_5, SS, NH_4-N, N_{tot} and P_{tot} with the statutory limits (stay below probability) are

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[*] See Chapter 5.1.2: Due to the low influent concentrations, testing under increased hydraulic load conditions (150%) was discontinued in order to increase the influent load.

shown below (Table 84 and Table 85). Mean, median, minimum and maximum values as well as the statutory limits in France (FR) and Germany (DE) are expressed in mg/L. The number of samples is a dimensionless parameter. The stay below probability is given in percent (%).

Table 84: UFZ C+H 4 E: Statistical analysis of COD, BOD$_5$ and SS

UFZ - UFZ C+H 4E	COD		BOD			SS	
	In	Out	In	Load (real)*	Out	In	Out
	[mg/l]	[mg/l]	[mg/l]	[E]	[mg/l]	[mg/l]	[mg/l]
Number of samples	50	49	50	50	47	49	48
mean	456	34	207	3,5	3	269,0	4,5
median	469	31	215	3,2	0	260,0	2,4
min.	180	21	78	1,0	< 3	120,0	< 1,0
max.	830	82	301	5,8	24	730,0	20,0
legally binding value (DE / FR)		**150 / 125**			**40 / 25**		**-- / 35**
stay below of legally binding value (DE)		100%			100%		
stay below of legally binding value (FR)		100%			100%		100%

* Load (real): See Section 2.3

Table 85: UFZ C+H 4 E: Statistical analysis of nitrogen and phosphorus

UFZ - UFZ C+H 4E	NH_4-N		N_{tot}		P_{tot}	
	In	Out	In	Out	In	Out
	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]
Number of samples	50	49	50	49	50	48
mean	35,1	12,0	47,4	29,8	7,0	3,5
median	34,8	8,1	46,5	30,5	7,3	3,5
min.	11,6	3,2	19,8	14,5	2,9	1,3
max.	54,5	31,9	71,6	51,6	10,2	5,5
legally binding value (DE / FR)		-- / --		-- / --		-- / --
stay below of legally binding value (DE)						
stay below of legally binding value (FR)						

Chemical oxygen demand (COD)

The system achieved a mean effluent COD of 34 mg/L over the entire study period; the maximum was 82 mg/L. Measured COD concentrations were below both the German statutory limit of 150 mg/L (see Section 2.2.1.1) and the French statutory limit of 125 mg/L (see Section 2.2.1.2) in 100% of cases. In other words, none of the measured values exceeded the German or French maximum limit (see Section 7.8.4). Hence, the system met the German and French statutory effluent requirements in all cases.

Biochemical oxygen demand (BOD_5)

The system achieved a mean effluent BOD_5 of 3 mg/L over the entire study period; the maximum was 24 mg/L. Measured BOD_5 concentrations were below both the German statutory limit of 40 mg/L and the French statutory limit of 25 mg/L in 100% of cases. In other words, none of the measured values exceeded the German or French maximum limit (see Section 7.8.4). Hence, the system met the German and French statutory effluent requirements in all cases.

Suspended solids (SS)

The system achieved a mean effluent SS concentration of 4.5 mg/L over the entire study period; the maximum was 20 mg/L. Measured SS concentrations were below the French statutory limit of 35 mg/L in 100% of cases. In other words, none of the measured values exceeded the French statutory limit (see Section 7.8.6). Hence, the system met the statutory effluent requirements for France in all cases. There are no statutory limits for suspended solids in Germany.

Nitrogen

- **Ammonia (NH_4-N):**
  The system achieved a mean effluent NH_4-N concentration of 12.0 mg/L over the entire study period; the maximum was 31.9 mg/L (see Section 7.8.5).
- **Total nitrogen (N_{tot}):**
  The system achieved a mean effluent N_{tot} concentration of 29.8 mg/L over the entire study period; the maximum was 51.6 mg/L (see Section 7.8.5).

Total phosphorus (P_{tot})

The system achieved a mean effluent P_{tot} concentration of 3.5 mg/L over the entire study period; the maximum was 5.5 mg/L (see Section 7.8.7).

7.8.3 Operational and process stability

Process stability was described in terms of compliance with statutory limits for target parameters (stay below probability) as shown in Figure 130. The steeper the curve, the more "stably" the system is operating. A stable system maintains steady effluent concentrations in spite of changes in influent concentrations, temperature etc. (see Section 2.10.9).

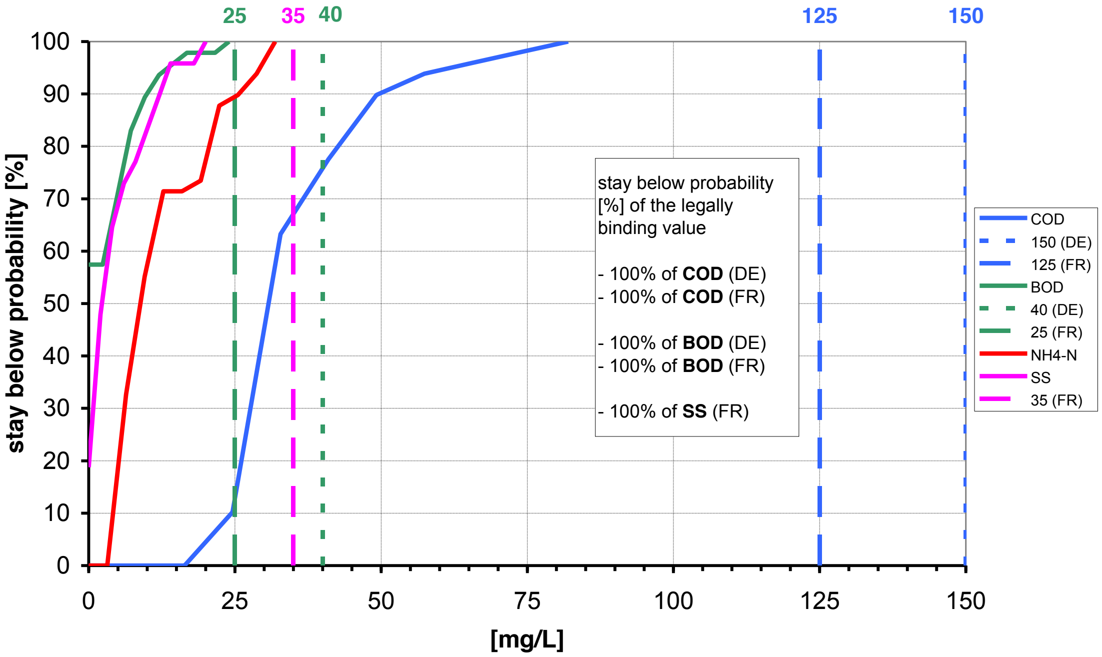

Figure 130: UFZ C+H 4 E:

Stay below probability for COD, BOD_5, NH_4-N and SS

7.8.4 COD and BOD_5 elimination

The combined parameters for organic matter were analysed based on the COD curve across the entire study period. In Figure 131, the horizontal lines at 150 mg/L and 125 mg/L. respectively, represent the German and French maximum limits.

The course of the BOD_5 curve (Figure 132) is similar to that of the COD curve. The mean effluent COD/ BOD_5 ratio is 11 to 1.

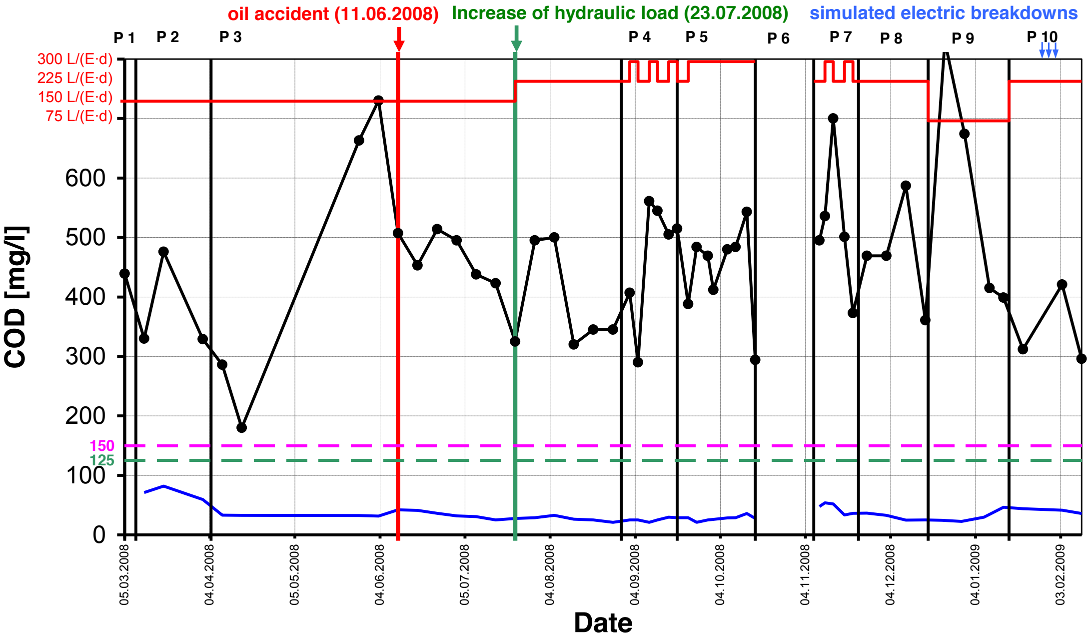

Figure 131: UFZ C+H 4 E: Influent and effluent COD curves

Effluent COD concentrations remained below 100 mg/L during the entire study period; in fact, they were below 50 mg/L in most cases (Figure 131). The only higher concentrations occurred in the time between the start of testing and the beginning of Phase 3, when effluent concentrations rose as high as 82 mg/L due to the equilibration phase, but subsequently decreased to about 32 mg/L. The oil accident also did not have any significant effect on effluent COD concentrations, although the only action taken was to clean the primary clarifier. The switch to the higher hydraulic load on 23 Jul 2008 and the increased hydraulic loads in Phases 4 and 5 also had no measurable effect on effluent COD concentrations. After the resting period (Phase 6), the parameter increased minimally (53 mg/L) but fell to levels below 35 mg/L within one week. A slight rise in COD concentration was also observed at the end of Phase 9. This increase can be attributed to the very low wastewater temperatures (below 5°C) and delayed response to the extremely high influent concentration of over 800 mg/L. The simulated electrical breakdowns had no significant effect on effluent COD concentrations.

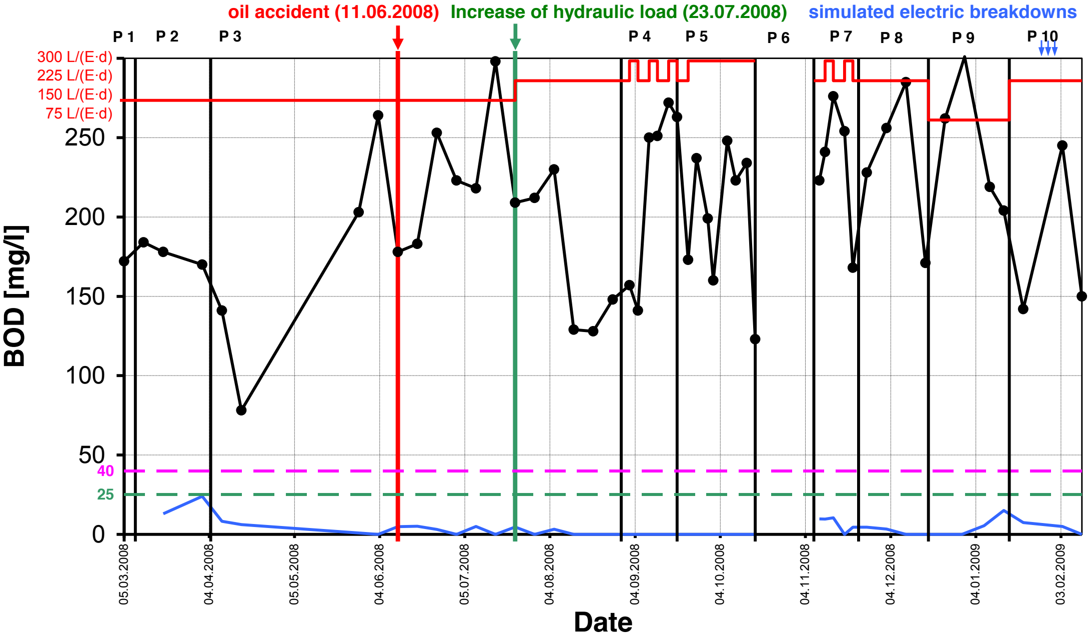

Figure 132: UFZ C+H 4 E: Influent and effluent BOD_5 curves

7.8.5 Nitrogen

Ammonia (NH_4-N)

The course of ammonia concentration (Figure 133) reflects the course of nitrification. As a biological process very sensitive to changes in process control, nitrification can be used as an indicator of changes in wastewater treatment systems.

Before 28 May 2008, no significant nitrification was observed due, perhaps, to the extended run-in time because of low temperatures (below 10°C until 16 April 2008).

From 28 May 2008 until the beginning of Phase 6, effluent NH_4-N concentrations remained mostly below 10 mg/L. The only exception was a brief rise to 12 mg/L at the end of Phase 5, due, presumably, to hydraulic overloading at 300 L/(PE·d).

After the resting period, concentrations rose from 7 mg/L to over 20 mg/L. This rise suggests that part of the nitrifier population could have died during Phase 6, leaving a residual population inadequate for nitrification. This theory is supported by the fact that, during Phases 8 and 9, effluent NH_4-N concentrations decreased to levels below 10 mg/L. The increase at the end of Phase 9 can again be attributed to the low wastewater temperatures (below 5°C). The simulated electrical breakdowns seemed to increase the effluent NH_4-N concentrations with a time lag, which can be attributed to the long transit time of wastewater through the system.

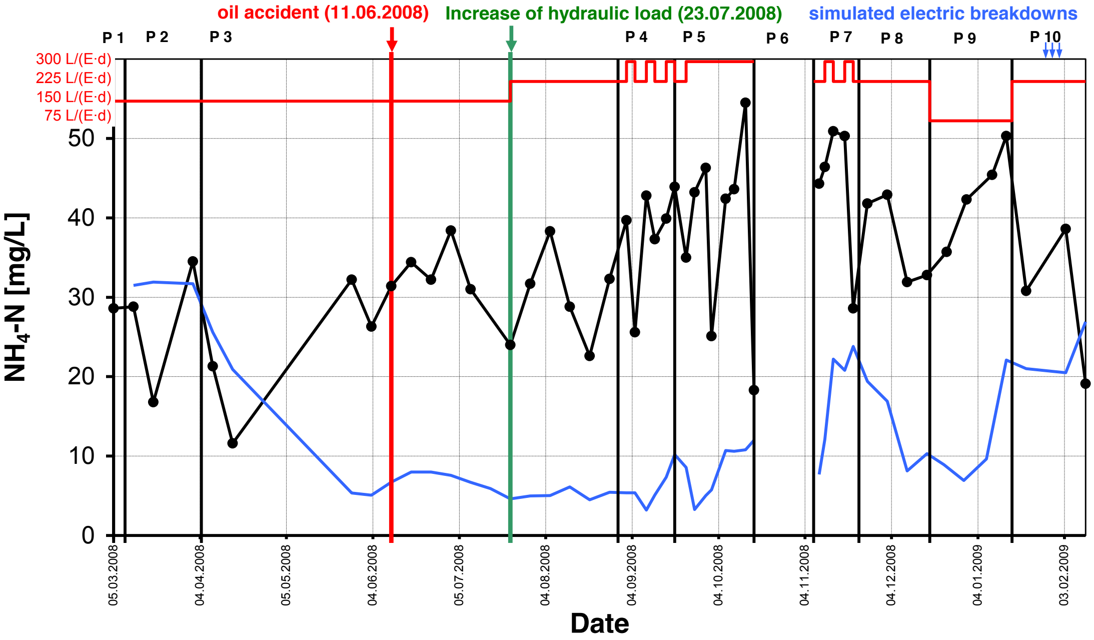

Figure 133: UFZ C+H 4 E: Influent and effluent NH_4-N curves

Inorganic nitrogen

The inorganic nitrogen curve can be found in the Appendix.

Inorganic nitrogen concentrations ranged from 10 to 20 mg/L until the end of Phase 3. As these concentrations were 5 to 10 mg/L lower than the influent concentrations and because the NH_4-N concentrations were predominantly very low, the occurrence of partial denitrification (approx. 25-75%) can be assumed. After the oil accident until the end of Phase 5, inorganic nitrogen concentrations rose continuously, reaching 30 mg/L. After Phase 6, they remained at a mean of about 40 mg/L, which was slightly lower than effluent NH_4-N concentrations. Partial denitrification (<25%) occurred.

7.8.6 Suspended solids

Effluent SS concentrations generally remained relatively constant at very low levels below 15 mg/L (Figure 134). In some cases, effluent SS concentrations remained far below 15 mg/L, even under increased hydraulic loading conditions (Phases 4 and 5) and resting conditions (Phase 6 and simulated electrical breakdowns).

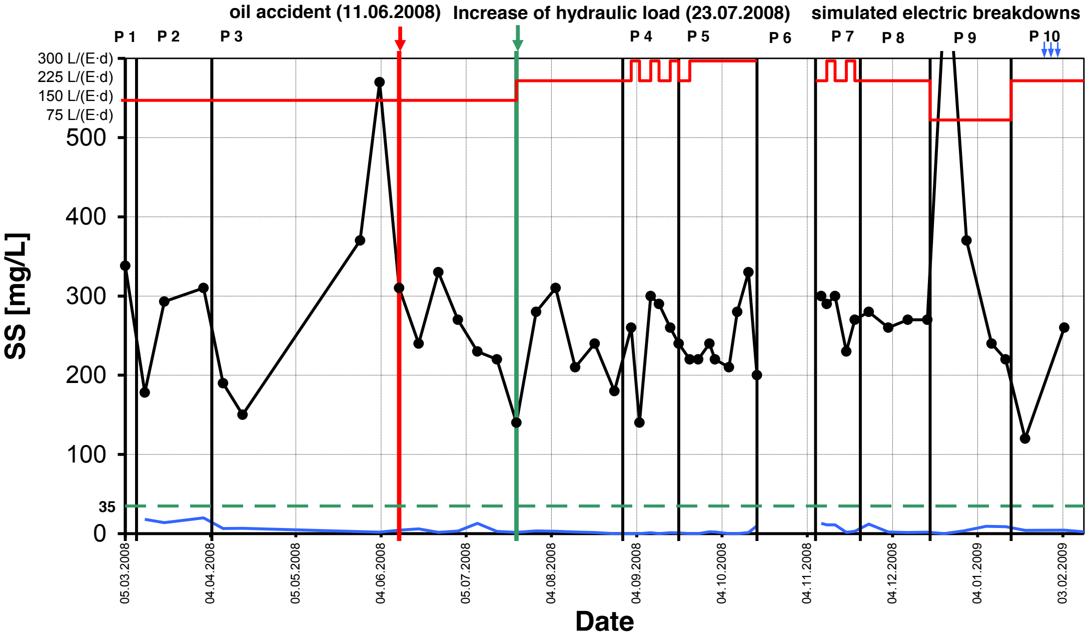

Figure 134: UFZ C+H 4 E: Influent and effluent SS curves

7.8.7 Phosphorus

Phosphorus elimination (Figure 135) was low and hydraulic load-independent during the entire study period. Effluent phosphorus concentrations ran parallel to the influent concentrations, but generally with a slight time lag.

Because of the very low level of suspended solids discharge (Figure 134), no direct correlation between suspended solids and phosphorus could be detected although phosphorous is not degraded, but rather is "bound" and removed by sludge. Thus, the effluent phosphorus concentration is almost totally dependent on the influent phosphorus concentration (see Figure 135: Phases 4 and 5).

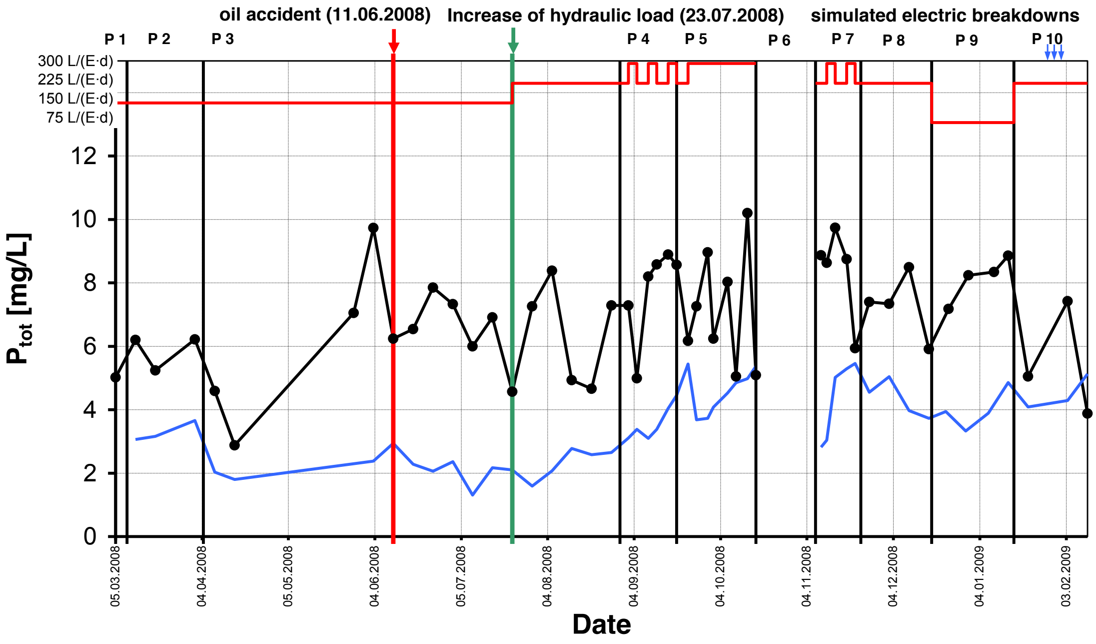

Figure 135: UFZ C+H 4 E: Influent and effluent P_{tot} curves

7.8.8 Degradation rate

Degradation rates for COD, BOD_5, NH_4-N, N_{tot}, P_{tot} and SS are expressed as percentage values (Table 86, Table 87 and Table 88; cf. Section 2.9). Negative values imply that influent concentrations were smaller than effluent concentrations. In this case, redissolution, wash-out or conversion/re-conversion from the biomass could have occurred. Measurement error is also possible, but was tested for in the scope of quality assurance. The data for Phases 1, 2 and 3, during which the system was tested at 100% hydraulic load, are presented in Table 87, and those for Phases 4, 5 and 7, during which the system was tested under hydraulic overload conditions, are shown in Table 88.

Phosphorus is not eliminated. Instead, a fraction either settles in the primary clarifier or is incorporated in the biomass and transported with excess sludge back to the primary clarifier.

The mean degradation rate was 92% for COD and 98% for BOD_5. Mean elimination rates were 60% for NH_4-N, 33% for N_{tot}, and 47% for P_{tot}.

Table 86: UFZ C+H 4 E: Degradation rates (%) for COD, BOD_5, NH_4-N, N_{tot}, SS and P (overall for entire study period)

UFZ - UFZ C+H 4E	η_{COD}	η_{BOD}	η_{NH4-N}	η_{N-tot}	η_{P}	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	49	47	49	49	48	47
mean	92	98	60	33	47	98
median	93	100	77	36	50	99
min.	78	86	-90	-47	-32	90
max.	97	100	93	64	78	100

Table 87: UFZ C+H 4 E: Degradation rates (%) for COD, BOD_5, NH_4-N, N_{tot}, SS and P during 100% loading (Phases 1, 2 and 3)

UFZ - UFZ C+H 4E	η_{COD}	η_{BOD}	η_{NH4-N}	η_{N-tot}	η_{P}	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	19	17	19	19	18	18
mean	90	97	49	35	59	97
median	93	99	79	47	60	99
min.	78	86	-90	-33	38	90
max.	96	100	87	64	78	100

Table 88: UFZ C+H 4 E: Degradation rates (%) for COD, BOD_5, NH_4-N, N_{tot}, SS and P during overloading periods (Phases 4, 5 and 7)

UFZ - UFZ C+H 4E	η_{COD}	η_{BOD}	η_{NH4-N}	η_{N-tot}	η_{P}	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	19	19	19	19	19	19
mean	93	99	73	35	42	99
median	94	100	77	41	48	100
min.	90	96	17	-33	-6	95
max.	96	100	93	60	68	100

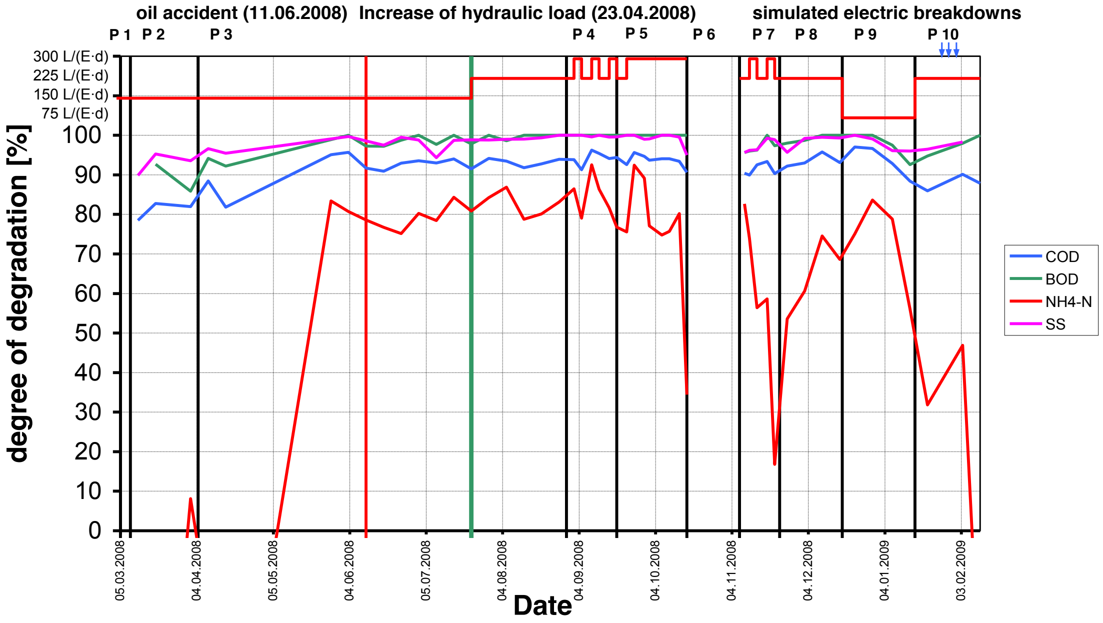

Figure 136: UFZ C+H 4 E:

Degradation curves for COD, BOD_5, NH_4-N and SS

The COD degradation rate achieved at 100% design load (90%) was slightly lower than the overall rate (92%) during the entire study period due to the slightly worse rates achieved at the beginning of the testing period. Degradation rates achieved during the hydraulic overloading phases tended to be somewhat better (see above). The lowest rate of COD elimination was observed at the beginning and end of the trial. The degradation curves (Figure 136) show that the increase in design flow from 150 L/(PE·d) to 225 L/(PE·d) resulted in fluctuations in the degradations rates, particularly in the case of NH_4-N.

They also show a slight decrease in COD, BOD_5 and SS degradation rates and a strong decrease in NH_4-N degradation during hydraulic overloading (Phase 5) and during interruptions after Phase 6 and during Phase 10 (simulated electrical breakdowns).

More detailed analyses of effluent values are presented in Section 7.8.4.

7.8.9 Power consumption

Mean power consumption for this system could not be determined due to missing data.

Based on the manufacturer's assessment (three-day test; see p. 71), the pumps consume 44 kWh/y and the UV disinfection unit 140 kWh/y, yielding a total annual consumption of 184 kWh/a.

Total power consumption of the investigational system across the entire study period was a mean 54.1 kWh/(PE·a). Calculated based on the mean population equivalent of 3.4 PE relative to BOD_5 (see Section 2.3), this corresponds to a daily power consumption rate of 0.5 kWh/d.

7.8.10 Sludge

Sludge production was estimated based on the measured sludge height and the known container geometry. Such geometry-dependent estimates are relatively imprecise and of limited value.

Total sludge production for the entire study period was estimated to be 0.79 m³. At a sludge dry matter content of 35 g/L (measured), this corresponds to a sludge mass of 27.5 kg.

At the calculated actual load of 3.4 PE, this yields a specific sludge production of 22.1 g dry matter/(PE·d).

7.8.11 Operation and maintenance

There is no data available on operation and maintenance of the UFZ C+H 4E. However, it was assumed that no malfunctions of the plant bed occurred.

06 Jan 2009 (08:00 hrs) to 07 Jan 2009 (12:00 hrs): Inflow was obstructed due to a frozen non-return check flap. The valve was not part of the standard system equipment but rather, an experimental device. Therefore, the manufacturer (ÖKOTEC) was not responsible for this malfunction. Although no specific data for constructed wetlands exist, we assume that all of the SWWTPs were affected by this flow interruption.

7.8.12 Microbiological parameters

Effluent water samples were collected on three consecutive days and tested for total coliform bacteria, faecal coliform bacteria, intestinal enterococci, salmonella and intestinal nematodes (see Section 5.4.2). The results of the microbiological analysis are presented in Table 89. The plant was operated with a downstream UV disinfection.

On average of three consecutive days, total coliform bacteria were reduced by 6.0 log steps, and intestinal enterococci by 1.2 log steps. In faecal coliform bacteria and salmonella, the log reduction could not be determined, because the effluent values were on all three days at 0 MPN/mL or less than 0.3 MPN/mL (< 0.3 is assumed to be zero). In intestinal nematodes, there was an avarage reduction of 6 eggs/L. On some days, there were an increase, although this may be explained by statistical uncertainty in the determination of the number. In addition, the simultaneous sampling in the influent and effluent did not consider the time lag during the system passage.

It can generally be assumed that the number of faecal coliform bacteria undergoes a one- to two-log reduction per treatment stage (compare DWA, 1998). This was completly achieved by this plant. Zero MPN/ml have been measured in the effluent.

Based on effluent microbiological quality, the investigational system achieved the rating of "excellent bathing water quality for inland waters". This is based on compliance with the maximum limits for intestinal enterococci (200 per 100mL) and Escherichia coli (500 per 100 mL). The investigational system achieved effluent counts of 73 per 100 mL (maximum) for intestinal enterococci and 91 per 100 mL for Escherichia coli (faecal coliform bacteria). The good treatment efficacy in terms of bacterial reduction can be attributed to the downstream UV disinfection unit.

Table 89: UFZ C+H 4 E: Microbiological analysis

Date		**1 Dec 08**			**2 Dec 08**			**3 Dec 08**			**Mean**
		[MPN/ mL]	[log]	Δ [log]	[MPN/ mL]	[log]	Δ [log]	[MPN/ mL]	[log]	Δ [log]	Δ [log]
Total coliform bacteria	Influent	930,000	5.97	6.41	390,000	5.59	5.63	430,000	5.63	6.08	6.0
	Effluent	0.36	-0.44		0.91	-0.04		0.36	-0.44		
Faecal coliform bacteria	Influent	150,000	5.18	- 2)	240,000	5.38	- 2)	73,000	4.86	- 2)	- 2)
	Effluent	< 0.3	- 2)		0.0	- 2)		< 0.3	- 2)		
Intestinal enterococci	Influent	43,000	4.63	5.08	93,000	4.97	5.11	93,000	4.97	- 2)	5.3
	Effluent	0.36	-0.44		1	-0.14		< 0.3	- 2)		
Salmonella	Influent	2,100	3.32	- 2)	750	2.88	- 2)	46,000	4.66	- 2)	- 2)
	Effluent	< 0.3	- 2)		< 0.3	- 2)		< 0.3	- 2)		
		[Eggs/L]		Δ [Eggs]	[Eggs/L]		Δ [Eggs]	[Eggs/L]		Δ [Eggs]	Δ [Eggs]
Intestinal nematodes	Influent	<1		-1	13 1)		13	<1			6
	Effluent	1			< 1			-			

1) statistical uncertainty in determination of the egg counts

2) 0 MPN/ml in effluent, no log reduction determined

"< 1" is assumed to be zero

"<0.3" is assumed to be zero

7.8.13 Comparison of test results with reports and literature data

Chemical oxygen demand

According to the manufacturer's specifications, the investigational system is an effluent class C + H system for 4 PE. Thus, effluent COD concentrations in composite samples should be below 100 mg/L (in conformity with DIBt requirements in Table 2). Measured COD concentrations were below the 100 mg/L limit in 100% of all cases. This was also the case under 100% design load conditions in Phases 1, 2, und 3.

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 65 mg/L during 100% loading, which is much higher than the overall mean 34 mg/L achieved by the investigational system.

Considering that the average effluent COD concentration for horizontal flow constructed wetlands in practice was determined to be 39 mg/L (STRAUB 2008) and that for vertical flow constructed wetlands is 30 mg/L, the overall mean 34 mg/L achieved by the investigational system is far lower than that of the two reference systems, but was achieved using a two-stage, vertical and horizontal bed.

The vertical flow constructed wetland (6 PE) used in the test series in *Dorf Mecklenburg* (JIROUDI 2605) achieved a mean effluent concentration of 107 mg/L (n=26), which is much higher than the mean achieved by the investigational system. The horizontal flow constructed wetland (1 PE) investigated in the same study achieved a mean 36 mg/L (n=26), which is comparable to that achieved by the investigational system. In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 1.087 mg/L (223 mg/L - 2.128 mg/L, 135 measurements).

The 14 filter systems studied by FLASCHE (2004) achieved a mean effluent COD of 54.9 mg/L, which is slightly higher than the mean 34 mg/L achieved by this system.

The 31 constructed wetlands studied by BOLLER (2004) achieved a mean effluent COD of 72 mg/L, which is much higher than the mean 34 mg/L achieved by this system.

Biochemical oxygen demand (BOD_5)

According to the manufacturer's specifications, the investigational system is an effluent class C + H system for 4 PE. Thus, effluent BOD_5 concentrations in composite samples should be below 25 mg/L (in conformity with DIBt requirements in Table 2). Measured BOD_5 concentrations were below the 25 mg/L limit in 100% of all cases. This was also the case under 100% design load conditions in Phases 1, 2, und 3.

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 12 mg/L during 100% loading, which is much higher than the overall mean 3 mg/L achieved by the investigational system.

Considering that the average effluent BOD_5 concentration for horizontal flow constructed wetlands in practice was determined to be 39 mg/L (STRAUB 2008) and that for vertical flow constructed wetlands is 30 mg/L, the overall mean 3 mg/L achieved by the investigational system is far lower than that of the two reference systems, but was achieved using a vertical and a horizontal filter bed.

The vertical (6 PE) and horizontal flow constructed wetlands (1PE) used in the test series in *Dorf Mecklenburg* (JIROUDI 205) achieved a mean effluent BOD_5 concentration of 47 mg/L (n=2) and 35 mg/L (n=10), respectively, which is much higher than that achieved by the investigational system. In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 598 mg/L (160 mg/L - 960 mg/L, 136 measurements).

The 14 filter systems studied by FLASCHE (2002) achieved a mean effluent BOD_5 of 54.9 mg/L, which is slightly higher than the mean 34 mg/L achieved by this system.

Ammonia (NH_4-N)

The reference value, calculated as the average of 51 SWWTPs with nitrogen elimination tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 5 mg/L during 100% loading. The investigational system achieved a mean effluent NH_4-N concentration of approximately 12 mg/L during 100% loading (Phases 1 to 3, until 23 July 2008) and overall for the entire study period.

Considering that the average effluent NH_4-N concentration for horizontal flow constructed wetlands in practice was determined to be 26 mg/L (STRAUB 2008) and that for vertical flow constructed wetlands 22 mg/L, the overall mean 12 mg/L achieved by this system is lower than that of the two reference systems, but was achieved using a two-stage bed.

The vertical flow constructed wetland (6 PE) used in the test series in *Dorf Mecklenburg* (JIROUDI 2005) achieved a mean effluent concentration of 17 mg/L (n=20), which is higher than the mean achieved by the investigational system. The vertical flow constructed wetland (1 PE) used there achieved a mean effluent concentration of 6 mg/L (n=20), which is lower than that of the investigational system. In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 72 mg/L (24 mg/L - 114 mg/L, 137 measurements).

Suspended solids (SS)

According to the manufacturer's specifications, the investigational system is an effluent class C + H system for 4 PE. Thus, effluent SS concentrations in composite samples should be below 75 mg/L (in conformity with DIBt requirements in Table 2). Measured concentrations were below the 75 mg/L limit in 100% of all cases. This was also the case under 100% design load conditions in Phases 1, 2, und 3.

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 25 mg/L during 100% loading, which is higher than the overall mean 4.5 mg/L achieved by the investigational system across the entire study period. During 100% loading (Phases 1-3), the investigational system achieved a mean effluent concentration of 6 mg/L.

Considering that the average effluent SS concentration for horizontal flow constructed wetlands in practice was determined to be 10 mg/L (STRAUB 2008) and that for vertical flow constructed wetlands 43 mg/L, the overall mean 4.5 mg/L achieved by the investigational system is lower than that of the two reference systems.

The vertical flow constructed wetland (6 PE) used in the test series in *Dorf Mecklenburg* (JIROUDI 1005) achieved a mean effluent concentration of 12 mg/L (n=10), which is higher than that achieved by the investigational system. The horizontal flow constructed wetland (1 PE) investigated in the same study achieved a mean 4 mg/L (n=20), which is comparable to that achieved by the investigational system.

Power consumption

According to the manufacturer, the power consumption for a 3-day period in this study should be 0.5 kWh/d, which yields 0.148 kWh/(PE·d) at a population equivalent of 3.4 PE.

The vertical (6 PE) and horizontal flow constructed wetlands (1 PE) used in the test series in *Dorf Mecklenburg* (JIROUDI 2605) achieved power consumption rates of 0.05 to 0.06 kWh/(PE·d) and 0.039 kWh/(PE·d), respectively, which were much lower than that achieved by the investigational system.

Sludge

Based on the reference values (DWA, 2003), a specific sludge accumulation rate of approximately 70 g dry matter/(PE·d) was expected. The actual measured value was 21 g dry matter/(PE·d), suggesting that the suspended solids load in the raw sewage was below the expected value because the investigational system operates using primary sludge only. On the other hand a part of the solids has been trapped in the filter.

7.8.14 Summary

The investigational system operated at a mean load of 3.4 PE across the entire study period. Effluent COD concentrations (mean 34 mg/L) remained below 100 mg/L during the entire study period, even during 200% hydraulic loading periods.

Effluent SS concentrations (mean 4.5 mg/L) remained below the 20 mg/L limit.

Overall, the investigational system achieved very stable treatment performance.

Power consumption specified by the manufacturer is consistent with the reference values in the literature.

The investigational system achieved a rating of "excellent bathing water quality for inland waters".

7.9 PREMIER TECH – Ecofix® STB-500

7.9.1 Loading conditions

The Ecofix® STB-500 was installed by the manufacturer (PREMIER TECH). The system has a design capacity of 6 PE and was tested accordingly. The design organic load is equivalent to 360 g BOD_5/d, which is consistent with the influent load specified by the manufacturer.

The design hydraulic load is 900 L/day. The system was also stressed with 200-litre bath water loads (bathtub tests) 5 times a week, corresponding to approximately 114 L/d (see Section 5.1.2). According to the manufacturer's specifications, the maximum permissible hydraulic load for this system is 900 L/d.

The system was operated under the following influent loadings level:

- Before 23 Jul 2008[1]:	3.6 $PE_{BOD,60}$
- From 23 Jul to 27 Aug 2008:	4.4 $PE_{BOD,60}$
- Overall mean (across entire study period):	4.9 $PE_{BOD,60}$

Therefore the system achieved a 81% capacity relative to influent BOD_5 over the entire study period.

According to the manufacturer's specification, the primary clarifier volume is 4 m³ and the filter volume 3.9 m³. Partial residence times were therefore estimated to be 2.8 days for the primary clarifier and 2.7 days for the filter, yielding a total residence time of 5.5 days in the system (see Section 2.6).

7.9.2 Statistical overview of results

The results of the statistical analysis for the entire study period, including the number of samples, the mean, median, minimum and maximum values, the statutory limits in France and Germany (see Sections 2.2.1.1 and 2.2.1.2), and the rates of compliance of effluent COD, BOD_5, SS, NH_4-N, N_{tot} and P_{tot} with the statutory limits (stay below probability) are shown below (Table 90 and Table 91). Mean, median, minimum and maximum values as well as the statutory limits in France (FR) and Germany (DE) are expressed in mg/L. The number of samples is a dimensionless parameter. The stay below probability is given in percent (%).

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[1] See Section 5.1.2: A higher hydraulic load (150% design load) was used at the later date in order to compensate for the low influent concentrations at design load.

Table 90: PREMIER TECH – Ecofix® STB-500: Statistical analysis of COD, BOD_5 and SS

Premier Tech - ECOFIX	COD		BOD			SS	
	In	**Out**	**In**	**Load (real)**	**Out**	**In**	**Out**
	[mg/l]	[mg/l]	[mg/l]	[E]	[mg/l]	[mg/l]	[mg/l]
Number of samples	50	50	50	50	50	49	50
mean	456	63	207	4,9	16	269,0	14,2
median	469	55	215	4,4	12	260,0	11,0
min.	180	21	78	1,5	3	120,0	2,8
max.	830	196	301	8,3	65	730,0	66,0
legally binding value (DE / FR)		**150 / 125**			**40 / 25**		**-- / 35**
stay below of legally binding value (DE)		96%			94%		
stay below of legally binding value (FR)		96%			84%		94%

* Load (real): See Section 2.3.

Table 91: PREMIER TECH – Ecofix® STB-500: Statistical analysis of nitrogen and phosphorus

Premier Tech - ECOFIX	NH_4-N		N_{tot}		P_{tot}	
	In	**Out**	**In**	**Out**	**In**	**Out**
	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]
Number of samples	50	50	50	50	50	50
mean	35,1	15,6	47,4	40,1	7,0	5,3
median	34,8	12,4	46,5	37,7	7,3	5,1
min.	11,6	0,0	19,8	15,5	2,9	2,7
max.	54,5	49,4	71,6	99,4	10,2	9,2
legally binding value (DE / FR)		-- / --		-- / --		-- / --
stay below of legally binding value (DE)						
stay below of legally binding value (FR)						

Chemical oxygen demand (COD)

The system achieved a mean effluent COD of 63 mg/L over the entire study period; the maximum was 196 mg/L. Measured COD levels were below the German and statutory limits of 150 mg/L and 125 mg/L (see Sections 2.2.1.1 and 2.2.1.2), respectively, in 96% of cases. In other words, two measurements exceeded the German and French limits, respectively (see Section 7.9.4). Hence, the system met the statutory effluent requirements for Germany and France in the vast majority of cases.

Biochemical oxygen demand (BOD_5)

The system achieved a mean effluent BOD_5 of 16 mg/L over the entire study period; the maximum was 65 mg/L. Measured BOD_5 levels were below the German statutory limit of 40 mg/L in 94% of cases, and were below the French statutory limit of 25 mg/L in 84%. In other words, the measured values exceeded the German limit in 3 cases and exceeded the French limit in 6 cases (see Section 7.9.4). Hence, the system met the statutory effluent requirements for Germany and France in the majority of cases.

Suspended solids (SS)

The system achieved a mean effluent SS concentration of 14.2 mg/L over the entire study period; the maximum was 66 mg/L. Measured SS concentrations were below the French statutory limit of 35 mg/L in 94% of cases. In other words, the measured values exceeded the French limit in 3 cases (see Section 7.9.6). Hence, the system met the statutory effluent requirements for France in the majority of cases. There are no statutory limits for suspended solids in Germany.

Nitrogen

- **Ammonia (NH_4-N):**
  The system achieved a mean effluent NH_4-N concentration of 15.6 mg/L over the entire study period; the maximum was 49.4 mg/L (see Section 7.9.5).
- **Total nitrogen (N_{tot}):**
  The system achieved a mean effluent N_{tot} concentration of 40.1 mg/L over the entire study period; the maximum was 99.4 mg/L (see Section 7.9.5).

Total phosphorus (P_{tot})

The system achieved a mean effluent P_{tot} concentration of 5.3 mg/L over the entire study period; the maximum was 9.2 mg/L (see Section 7.9.7).

7.9.3 Operational and process stability

Process stability was described in terms of compliance with statutory limits for target parameters (stay below probability), as shown in Figure 137. The steeper the curve, the more "stably" the system is operating. A stable system maintains steady effluent concentrations in spite of changes in influent concentrations, temperature etc. (see Section 2.10.9).

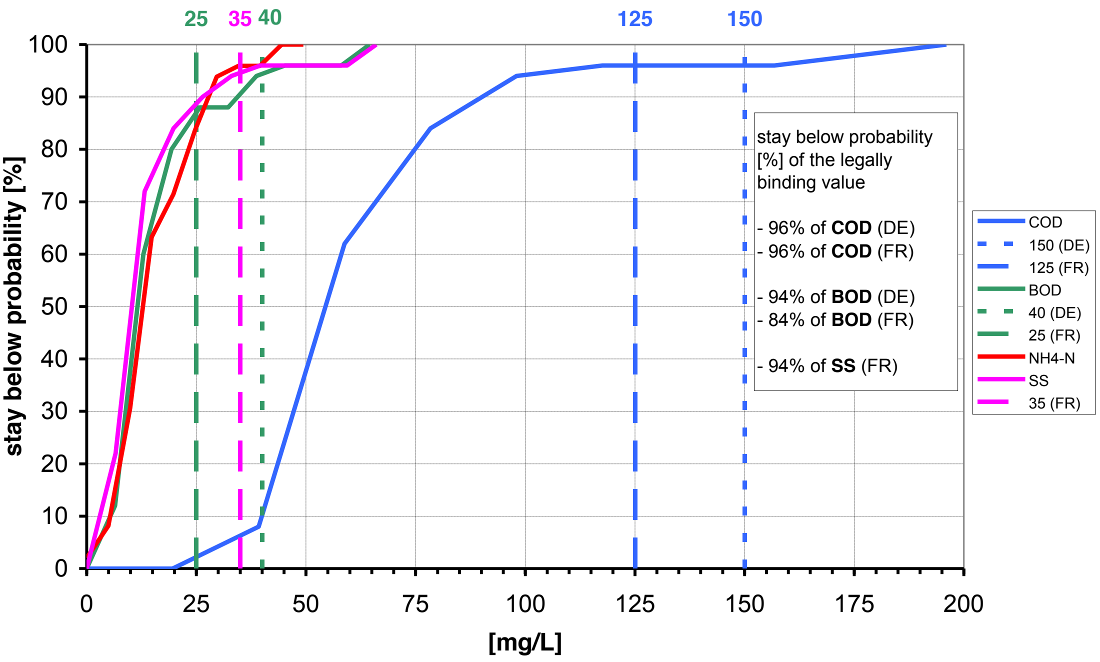

Figure 137: PREMIER TECH – Ecofix® STB-500:

Stay below probability for COD, BOD$_5$, NH$_4$-N and SS

7.9.4 COD and BOD$_5$ elimination

The combined parameters for organic matter were analysed based on the COD curve across the entire study period. In Figure 138, the horizontal lines at 150 mg/L and 125 mg/L, respectively, represent the German and French maximum limits.

The course of the BOD$_5$ curve (Figure 139) is similar to that of the COD curve. The mean effluent COD/ BOD$_5$ ratio is 4 to 1.

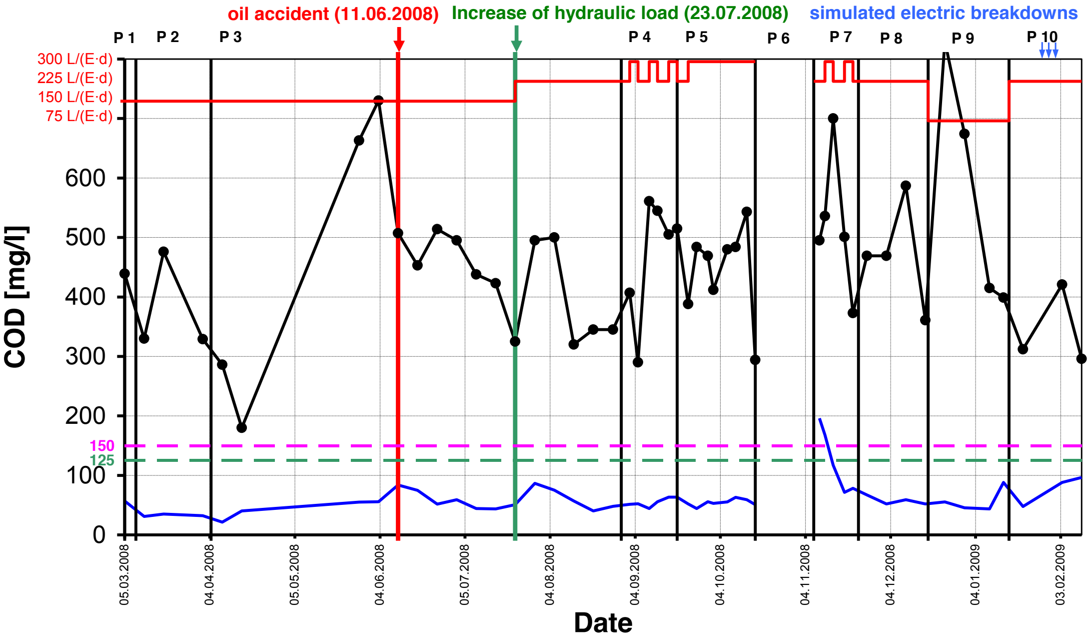

Figure 138: PREMIER TECH – Ecofix$^{®}$ STB-500: Influent and effluent COD curves

Effluent COD levels remained below 100 mg/L with only one exception (Figure 138). The oil accident resulted in a slight rise in COD concentration. Although the only action taken was to clean the primary clarifier, COD concentrations returned to baseline levels within about 14 days of the oil accident. The switch to a higher design hydraulic load in Phase 3 had a very slight effect, which also could have been a result of the higher influent concentration. Periodic 200% hydraulic loading on 3 days per week (Phase 4) and continuous 200% hydraulic loading for 4 weeks (Phase 5) did not result in any increase in effluent COD concentration.

COD rose to the highest level (196 mg/L) after completion of Phase 6 (3 weeks without load), but had normalised (to about 70 mg/L) by the middle of Phase 7. This could be due to an increased discharge of dead biomass after the system was restarted.

The brief rise in effluent COD concentrations at the end of Phase 9 may have been caused by obstruction of inflow due to a frozen non-return check flap (see Section 7.9.11) or the low wastewater temperatures (below 6°C).

The simulated electrical breakdowns only resulted in a very slight rise in effluent concentrations because the investigational system normally does not operate on electricity. This slight increase could be due to a temporary increase in influent concentrations of hard-to-degrade substances because this phenomenon was observed at the same time in nearly all of the SWWTPs studied (see Section 7.9.13).

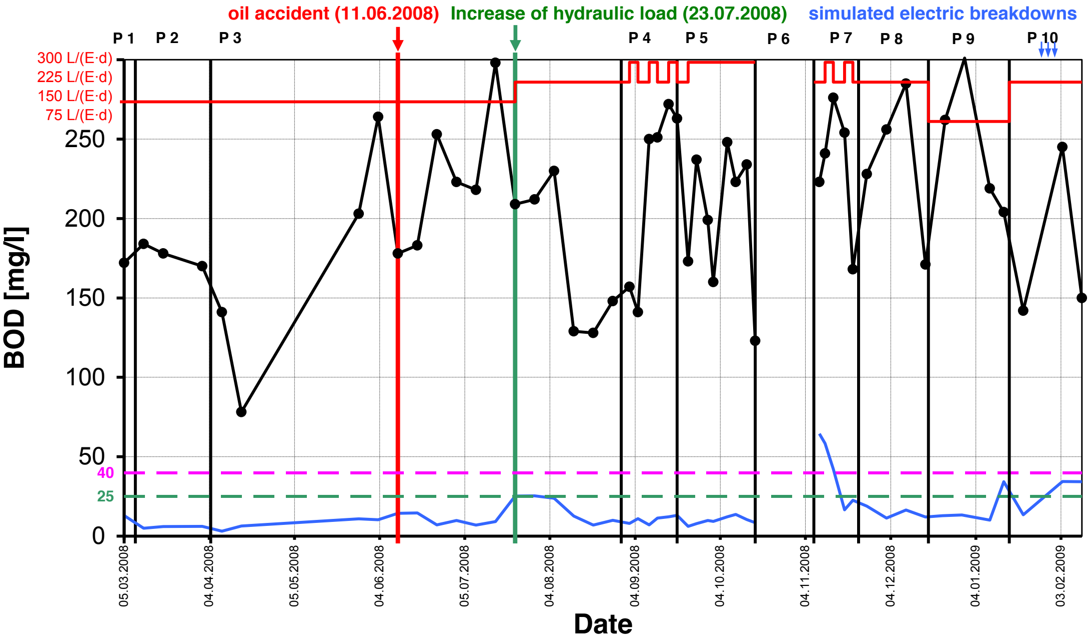

Figure 139: PREMIER TECH – Ecofix® STB-500: Influent and effluent BOD_5 curves

7.9.5 Nitrogen

Ammonia (NH_4-N)

The course of ammonia concentration (Figure 140) reflects the course of nitrification. As a biological process very sensitive to changes in process control, nitrification can be used as an indicator of changes in wastewater treatment systems.

From Phase 1 to Phase 3, effluent NH_4-N concentrations remained below 10 mg/L with few exceptions. In response to hydraulic overloading during Phase 4, effluent NH_4-N concentrations rose slowly and discontinuously to about 10 mg/L, although temperatures were in the highest range observed during the entire test period (mean 16.7°C for Phases 4-5).

No significant nitrification occurred during Phase 7. The reason for this could be the death and loss of such a large fraction of nitrifiers during the resting phase that it took about 4 weeks to re-establish the necessary number of microorganisms. This was also observed in Phases 8 and 9, where effluent NH_4-N, concentrations decreased from 25 mg/L to below 5 mg/L; this is likewise an effect of the reduced hydraulic and organic load during Phases 8 and 9.

The worsening of nitrification at the end of Phase 9 and during Phase 10 is most likely due to the very low wastewater temperatures and the brief interruption of inflow due to the frozen non-return check flap.

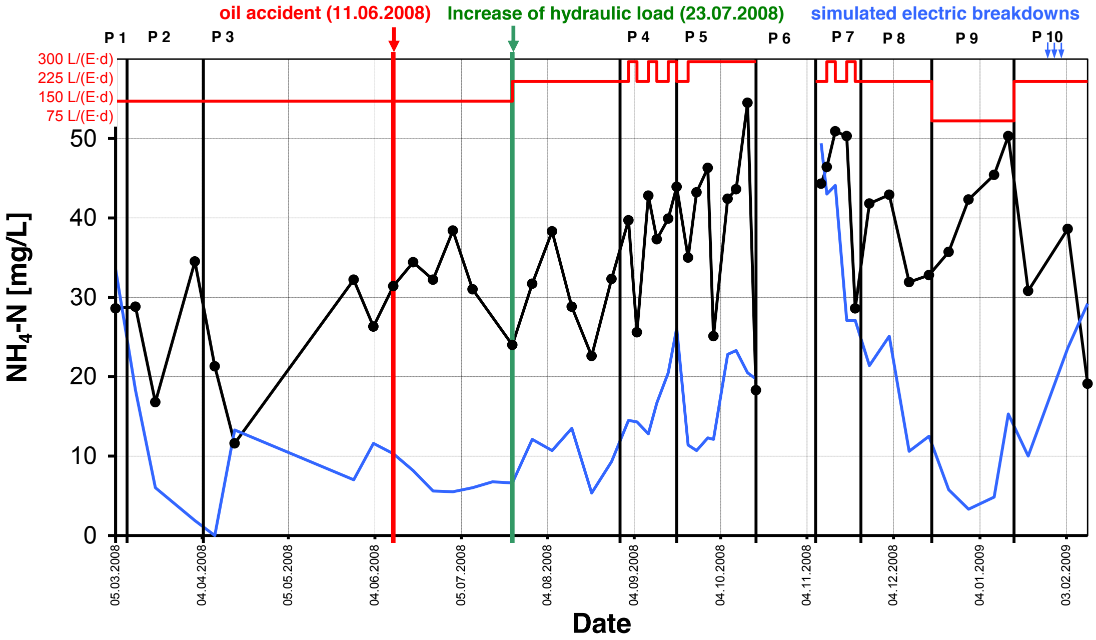

Figure 140: PREMIER TECH – Ecofix® STB-500: Influent and effluent NH_4-N curves

Inorganic nitrogen

The inorganic nitrogen curve is provided in the Appendix.

During the entire study period, there was no significant denitrification and the influent and effluent concentrations of inorganic nitrogen were mostly identical.

7.9.6 Suspended solids

Effluent SS concentrations generally remained relatively constant at very low levels below 15 mg/L (Figure 141).

After the resting phase (Phase 6), values peaked at 66 mg/L (see COD) but normalized within about 7 days. This initial elevation can be attributed to the partial wash-out of biomass after the resting phase.

The worsening of effluent values at the end of Phase 9 and during Phase 10 is most likely due to the very low wastewater temperatures and the brief interruption of inflow due to the frozen non-return check flap (death and loss of biomass due to the brief interruption of inflow). Biomass death occurring during the simulated electrical breakdowns could also have been caused by a temporary increase in influent concentrations of hard-to-degrade substances because this peak was observed in nearly all of the SWWTPs studied and was also reflected by influent COD and BOD$_5$ (Figure 138 and Figure Figure 139; cf. Section 7.9.13).

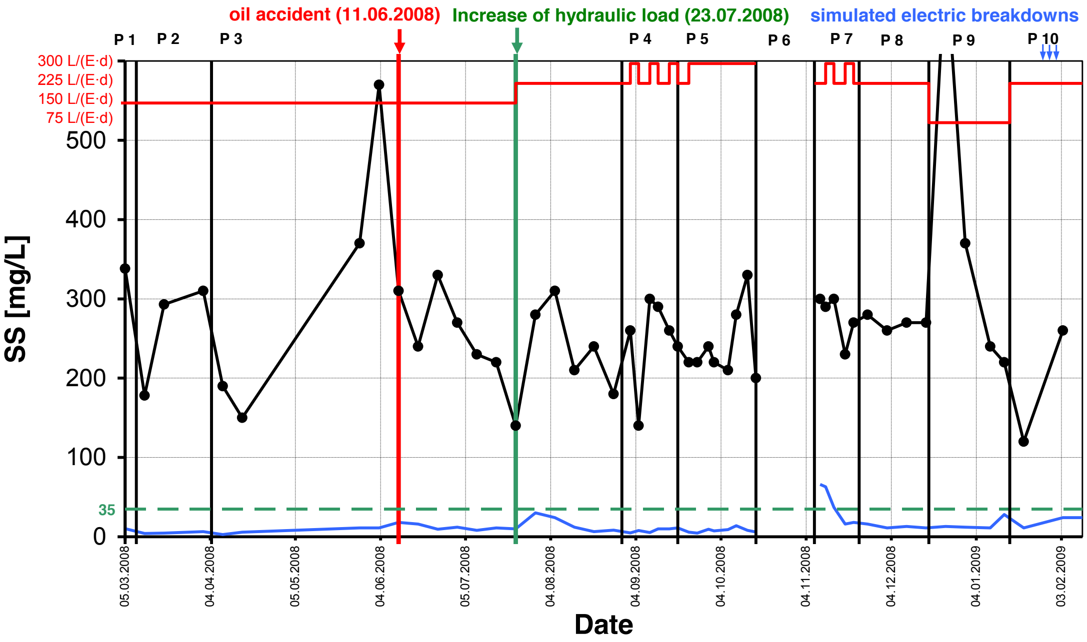

Figure 141: PREMIER TECH – Ecofix® STB-500: Influent and effluent SS curves

7.9.7 Phosphorus

Phosphorus elimination (Figure 142) was low and hydraulic load-independent during the entire study period. Effluent phosphorus concentrations ran parallel to the influent concentrations, but generally with a slight time lag.

Comparison shows that effluent phosphorus concentrations are directly related to effluent SS concentrations because bound phosphorous is eliminated together with suspended solids. Phosphorus is not degraded, but rather is "bound" and removed by sludge.

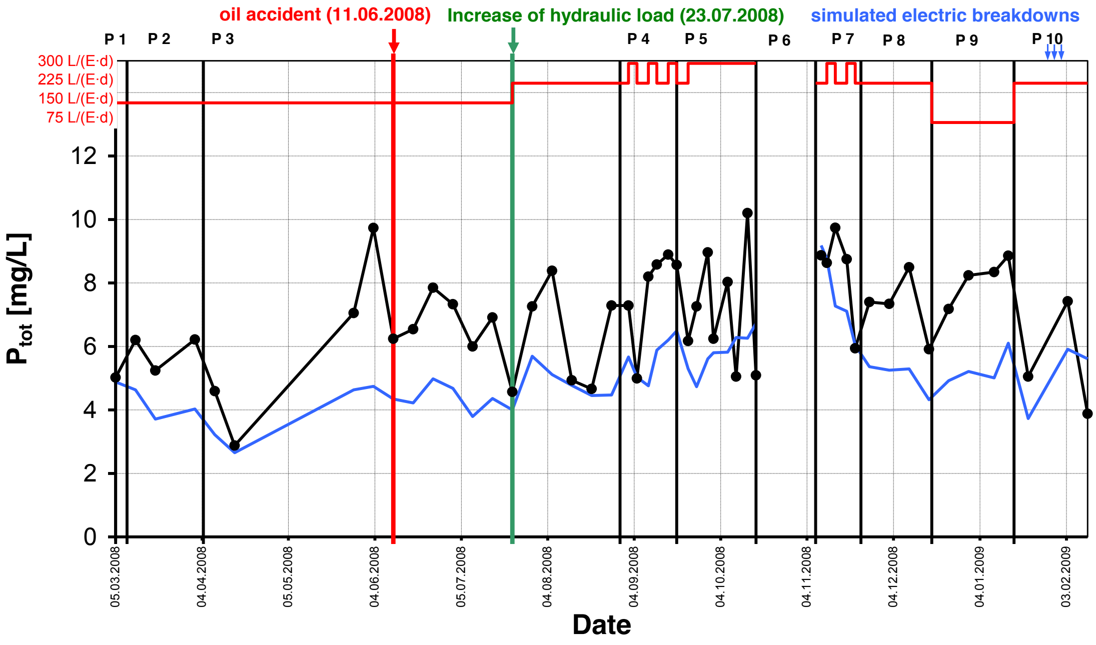

Figure 142: PREMIER TECH – Ecofix® STB-500: Influent and effluent P_{tot} curves

7.9.8 Degradation rate

Degradation rates for COD, BOD_5, NH_4-N, N_{tot}, P_{tot} and SS are expressed as percentage values (Table 92, Table 93 and Table 94; cf. Section 2.9). Negative values imply that influent concentrations were smaller than effluent concentrations. In this case, redissolution, wash-out and conversion (or re-conversion) from the biomass could have occurred. Measurement error is also possible, but was tested for in the scope of quality assurance. The data for Phases 1, 2 and 3, during which the system was tested at 100% hydraulic load, are presented in Table 93, and those for Phases 4, 5 and 7, during which the system was tested under hydraulic overload conditions, are shown in Table 94.

Phosphorus is not eliminated. Instead, a fraction either settles in the primary clarifier or is incorporated in the biomass and transported with excess sludge back to the primary clarifier.

The mean degradation rate was 86% for COD and 92% for BOD_5. Mean elimination rates were 54% for NH_4-N, 13% for N_{tot}, and 22% for P_{tot}.

Table 92: PREMIER TECH – Ecofix® STB-500: Degradation rates (%) for COD, BOD_5, NH_4-N, N_{tot}, SS and P (overall for entire study period)

Premier Tech - ECOFIX	η_{COD}	η_{BOD}	η_{NH4-N}	η_{Not}	η_{P}	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	50	50	50	50	50	49
mean	86	92	54	13	22	95
median	87	94	63	20	28	96
min.	60	71	-53	-70	-45	78
max.	93	98	100	50	51	99

Table 93: PREMIER TECH – Ecofix® STB-500: Degradation rates (%) for COD, BOD_5, NH_4-N, N_{tot}, SS and P during 100% loading (Phases 1, 2 and 3)

Premier Tech - ECOFIX	η_{COD}	η_{BOD}	η_{NH4-N}	η_{N-tot}	η_{P}	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	20	20	20	20	20	20
mean	87	94	64	17	27	96
median	88	95	72	20	32	96
min.	78	88	-17	-19	3	89
max.	93	98	100	50	51	99

Table 94: PREMIER TECH – Ecofix® STB-500: Degradation rates (%) for COD, BOD_5, NH_4-N, N_{tot}, SS and P during overloading periods (Phases 4, 5 and 7)

Premier Tech - ECOFIX	η_{COD}	η_{BOD}	η_{NH4-N}	η_{N-tot}	η_{P}	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	19	19	19	19	19	19
mean	84	92	42	12	15	94
median	87	95	47	23	22	96
min.	60	71	-12	-57	-32	78
max.	92	97	75	43	42	98

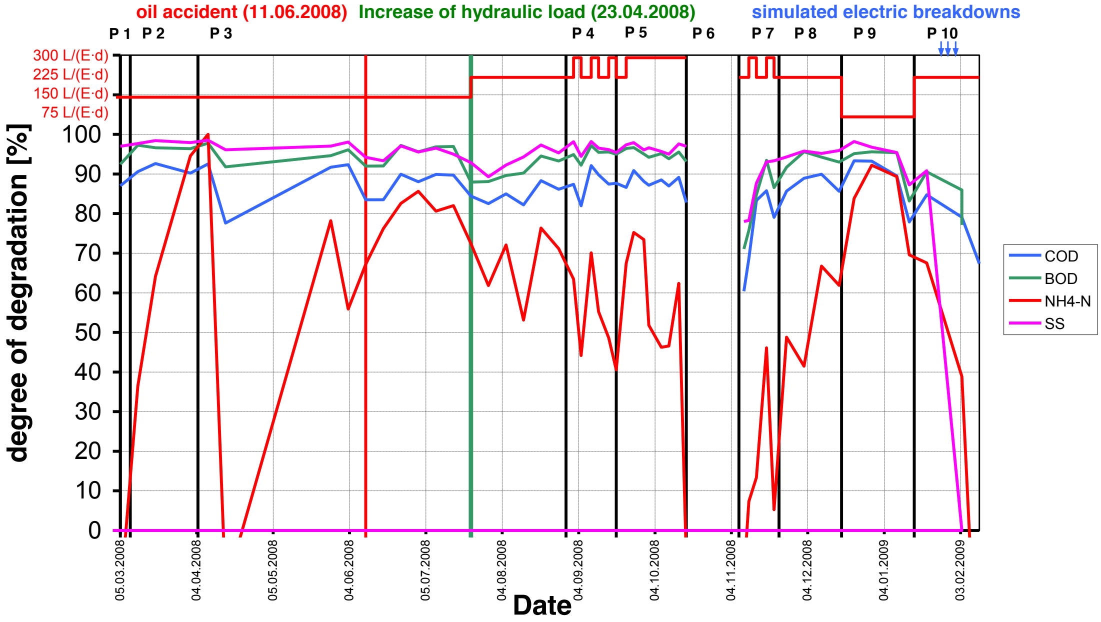

Figure 143: PREMIER TECH – Ecofix® STB-500:

Degradation curves for COD, BOD_5, NH_4-N and SS

The COD degradation rate achieved at 100% design load (87%) was approximately equal to the overall rate (86%). During the hydraulic overloading phases, degradation rates for all parameters except NH_4-N remained approximately constant. In terms of COD elimination, the lowest treatment efficacy was observed after Phase 6 (no load). The degradation curves (Figure 143) show that the increase in design flow from 150 L/(PE·d) to 225 L/(PE·d) resulted in a decrease in NH_4-N degradation.

More detailed analyses of effluent values are presented in Section 7.9.4.

7.9.9 Power consumption

This system does not need electrical power if installed conventionally. At the BDZ facility, power was needed solely due to the fact that the treated wastewater had to be pumped from the sample collection shaft to the level of the discharge channel (pump characteristics: 3.2 A, 600 W, max Q=300 l/min).

Therefore, total power consumption for the entire study period was assigned a value of 0 kWh/d.

7.9.10 Sludge

Sludge production was estimated based on the measured sludge height and the known container geometry. Such geometry-dependent estimates are relatively imprecise and of limited value.

Total sludge production for the entire study period was estimated to be 1.88 m³. At a sludge dry matter content of 32.7 g/L (measured), this corresponds to a sludge mass of 61.48 kg.

At the calculated actual load of 4.8 PE, this yields a specific sludge production of 35.2 g dry matter/(PE·d).

7.9.11 Operation and maintenance

Figure 144 shows all unusual incidents occurring while the system was in operation during the study. Hydraulic loads and influent COD concentrations are also shown for better clarity. The diagram shows the temporal sequence of events over time.

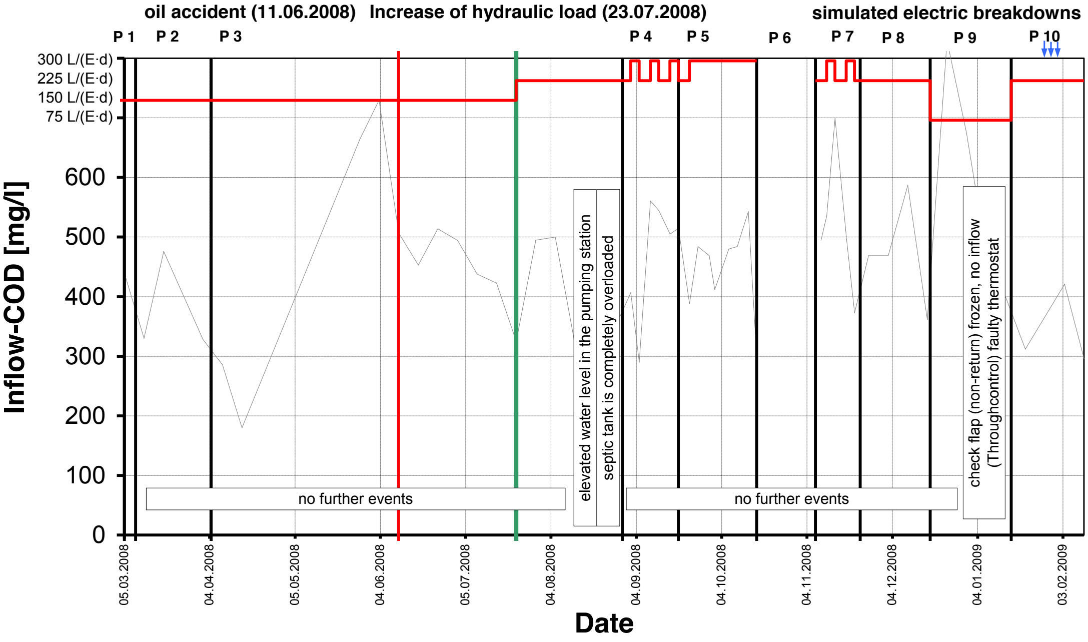

Figure 144: PREMIER TECH – Ecofix® STB-500: Maintenance log analysis

11 Sep 2008: The water level in the pump shaft was very high.

20 Aug 2008: Run times could not be read due to a malfunction. The septic tank was completely overloaded.

06 Jan 2009 (08:00 hrs) to 07 Jan 2009 (12:00 hrs): Inflow was obstructed due to a frozen non-return check flap. The valve was not part of the standard system equipment but rather, an experimental device. Therefore, the manufacturer (PREMIER TECH) was not responsible for this malfunction.

7.9.12 Microbiological parameters

Effluent water samples were collected on three consecutive days and tested for total coliform bacteria, faecal coliform bacteria, intestinal enterococci, salmonella and intestinal nematodes (see Section 5.4.2). The results of the microbiological analysis are presented in Table 95.

On average of three consecutive days, total coliform bacteria were reduced by 1.3 log steps, faecal coliform bacteria by 0.8 log steps, intestinal enterococci by 1.7 log steps and salmonella by around 1.5 log steps. In intestinal nematodes, there was an avarage reduction of 1 egg/L. On some days, there was an increase, although this may be explained by statistical uncertainty in the determination of the number In addition, the simultaneous sampling in the influent and effluent did not consider the time lag during the system passage.

It can generally be assumed that the number of faecal coliform bacteria undergoes a one- to two-log reduction per treatment stage (compare DWA, 1998). This was almost achieved by this plant with a mean of 0.8-log reduction.

As expected, effluent microbiological quality did not meet the requirements for bathing water quality.

Table 95: PREMIER TECH – Ecofix® STB-500: Microbiological analysis

Date		1 Dec 08			2 Dec 08			3 Dec 08			Mean
		[MPN/ mL]	[log]	Δ [log]	[MPN/ mL]	[log]	Δ [log]	[MPN/ mL]	[log]	Δ [log]	Δ [log]
Total coliform bacteria	Influent	930,000	5.97	1.59	390,000	5.59	0.96	430,000	5.63	1.46	1.3
	Effluent	24,000	4.38		43,000	4.63		15,000	4.18		
Faecal coliform bacteria	Influent	150,000	5.18	1.21	240,000	5.38	0.75	73,000	4.86	0.69	0.8
	Effluent	9,300	3.97		43,000	4.63		15,000	4.18		
Intestinal enterococci	Influent	43,000	4.63	1.25	93,000	4.97	2.00	93,000	4.97	2.00	1.7
	Effluent	2,400	3.38		930	2.97		930	2.97		
Salmonella	Influent	2,100	3.32	0.28	750	2.88	0.70	46,000	4.66	2.30	1.5
	Effluent	> 1,100	3.04		150	2.18		230	2.36		
		[Eggs/L]		Δ [Eggs]	[Eggs/L]		Δ [Eggs]	[Eggs/L]		Δ [Eggs]	Δ [Eggs]
Intestinal nematodes	Influent	<1		-8	13$^{1)}$		12	<1		-1	1
	Effluent	8			1			1			

1) statistical uncertainty in determination of the egg counts

"< 1" is assumed to be zero

">1,100" is assumed to be 1,100

7.9.13 Comparison of test results with reports and literature data

Chemical oxygen demand

According to the DIBt approval specifications for effluent Class C systems (Table 2), effluent COD concentrations in composite samples must not exceed 100 mg/L. Measured concentrations were below the 100 mg/L limit in 94% of all cases. In addition, they were below the manufacturer's target value of 100 mg/L in 100% of cases during testing at 100% design load (Phases 1, 2, and 3).

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 65 mg/L during 100% loading, which is comparable to the overall mean 63 mg/L achieved by the investigational system during the entire study period (in spite of the stricter test conditions).

Considering that the average effluent concentration of trickling filter systems was determined to be 107 mg/L (STRAUB 2008), the mean 63 mg/L achieved by the investigational system is much lower than the reference average.

The vertical flow constructed wetland (6 PE) used in the test series in *Dorf Mecklenburg* (JIROUDI 2605) achieved a mean effluent concentration of 107 mg/L (n=26), which is higher than that achieved by the investigational system. In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 1.087 mg/L (223 mg/L - 2.128 mg/L, 135 measurements).

The 14 filter systems studied by FLASCHE (2002) achieved a mean effluent COD of 54.9 mg/L, which is slightly higher than the mean 63 mg/L achieved by the investigational system.

The 12 biological filter systems studied by BOLLER (2004) achieved a mean effluent COD of 71 mg/L, which is slightly higher than the mean 63 mg/L achieved by the investigational system.

Biochemical oxygen demand (BOD_5)

According to the DIBt approval specifications for effluent Class C systems (Table 2), effluent BOD_5 concentrations in composite samples must not exceed 25 mg/L. Measured concentrations were below the 25 mg/L limit in 84% of all cases. In addition, they were below the manufacturer's target value of 25 mg/L in 90% of cases during testing at 100% design load (Phases 1, 2, and 3).

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 12 mg/L during 100% loading, which is comparable to the overall mean 16 mg/L achieved by the investigational system during the entire study period (in spite of the stricter test conditions).

Considering that the average effluent concentration of trickling filter systems was determined to be 46 mg/L (STRAUB 2008), the mean 16 mg/L achieved by the investigational system is much lower than the reference average.

The vertical flow constructed wetland (6 PE) used in the test series in *Dorf Mecklenburg* (JIROUDI 205) achieved a mean effluent concentration of 47 mg/L (n=2), which is much higher than the mean achieved by the investigational system. In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 598 mg/L (160 mg/L - 960 mg/L, 136 measurements).

The 14 filter systems studied by FLASCHE (2002) achieved a mean effluent BOD_5 of 4.4 mg/L, which is much lower than the overall mean 16 mg/L and 100% loading phase mean of 11.7 mg/L achieved by the investigational system.

Ammonia (NH_4-N)

The reference value, calculated as the average of 51 SWWTPs with nitrogen elimination tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 5 mg/L during 100% loading. The investigational system achieved a mean effluent NH_4-N concentration of approximately 10 mg/L during 100% loading (Phases 1 to 3, until 23 July 2008) and an overall mean of 15.6 mg/L for the entire study period.

Considering that the average effluent concentration of trickling filter systems was determined to be 15 mg/L (STRAUB 2008), the mean 15.4 mg/L achieved by the investigational system (under stricter test conditions) is equivalent to the reference average.

The vertical flow constructed wetland (6 PE) used in the test series in *Dorf Mecklenburg* (JIROUDI 205) achieved a mean effluent concentration of 17 mg/L (n=2), which is comparable to the mean 15.4 mg/L achieved by the investigational system (under stricter test conditions). In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 72 mg/L (24 mg/L - 114 mg/L, 137 measurements).

The 14 filter systems studied by FLASCHE (2002) achieved a mean effluent NH_4-N of 6.5 mg/L, which is much lower than the overall mean 15.6 mg/L and slightly lower than the 100% loading mean of 11 mg/L achieved by the investigational system.

Suspended solids (SS)

According DIBt Class C specifications (Table 2), effluent SS concentrations in random samples must not exceed 75 mg/L. Measured concentrations were below the 75 mg/L limit in 100% of all cases, including 100% loading periods (Phases 1, 2 and 3).

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 25 mg/L during 100% loading, which is slightly higher than the overall mean 14.2 mg/L achieved by the investigational system (under stricter test conditions).

The vertical flow constructed wetland (6 PE) used in the test series in *Dorf Mecklenburg* (JIROUDI 1005) achieved a mean effluent concentration of 12 mg/L (n=10), which is comparable to the overall mean 14.2 mg/L achieved by the investigational system (under stricter test conditions).

Simulated electrical breakdowns

Increases in effluent concentrations of the target parameters during simulated electrical breakdowns (Figure 165, Figure 166, Figure 167 and Figure 168) can be attributed to the electrical breakdowns themselves or to the presence of hard-to-degrade substances in the influent. In the study in Nantes (VIGNOLES, CAUCHI, 2009), however, similar peaks were observed during simulated electrical breakdowns in almost all WWTPs independent of whether they operated using electricity or not. The researchers in Nantes also could not find a plausible explanation for this phenomenon. This issue requires further investigation.

Power consumption

This SWWTP is designed in such a way that it normally does not need electrical power. The reference value, calculated as the average power consumption of 5 trickling filter systems tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is 0 to 0.1 kWh/(PE·d), which is comparable to the zero energy requirement of the investigational system.

The vertical flow constructed wetland (6 PE) used in the test series in *Dorf Mecklenburg* (JIROUDI 2605) achieved a power consumption rate of 0.05 to 0.06 kWh/(PE·d).

Sludge

Based on the reference values (DWA 2003), a specific sludge accumulation rate of approximately 70 g dry matter/(PE·d) was expected. However, the measured actual value was 35.2 g dry matter/(PE·d), suggesting that the suspended solids load in the raw sewage was below the expected value.

Microbiological parameters

The system achieved effluent faecal coliform bacteria counts of roughly 15,000 to 43,000 per 100 ml. This is higher than the reference average for constructed wetland systems—a mean 8,400 per 100 ml within a minimum-maximum range of 5 ml to 33,000 per 100 ml (STRAUB et al. 2008). The investigational system had an average log reduction of 0.8 log steps. This is well below the log reduction of 1.9 log steps by STRAUB ET AL. 2008.

The vertical flow constructed wetland used in the test series in *Dorf Mecklenburg* (JIROUDI 2605) reduced total coliform bacteria counts to 5.61x 10^4/100 mL (slightly higher than the levels achieved by the investigational system) and faecal coliform bacteria counts to 3.49 x 10^4/100ml (comparable to the levels achieved by the investigational system). The investigational system had an average log reduction of 1.3 log steps. This is well below the faecal coliforms log reduction of 3.3 log steps by JIROUDI 2005.

7.9.14 Summary

The investigational system operated at a mean load of 4.8 PE across the entire study period. Effluent COD concentrations (mean 63 mg/L) remained below 100 mg/L during the entire study period, even during 200% hydraulic loading periods. Higher concentrations did not occur except when restarting the system after the no-load phase.

Effluent SS concentrations predominantly remained below the 35 mg/L limit (mean 14.2 mg/L). However, increased effluent SS concentrations were observed after restarting the system after the no-load phase.

Overall, the investigational system achieved very stable treatment performance. No system malfunctions occurred during the study period.

The measured power consumption corresponded to the rate specified by the manufacturer.

7.10 BUSSE - MF-HKA4

7.10.1 Loading conditions

The MF-HKA4 was installed by the manufacturer (BUSSE). The system has a design capacity of 4 PE and was tested accordingly. The design organic load is equivalent to 240 g BOD_5/d, which is consistent with the influent load specified in the DIBt approval.

The design hydraulic load is 600 L/day. The system was also stressed with 200-litre bath water loads (bathtub tests) 5 times a week, corresponding to approximately 114 L/d (see Section 5.1.2). According to the approval report, the maximum permissible hydraulic load for this system is 600 L/d.

The system was operated under the following influent loadings level:

Before 23 Jul 2008[1]:	2.6 $PE_{BOD,60}$
From 23 Jul to 27 Aug 2008:	3.1 $PE_{BOD,60}$
Overall mean (across entire study period):	3.4 $PE_{BOD,60}$

Therefore, the system achieved a 86% capacity relative to influent BOD_5 over the entire study period.

According to the manufacturer's specifications, the primary clarifier and aeration basin have a volume of 1000 L each. Using these volumes, partial residence times were calculated as approximately 1 day for the primary clarifier and 1 day for the aeration basin, yielding a total residence time of 2.1 days in the system (see Section 2.6).

7.10.2 Statistical overview of results

The results of the statistical analysis for the entire study period, including the number of samples, the mean, median, minimum and maximum values, the statutory limits in France and Germany (see Sections 2.2.1.1 and 2.2.1.2), and the rates of compliance of effluent COD, BOD_5, SS, NH_4-N, N_{tot} and P_{tot} with the statutory limits (stay below probability) are shown below (Table 96 and Table 97). Mean, median, minimum and maximum values as well as the statutory limits in France (FR) and Germany (DE) are expressed in mg/L. The number of samples is a dimensionless parameter. The stay below probability is given in percent (%).

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[1] See Section 5.1.2: A higher hydraulic load (150% design load) was used at the later date in order to compensate for the low influent concentrations at design load.

Table 96: BUSSE MF-HKA4: Statistical analysis of COD, BOD_5 and SS

Busse, MF HKA 4	COD		BOD			SS	
	In	Out	In	Load (real)*	Out	In	Out
	[mg/l]	[mg/l]	[mg/l]	[E]	[mg/l]	[mg/l]	[mg/l]
Number of samples	50	48	50	50	48	49	48
mean	456	77	207	3,3	27	269,0	24,9
median	469	37	215	3,1	6	260,0	6,1
min.	180	14	78	1,0	< 3	120,0	< 1,0
max.	830	404	301	5,8	185	730,0	180,0
legally binding value (DE / FR)		**150 / 125**			**40 / 25**		**-- / 35**
stay below of legally binding value (DE)		85%			79%		
stay below of legally binding value (FR)		81%			77%		79%

* Load (real): See Section 2.3.

Table 97: BUSSE MF-HKA4: Statistical analysis of nitrogen and phosphorus

Busse, MF HKA 4	NH_4-N		N_{tot}		P_{tot}	
	In	Out	In	Out	In	Out
	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]
Number of samples	50	48	50	48	50	48
mean	35,1	19,1	47,4	27,6	7,0	2,9
median	34,8	20,1	46,5	25,1	7,3	1,8
min.	11,6	< 0,5	19,8	4,9	2,9	0,1
max.	54,5	49,9	71,6	60,9	10,2	20,0
legally binding value (DE / FR)		**-- / --**		**-- / --**		**-- / --**
stay below of legally binding value (DE)						
stay below of legally binding value (FR)						

Chemical oxygen demand (COD)

The system achieved a mean effluent COD of 77 mg/L over the entire study period; the maximum was 404 mg/L. Measured COD levels were below the German statutory limit of 150 mg/L (see Section 2.2.1.1) in 85% of cases, and were below the French statutory limit of 125 mg/L (see Section 125) in 81%. In other words, the measured values exceeded the German limit in 7 cases and exceeded the French limit in 9 cases (see Section 7.10.4). Hence, the system met the statutory effluent requirements for Germany and France in the vast majority of cases.

Biochemical oxygen demand (BOD_5)

The system achieved a mean effluent BOD_5 of 27 mg/L over the entire study period; the maximum was 185 mg/L. Measured BOD_5 levels were below the German statutory limit of 40 mg/L in 79% of cases, and were below the French statutory limit of 25 mg/L in 77%. In other words, the measured values exceeded the German limit in 10 cases and exceeded the French limit in 11 cases (see Section 7.10.4). Hence, the system met the statutory effluent requirements for Germany and France in the majority of cases.

Suspended solids (SS)

The system achieved a mean effluent SS concentration of 24.9 mg/L over the entire study period; the maximum was 180 mg/L. Measured SS concentrations were below the French statutory limit of 35 mg/L in 79% of cases. In other words, the measured values exceeded the French limit in 10 cases (see Section 7.10.6). Hence, the system met the statutory effluent requirements for France in the majority of cases. There are no statutory limits for suspended solids in Germany.

Nitrogen

- **Ammonia (NH_4-N):**
  The system achieved a mean effluent NH_4-N concentration of 19.1 mg/L over the entire study period; the maximum was 49.9 mg/L (see Section 7.10.5).
- **Total nitrogen (N_{tot}):**
  The system achieved a mean effluent N_{tot} concentration of 27.6 mg/L over the entire study period; the maximum was 60.9 mg/L (see Section 7.10.5).

Total phosphorus (P_{tot})

The system achieved a mean effluent P_{tot} concentration of 2.9 mg/L over the entire study period; the maximum was 20 mg/L (see Section 7.10.7).

7.10.3 Operational and process stability

Process stability was described in terms of compliance with statutory limits for target parameters (stay below probability), as shown in Figure 145. The steeper the curve, the more "stably" the system is operating. A stable system maintains steady effluent concentrations in spite of changes in influent concentrations, temperature etc. (see Section 2.10.9). The further course of the COD curve is linear and rises to a maximum of 404 mg/L.

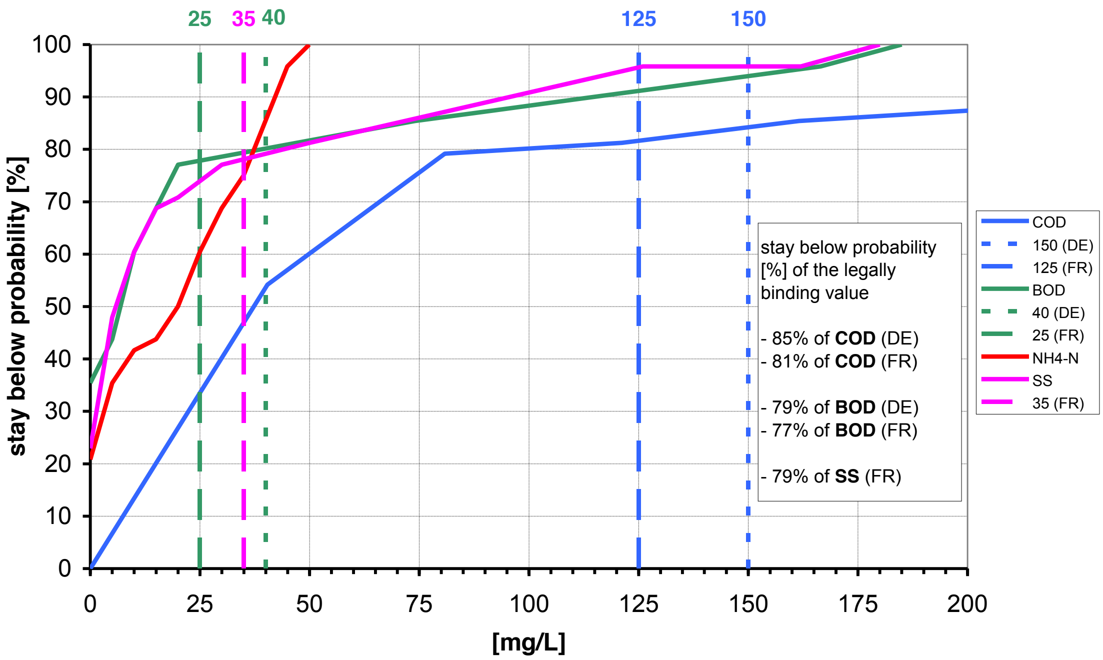

Figure 145: BUSSE MF-HKA4: Stay below probability for COD, BOD_5, NH_4-N and SS

7.10.4 COD and BOD_5 elimination

The combined parameters for organic matter were analysed based on the COD curve across the entire study period. In Figure 146, the horizontal lines at 150 mg/L and 125 mg/L, respectively, represent the German and French maximum limits.

The course of the BOD_5 curve (Figure 147) is similar to that of the COD curve. The mean effluent COD/ BOD_5 ratio is 5 to 1.

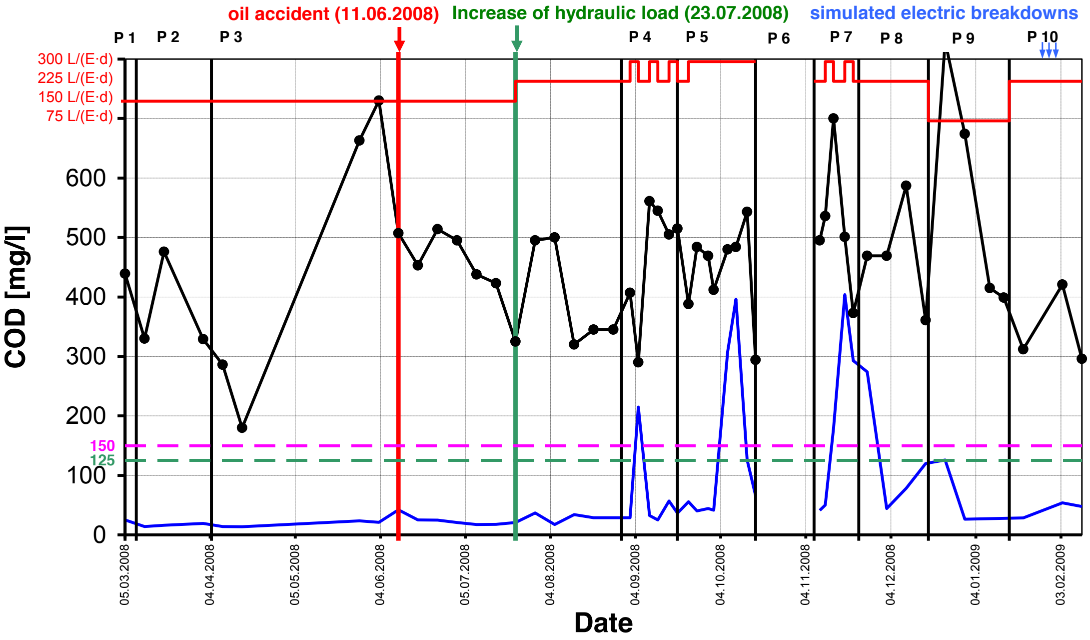

Figure 146: BUSSE MF-HKA4: Influent and effluent COD curves

Effluent COD levels remained well below 100 mg/L with few exceptions (Figure 146). The oil accident resulted in a very slight rise in COD concentration. The system was completely emptied and, the membrane was replaced, and sludge re-inoculated. This resulted in a normalization of effluent concentrations by the next sampling date (7 days later). The increase in design hydraulic load in Phase 3 had no measurable effect on COD concentrations. Due to the hydraulic overloading conditions in Phases 4, 5 and 7, there were three brief increases in effluent concentration, which subsequently decreased to "normal levels" of less than 100 mg/L. These peaks can be attributed to the spillover of wastewater from the primary clarifier into the effluent via the emergency overflow, which also resulted in three peaks in effluent suspended solids (see Figure 149). Increased suspended solids loads generally are not expected in the effluent of membrane systems. According to the manufacturer, this system normally does not come equipped with an emergency overflow. With the standard equipment, an alarm goes off when the collection tank, alerting the user to reduce water consumption until a maintenance technician arrives. Another less severe rise in effluent concentration, presumably due to the same reason, was observed between Phases 8 and 9.

After the hydraulic load was decreased in Phase 9, the effluent concentration remained below 30 mg/L. The only exception was during the simulated electrical breakdowns, when the effluent concentrations briefly rose to levels just below 50 mg/L. This increase could have been due to a temporary increase in influent concentrations of hard-to-degrade substances because this phenomenon was observed at the same time in nearly all of the SWWTPs studied (see Section 7.10.13).

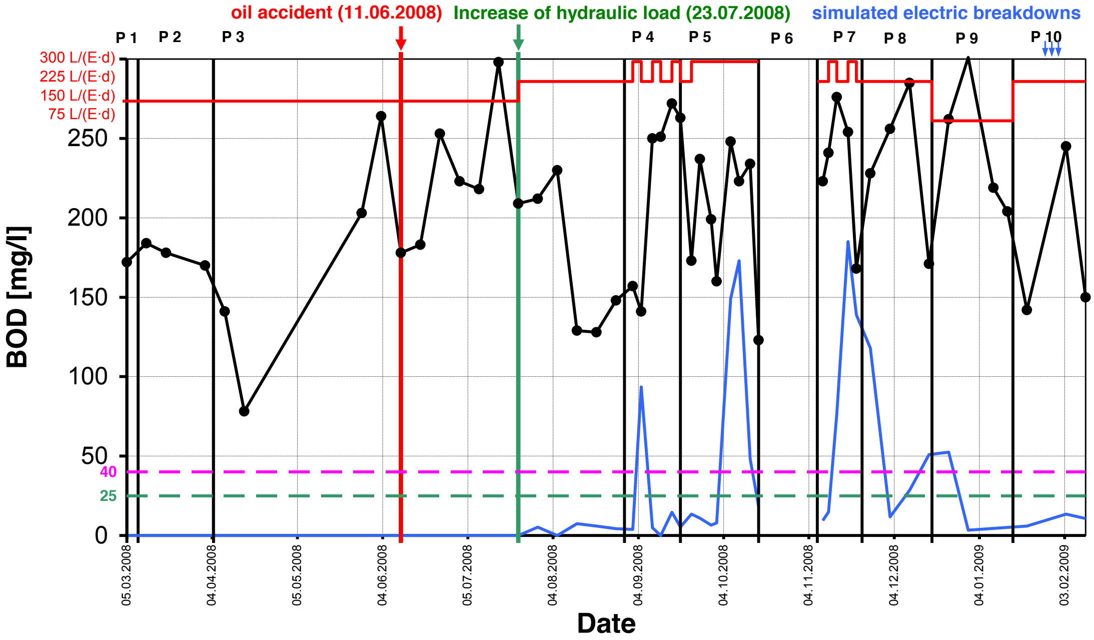

Figure 147: BUSSE MF-HKA4: Influent and effluent BOD_5 curves

7.10.5 Nitrogen

Ammonia (NH_4-N)

The course of ammonia concentration (Figure 148) reflects the course of nitrification. As a biological process very sensitive to changes in process control, nitrification can be used as an indicator of changes in wastewater treatment systems.

The oil accident led to slight worsening of nitrification, which lasted about 4 weeks and was apparently caused by adaptation of the inoculated biomass. Before the hydraulic load was increased, effluent concentrations again reached a minimum of < 0.5 mg/L.

In Phase 5, effluent NH_4-N concentrations rose sharply and discontinuously from ca. 0 to 47 mg/L in response to the increase in hydraulic load from 150 L/(PE·d) to 225 L/(PE·d) (starting on 23 July 2008) although temperatures were in the highest range observed during the entire test period (ca. 18 °C). During Phases 4, 5 and 7, no significant nitrification occurred due, presumably, to the reduced residence time and increased load.

In the middle of Phase 8, effluent NH_4-N concentrations improved briefly due to the stoppage of wastewater inflow (see Section 7.10.11) and the related increase in residence time.

From Phase 9 on, NH_4-N concentrations decreased continuously due to the decreased hydraulic and organic loads. The low wastewater temperatures (below 5 °C in some cases) did not have a negative effect on effluent NH_4-N concentrations.

During the simulated electrical breakdowns, oxygen input (aeration) was interrupted, which presumably led to a decrease in oxygen concentration in the aeration basis, causing effluent NH_4-N to rise briefly yet sharply to levels above 30 mg/L. After the electrical breakdowns, concentrations decreased again to levels below 20 mg/L.

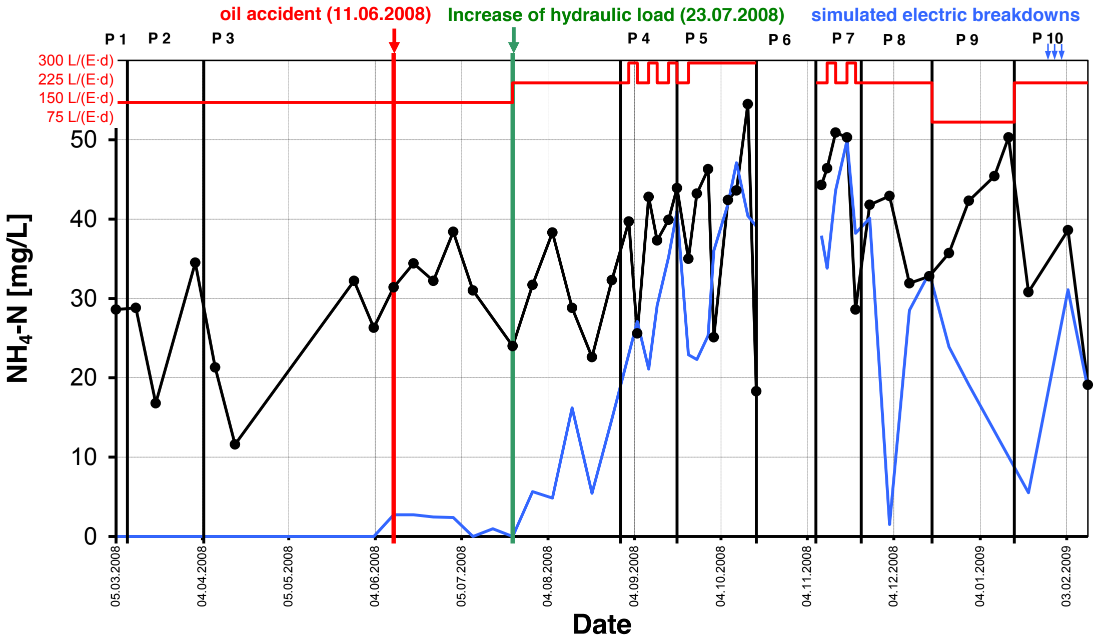

Figure 148: BUSSE MF-HKA4: Influent and effluent NH_4-N curves

Inorganic nitrogen

The inorganic nitrogen curve can be found in the Appendix.

Inorganic nitrogen concentrations ranged from 5 to 20 mg/L until the end of Phase 3. As these concentrations were 5 to 10 mg/L lower than the influent concentrations and because the NH_4-N concentrations were predominantly very low, the occurrence of partial denitrification (approx. 25-75%) can be assumed. Inorganic nitrogen concentrations increased to levels above 45 mg/L starting in Phase 4. Therefore, no significant nitrification occurred from that time until the end of Phase 9.

Partial denitrification (ca. 60%) occurred in Phases 9 and 10, but was stopped by the simulated electrical breakdowns.

7.10.6 Suspended solids

Until 23 July 2008, effluent SS concentrations generally remained relatively constant at very low levels below 2 mg/L (Figure 149). The increase to a hydraulic of 225 L/(E·d) caused effluent SS concentrations to rise to levels just below 10 mg/L. The high hydraulic loads in Phases 4, 5 and 7 each led to a brief yet massive washout of suspended solids via the emergency overflow. The primary clarifier volume of 1000 L did not provide sufficient storage volume for these high-stress conditions. Likewise, the increase in SS concentration between Phases 8 and 9 must have been caused by discharge via the emergency overflow because a membrane system of this type should be able to maintain very low effluent SS concentrations. A membrane defect can be excluded due to the fact that the system achieved very low SS concentrations of less than 12 mg/L in the further course of Phases 9 and 10 although the membrane had not been exchanged. The fact that effluent SS concentrations no longer reached levels below 2 mg/L could have been caused by deposits in the effluent being discharged via the emergency overflow and further transported by clear water.

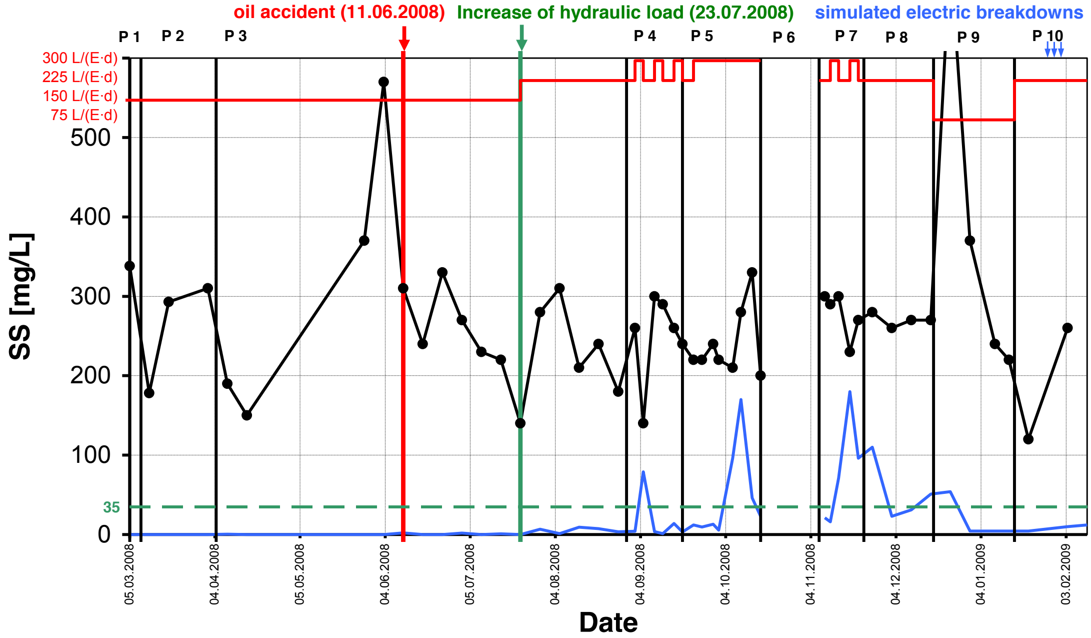

Figure 149: BUSSE MF-HKA4: Influent and effluent SS curves

7.10.7 Phosphorus

Phosphorus elimination (Figure 150) was extremely variable. In Phase 1 to 3, the phosphorus elimination rate ranged from 30 to 100 percent. The concentration increases in Phases 4, 5, 7 and 8 are clearly related to the elevated SS concentrations because bound phosphorus is transported out by suspended solids. Phosphorus is not degraded, but rather is "bound" and removed by sludge.

In Phase 9, effluent phosphorus concentrations improved due to lowering of the hydraulic load. Increases observed during the simulated electrical breakdowns may have been due to re-dissolution of phosphorus as a result of the prolonged retention time.

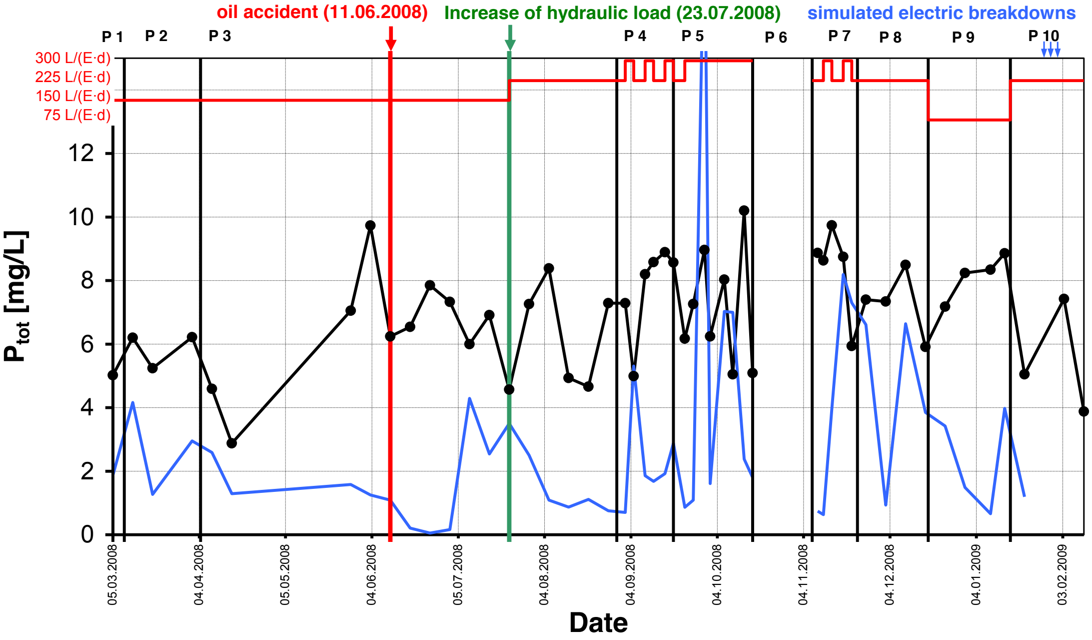

Figure 150: BUSSE MF-HKA4: Influent and effluent P_{tot} curves

7.10.8 Degradation rate

Degradation rates for COD, BOD_5, NH_4-N, N_{tot}, P_{tot} and SS are expressed as percentage values (Table 98, Table 99 and Table 100; cf. Section 2.9). Negative values imply that influent concentrations were smaller than effluent concentrations. In this case, redissolution, washout and conversion (or re-conversion) from the biomass could have occurred. Measurement error is also possible, but was tested for in the scope of quality assurance. The data for Phases 1, 2 and 3, during which the system was tested at 100% hydraulic load, are presented in Table 99, and those for Phases 4, 5 and 7, during which the system was tested under hydraulic overload conditions, are shown in Table 100.

Phosphorus is not eliminated. Instead, a fraction either settles in the primary clarifier or is incorporated in the biomass and transported with excess sludge back to the primary clarifier.

The mean degradation rate was 83% for COD and 87% for BOD_5. Mean elimination rates were 47% for NH_4-N, 40% for N_{tot}, and 57% for P_{tot}.

Table 98: BUSSE MF-HKA4: Degradation rates (%) for COD, BOD_5, NH_4-N, N_{tot}, SS and P (overall for entire study period)

Busse, MF HKA 4	η_{COD}	η_{BOD}	η_{NH4-N}	η_{N-tot}	η_P	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	48	48	48	48	48	47
mean	83	87	47	40	57	90
median	92	96	47	43	72	97
min.	18	17	-114	-46	-123	22
max.	97	100	100	88	99	100

Table 99: BUSSE MF-HKA4: Degradation rates (%) for COD, BOD_5, NH_4-N, N_{tot}, SS and P during 100 % loading (Phases 1, 2 and 3)

Busse, MF HKA 4	η_{COD}	η_{BOD}	η_{NH4-N}	η_{N-tot}	η_P	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	20	20	20	20	20	20
mean	94	99	91	60	69	99
median	95	100	99	63	76	100
min.	89	94	44	15	23	96
max.	97	100	100	88	99	100

Table 100: BUSSE MF-HKA4: Degradation rates (%) for COD, BOD$_5$, NH$_4$-N, N$_{tot}$, SS and P during overloading periods (Phases 4, 5 and 7)

Busse, MF HKA 4	η_{COD}	η_{BOD}	η_{NH4-N}	η_{N-tot}	η_P	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	19	19	19	19	19	19
mean	71	76	7	22	45	81
median	89	94	14	28	74	94
min.	18	17	-114	-46	-123	22
max.	95	100	51	58	93	100

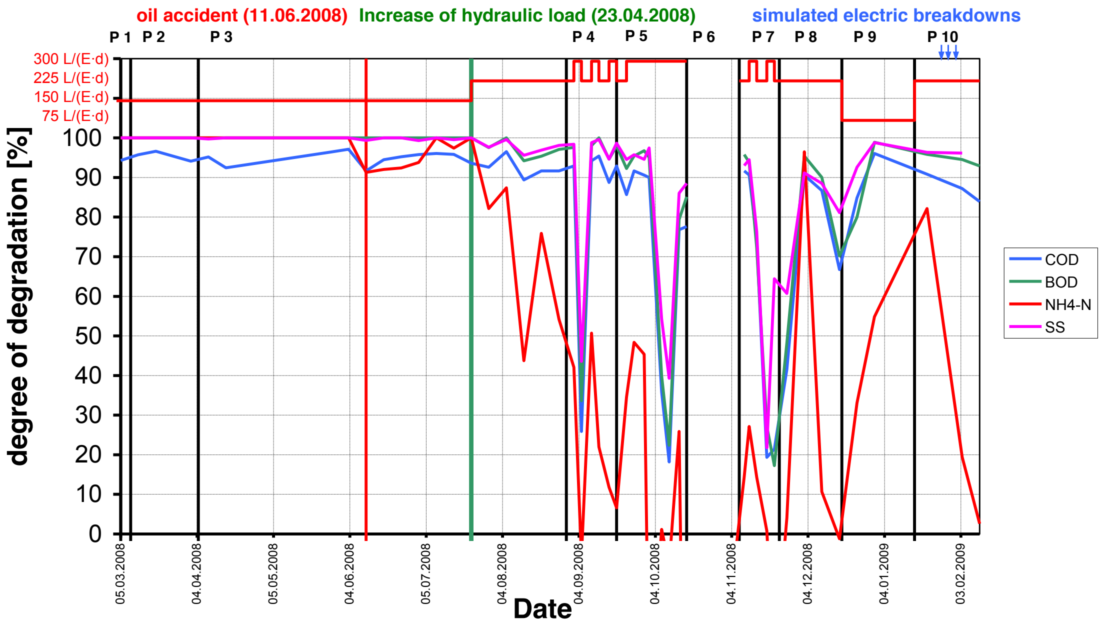

Figure 151: BUSSE MF-HKA4: Degradation curves for COD, BOD$_5$, NH$_4$-N and SS

The COD degradation rate at 100% design load (94%) was slightly better than the overall rate (83%) during the entire study period because the hydraulic load was lower. Degradation rates achieved during the hydraulic overloading phases tended to be lower. In terms of COD elimination, the lowest treatment efficacy was observed in Phases 4, 5 and 7, in each case, due to discharge of wastewater via the emergency overflow. NH$_4$-N degradation rates decreased sharply after the design load was raised from 150 to 225 L/(PE·d), as can be seen in the degradation curves (Figure 151).

More detailed analyses of effluent values are presented in Section 7.10.4.

7.10.9 Power consumption

Power consumption (Figure 153) was classified according to the PE-specific hydraulic load of the individual SWWTPs (no load and 75, 150, 225, 225+300 or 300 L/[PE·d]) using the design population equivalent specified in the approval (4 PE).

Mean power consumption values are expressed in units of kWh/(PE·a) (see Section 2.3). Since power consumption in Phase 6 (no load) was calculated based on the design population equivalent (4 PE), specific power consumption values estimated under other hydraulic loading conditions may be lower because they were calculated as the quotient of the measured power consumption and the actual population equivalent. At higher loads, the actual population equivalent is often higher than the design population equivalent, resulting in a lower power consumption rate per inhabitant.

Only total power consumption (sum of all power consumed by the system) was assessed. At the COMPAS test facility, the investigational system was installed in a container and not in a frost-proof room, as specified by the manufacturer. Therefore, an electrical heater was used to keep it warm during very cold periods in the winter. The heater was connected to the electric meter for the SWWTP, simulating a very high power consumption rate for the investigational system during the winter. Therefore, the estimated power consumption for the heater was subtracted from the meter reading, which was complicated by the discontinuous operation and ambiguous power specifications of the heater. The period after 3 Dec 2008 was affected.

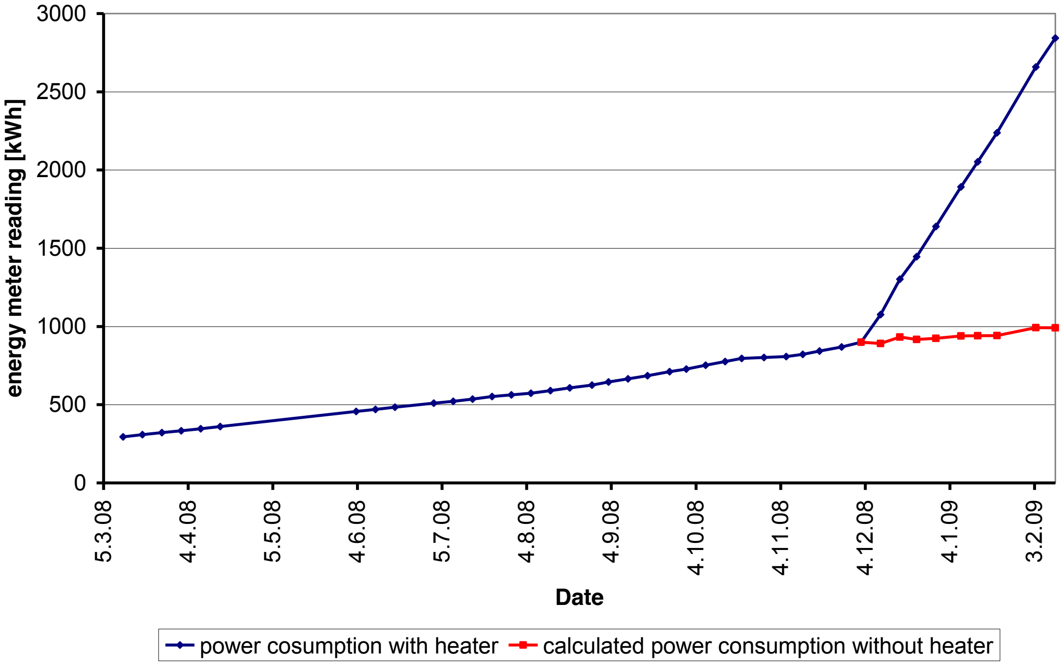

Figure 152: BUSSE MF-HKA4: Electric meter reading with and without heater

The system contains the following power-consuming units (Figure 153):

- Mammoth pump (pumping from primary clarifier to aeration basin)
- Two blowers

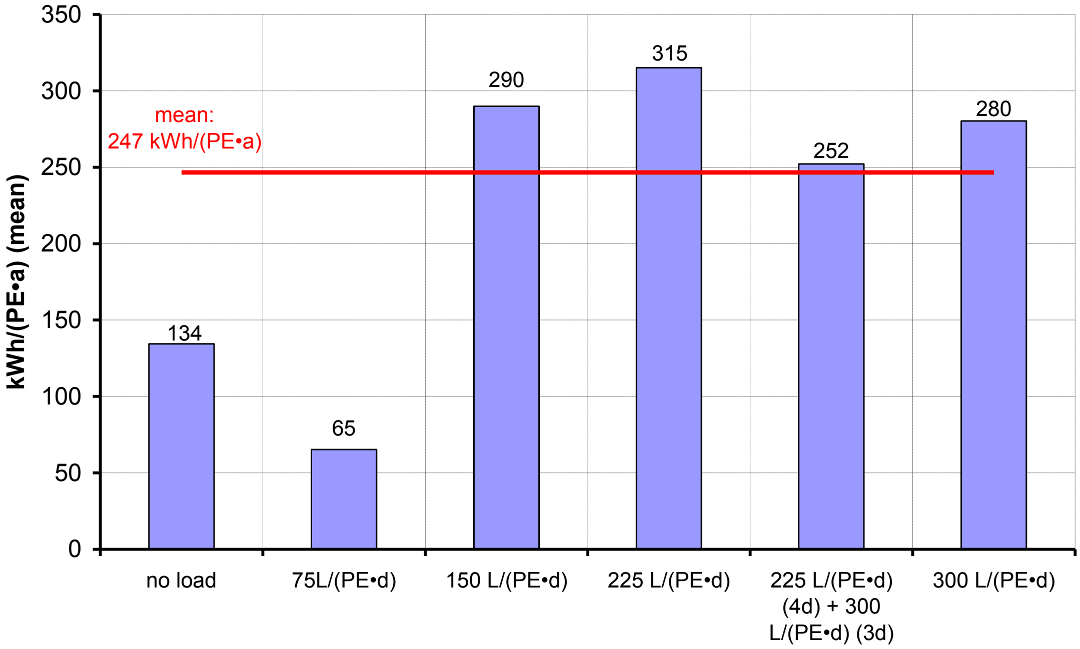

Figure 153: BUSSE MF-HKA4: Power consumption

Total power consumption of the system across the entire study period was a mean 247 kWh/(PE·a). Calculated based on the mean population equivalent of 3.4 PE relative to BOD_5 (see Section 2.3), this corresponds to a daily power consumption rate of 2.3 kWh/d.

Population-independent consumption, calculated based on power consumption at 4 PE during Phase 6 (no load), was 134 kWh/(PE·a) or 1.5 kWh/d.

7.10.10 Sludge

No analysis of sludge volume, dry matter content or loss on drying was performed for this system.

7.10.11 Operation and maintenance

Figure 154 shows all unusual incidents occurring while the system was in operation during the study. Hydraulic loads and influent COD concentrations are also shown for better clarity. The diagram shows the temporal sequence of events over time.

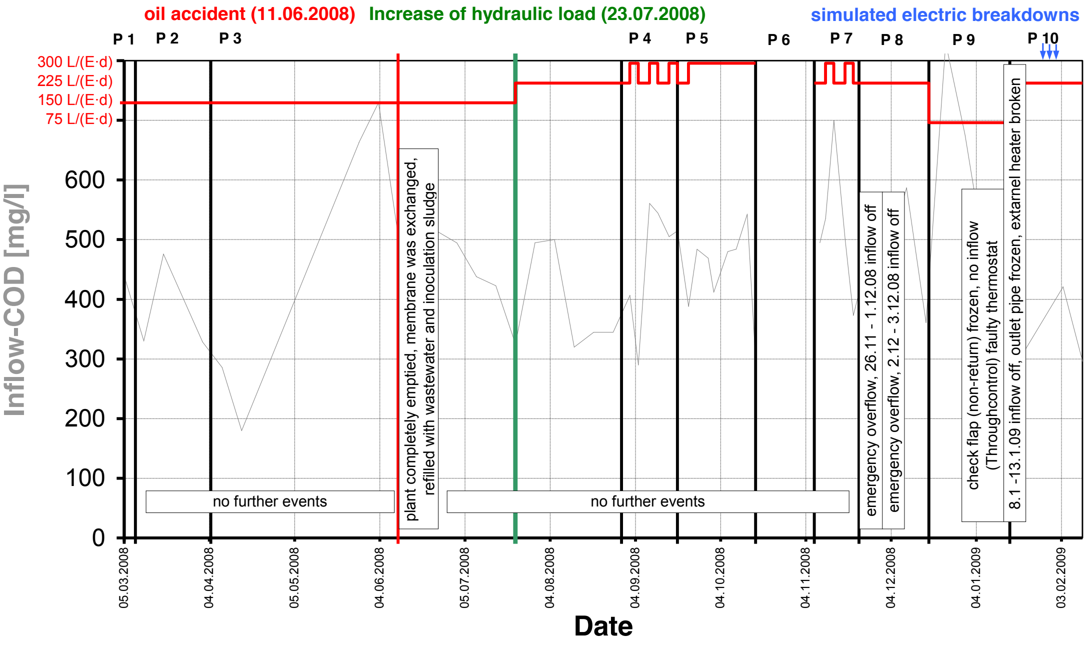

Figure 154: BUSSE MF-HKA4: Maintenance log analysis

11 June 2008: Due to the oil accident, the system was switched off and completely emptied by the manufacturer. The membrane was replaced and new sludge added (re-inoculation). The system was put back into operation on 12 June 2008.

26 Nov 08: Wastewater spilled out via the emergency overflow. The inflow was switched off after consulting with the manufacturer. 01 Dec 08: The system was re-started.

02 Dec 08: The inflow was switched off after consulting with the manufacturer. 03 Dec 08: The system was re-started.

06 Jan 09 (08:00 hrs) to 07 Jan 09 (12:00 hrs): Inflow was obstructed due to a frozen non-return check flap. The valve was not part of the standard system equipment but rather, an experimental device. Therefore, the manufacturer (BUSSE) was not responsible for this malfunction.

08 Jan 09: Inflow was switched off due to a heater malfunction, and the effluent line froze due to the very low temperatures. As the approval states that this system must be installed in a frost-proof room, this incident cannot occur under "normal" operating conditions. 13 Dec 09: The system was re-started.

7.10.12 Microbiological parameters

Effluent water samples were collected on three consecutive days and tested for total coliform bacteria, faecal coliform bacteria, intestinal enterococci, salmonella and intestinal nematodes (see Section 5.4.2). The results of the microbiological analysis are presented in Table 101.

In total coliform bacteria, faecal coliform bacteria, intestinal enterococci and salmonella, the log reduction could not be determined, because the effluent values were on all three days at 0 MPN/mL or less than 0.3 MPN/mL (< 0.3 is assumed to be zero). In intestinal nematodes, there was an avarage reduction of 4 eggs/L. On some days, there was an increase, although this may be explained by statistical uncertainty in the determination of the number. In addition, the simultaneous sampling in the influent and effluent did not consider the time lag during the system passage.

It can generally be assumed that the number of faecal coliform bacteria undergoes a one- to two-log reduction per treatment stage (compare DWA, 1998). This was completly achieved by this plant. Zero MPN/ml have been measured in the effluent.

As expected, effluent microbiological quality met the standards for "excellent bathing water quality" due to the use of membrane filtration.

Table 101: BUSSE MF-HKA4: Microbiological analysis

Date		**1 Dec 08**			**2 Dec 08**			**3 Dec 08**			**Mean**
		[MPN/ mL]	[log]	Δ [log]	[MPN/ mL]	[log]	Δ [log]	[MPN/ mL]	[log]	Δ [log]	Δ [log]
Total coliform bacteria	Influent	930,000	5.97	- 2)	390,000	5.59	- 2)	430,000	5.63	- 2)	- 2)
	Effluent	0	- 2)		< 0,3	- 2)		< 0,3	- 2)		
Faecal coliform bacteria	Influent	150,000	5.18	- 2)	240,000	5.38	- 2)	73,000	4.86	- 2)	- 2)
	Effluent	0	- 2)		< 0,3	- 2)		< 0,3	- 2)		
Intestinal enterococci	Influent	43,000	4.63	- 2)	93,000	4.97	- 2)	93,000	4.97	- 2)	- 2)
	Effluent	< 0,3	- 2)		< 0,3	- 2)		< 0,3	- 2)		
Salmonella	Influent	2,100	3.32	- 2)	750	2.88	- 2)	46,000	4.66	- 2)	- 2)
	Effluent	< 0,3	- 2)		< 0,3	- 2)		< 0,3	- 2)		
		[Eggs/L]		Δ [Eggs]	[Eggs/L]		Δ [Eggs]	[Eggs/L]		Δ [Eggs]	Δ [Eggs]
Intestinal nematodes	Influent	<1		0	13 1)		13	<1		0	4
	Effluent	<1			<1			<1			

1) statistical uncertainty in determination of the egg counts

2) 0 MPN/ml in effluent, no log reduction determined

"< 1" is assumed to be zero

"<0.3" is assumed to be zero

7.10.13 Comparison of test results with reports and literature data

Chemical oxygen demand

According to the manufacturer's specifications, the system achieves effluent COD concentrations of < 75 mg/L in random samples, in conformity with the DIBt Class N requirements. Measured concentrations were below the 75 mg/L limit in 77% of all cases. In addition, they were below the manufacturer's target value of 75 mg/L in 100% of cases during testing at 100% design load (Phases 1, 2, and 3).

The reference value, calculated as the average of 6 SWWTPs with membrane technology tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approx. 21 mg/L during 100% loading, which is much lower than the overall mean 77 mg/L achieved by this system (in spite of the stricter test conditions). However, during testing at 100% design load (Phases 1, 2, and 3), the investigational system achieved a mean COD of 23 mg/L, which is comparable to the mean of the 6 SWWTPs investigated in the PIA study in Aachen.

The 5 membrane systems studied by FLASCHE (2002) achieved a mean effluent COD of 41.6 mg/L, which is much lower than the overall mean 77 mg/L achieved by this system over the entire study period. The concentration achieved during the 100% loading phases was 23 mg/L, which is far below that achieved by the SWWTPs investigated by FLASCHE.

Biochemical oxygen demand (BOD_5)

According to the manufacturer's specifications, the system achieves effluent BOD_5 concentrations of < 15 mg/L in random samples, in conformity with the DIBt Class N requirements (Table 2). Measured concentrations were below the 15 mg/L limit in 75% of all cases. In addition, they were below the manufacturer's target value of 15 mg/L in 100% of cases during testing at 100% design load (Phases 1, 2, and 3).

The reference value, calculated as the average of 6 SWWTPs with membrane technology tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 2 mg/L during 100% loading, which is much lower than the overall mean 27 mg/L achieved by the investigational system for the total study period. However, during testing at 100% design load (Phases 1, 2, and 3), the investigational system achieved a mean BOD_5 of 1 mg/L, which is comparable to that of the SWWTPs investigated in the PIA study in Aachen.

The 5 membrane systems studied by FLASCHE (2002) achieved a mean effluent BOD_5 of 2.7 mg/L, which is much lower than the overall mean 27 mg/L achieved by the investigational system. During 100% loading phases, however, this system achieved a mean 1 mg/L, which is much lower than that of the SWWTPs studied by FLASCHE.

Ammonia (NH_4-N)

According to the manufacturer's specifications, the system achieves effluent NH_4-N concentrations of < 10 mg/L in random samples, in conformity with the DIBt Class N requirements (Table 2). Measured concentrations were below the 10 mg/L limit in 42% of all cases. In addition, they were below the manufacturer's target value of 15 mg/L in 90% of cases during testing at 100% design load (Phases 1, 2, and 3).

The reference value, calculated as the average of 6 membrane-based SWWTPs with nitrogen elimination tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 4 mg/L during 100% loading. The investigational system achieved a mean effluent concentration of approximately 3 mg/L during 100% loading (Phases 1 to 3, until 23 July 2008). However, the overall mean for the entire test period (19.1 mg/L) was far higher than the reference average.

The 5 membrane systems studied by FLASCHE (2002) achieved a mean effluent NH_4-N of 6.5 mg/L, which is much lower than the overall mean 19.1 mg/L achieved by this system. During 100% loading phases, however, the investigational system achieved a mean 3 mg/L, which is much lower than that of the SWWTPs studied by FLASCHE.

Suspended solids (SS)

According to the manufacturer, the system achieves effluent SS concentrations < 50 mg/L in random samples, in conformity with DIBt requirements (Table 2). Measured concentrations were below the 50 mg/L limit in 81% of all cases. In addition, they were below the manufacturer's target value of 50 mg/L in 100% of cases during testing at 100% design load (Phases 1, 2, and 3).

The reference value, calculated as the average of 6 SWWTPs with membrane technology tested at the PIA test facility in Aachen, Germany (DORGELOH 1008), is ca. 1 mg/L during 100% loading, which is much lower than the overall mean 24.9 mg/L achieved by this system. During the 100% loading phases, however, the investigational system achieved a mean of 2 mg/L, which is comparable to that of the SWWTPs studied at the PIA in Aachen.

Simulated electrical breakdowns

The (sometimes minor) increases in effluent concentrations of the target parameters during simulated electrical breakdowns (Figure 146, Figure 147, Figure 148 and Figure 149) can be attributed to the electrical breakdowns themselves or to the presence of hard-to-degrade substances in the influent. In the study in Nantes (VIGNOLES, CAUCHI, 2009), however, similar peaks were observed during simulated electrical breakdowns in almost all WWTPs independent of whether they operated using electricity or not. The researchers in Nantes also could not find a plausible explanation for this phenomenon. This issue requires further investigation.

Power consumption

The investigational system achieved a power consumption rate of 2.3 kWh/d, which is consistent with the rate specified by the manufacturer (1.8 to 3.0 kWh/d). The reference value, calculated as the average power consumption of 6 membrane systems tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is 0.39 kWh/(PE·d), which is slightly lower than the mean 0.68 kWh/(PE·d) achieved by the investigational system. Power consumption rates for the SWWTPs tested at the PIA test facility in Aachen ranged from approximately 0.29 kWh/(PE·d) to 0.55 kWh/(PE·d). Power consumption of the investigational system is thus slightly higher.

Sludge

A sludge analysis could not be performed for this system due to missing data.

Microbiological parameters

The investigational system reduced total coliform bacteria, faecal coliform bacteria, intestinal enterococci, salmonella and intestinal nematode (egg) counts to less than 0.3 per 100 ml.

7.10.14 Summary

The investigational system operated at a mean load of 3.4 PE across the entire study period.

Effluent COD, BOD_5 and SS concentrations (mean 77, 27 and 25 mg/L, respectively) remained far below the maximum limits with only three exceptions. The exceptions were related to the spill-over of wastewater from the aeration basin on three occasions as a result of the high hydraulic load. Effluent values were excellent during testing at 100% design load (Phases 1-3).

Overall, the investigational system achieved stable treatment performance. No system malfunctions occurred during the study period, apart from the discharge of wastewater via the emergency overflow.

The measured power consumption corresponded to the rate specified by the manufacturer.

The investigational system achieved a rating of "excellent bathing water quality for inland waters".

7.11 ATB – AQUA max BASIC

7.11.1 Loading conditions

AQUAmax® BASIC by ATB has a design capacity of 8 PE but was initially tested at a load of 9 PE due to the system group classification used in this study (4 PE, 6 PE or 9 PE). After the start of increased hydraulic loading in Phase 4, the nominal load reduced to 4 PE on 30 Sep 2008 at the request of the manufacturer because the effluent quality results decreased..

Thus, the nominal influent load used for testing was 540 g BOD_5/d before 30 Sep 2008 and 240 g BOD_5/d from 30 Sep 2008 on. According to the authorisation, the system should be able to handle influent loads of up to 480 g BOD_5/d.

Likewise, the nominal hydraulic load was 1350 L/d before 16 Sep 2008 and 600 L/d from 16 Sep 2008 on. The system was also tested with 200-litre bathtub discharges 5 times a week which corresponding to approx. 114 l/d (see 5.1.2). According to the authorisation, the maximum permissible hydraulic load for this system is 1200 L/d.

The system was operated under the following influent loadings level:

- Before 23 Jul 2008[*]:	4.7 $PE_{BOD,60}$
- 23 Jul 2008 until before 27 Aug 2008:	6.3 $PE_{BOD,60}$
- Overall average for entire study period:	5.6 $PE_{BOD,60}$

Therefore, the system achieved a 62% capacity at a nominal pollution load of 9 PE relative to influent BOD_5, which corresponds to 70% capacity at a pollution load of 8 PE (see above).

The manufacturer specifies minimum and maximum volumes for the pretreatment tank (accumulating zone) and SBR tank (biological reactor). In the case of the pretreatment tank, the minimum volume occurs when the maximum sludge volume is reached. The corresponding residence times were therefore 1.4 to 0.2 days for the pretreatment tank and 1.2 to 1.3 days for the SBR tank at a hydraulic load of 9 PE. At a load of 4 PE, the residence times were 1.9 to 0.3 days in the pretreatment tank and 1.7 to 1.8 days in the SBR tank. The overall residence times for the entire system were 1.4 to 2.7 days at 9 PE and 2.0 to 3.7 days at 4 PE (average 2.1 days at 9 PE and 2.8 days at 4 PE) (see 2.6).

7.11.2 Statistical overview of results

Table 102 and Table 103 show the results of the statistical analysis for the entire study period, including the number of samples, the mean, median, minimum (min) and maximum (max) values, the statutory limits in France (FR) and Germany (DE) (see 2.2.1.1 and 2.2.1.2), and the rates of compliance of effluent COD, BOD_5, SS, NH_4-N, N_{tot} and P_{tot} with

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[*] See Chapter 5.1.2: Due to the low influent concentrations, testing under increased hydraulic load conditions (150%) was discontinued in order to increase the influent load.

the statutory limits (*stay below probability*). Mean, median, minimum and maximum values as well as the statutory limits in France (FR) and Germany (DE) are expressed in units of mg/L. The number of samples is a dimensionless parameter. The stay below probability is given in percent (%).

Table 102: ATB AQUAmax® BASIC – Statistical analysis of COD, BOD$_5$ and SS

ATB, AQUA max BASIC	COD		BOD			SS	
	In	Out	In	Load (real)*	Out	In	Out
	[mg/l]	[mg/l]	[mg/l]	[E]	[mg/l]	[mg/l]	[mg/l]
Number of samples	50	49	50	50	49	49	49
mean	456	163	207	5,7	50	269,0	93,0
median	469	72	215	5,2	17	260,0	27,0
min.	180	21	78	0,4	<3	120,0	3,0
max.	830	1350	301	12,0	424	730,0	1100,0
legally binding value (DE / FR)		**150 / 125**			**40 / 25**		**-- / 35**
stay below of legally binding value (DE)		69%			61%		
stay below of legally binding value (FR)		65%			55%		53%

* Load (real); see 2.3

Table 103: ATB AQUAmax® BASIC – Statistical analysis of nitrogen and phosphorus

ATB, AQUA max BASIC	NH_4-N		N_{tot}		P_{tot}	
	In	Out	In	Out	In	Out
	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]
Number of samples	50	49	50	49	50	49
mean	35,1	23,1	47,4	37,8	7,0	5,8
median	34,8	27,1	46,5	34,5	7,3	4,4
min.	11,6	<0,1	19,8	12,0	2,9	0,8
max.	54,5	46,8	71,6	113,0	10,2	25,5
legally binding value (DE / FR)		**-- / --**		**-- / --**		**-- / --**
stay below of legally binding value (DE)						
stay below of legally binding value (FR)						

Chemical oxygen demand (COD)

The system achieved a mean effluent COD of 163 mg/L over the entire study period; the maximum concentration was 1350 mg/L. Measured COD levels were below the German statutory limit of 150 mg/L in 69% of cases (see 2.2.1.1), and were below the French statutory limit of 125 mg/L in 65% (see. 2.2.1.2). In other words, the measured levels exceeded the German limit in 15 cases and exceeded the French limit in 17 cases (see 7.11.4). The system met the statutory effluent requirements for Germany and France in approximately two-thirds of all cases.

Biological oxygen demand (BOD_5)

The system achieved a mean effluent BOD_5 of 50 mg/L over the entire study period; the maximum concentration was 424 mg/L. Measured BOD_5 levels were below the German statutory limit of 40 mg/L in 61% of cases, and were below the French statutory limit of 25 mg/L in 55%. In other words, the measured levels exceeded the German limit in 19 cases and exceeded the French limit in 22 cases (see 7.11.4). The system met the statutory effluent requirements for Germany and France in slightly more than half of all cases.

Suspended solids (SS)

The system achieved a mean effluent SS concentration of 93 mg/L over the entire study period; the maximum concentration was 1100 mg/L. Measured SS concentrations were below the French statutory limit of 35 mg/L in 53% of cases. In other words, the measured concentrations exceeded the French limit in 23 cases (see 7.11.6). The system met the statutory effluent requirements for France in roughly half of all cases. There are no statutory limits for effluent SS concentrations in Germany.

Nitrogen

- **Ammonia (NH_4-N):**
  The system achieved a mean effluent NH_4-N concentration of 23 mg/L over the entire study period; the maximum concentration was 47 mg/L (see 7.11.5).
- **Total nitrogen (N_{tot}):**
  The system achieved a mean effluent N_{tot} concentration of 38 mg/L over the entire study period; the maximum concentration was 113 mg/L (see 7.11.5).

Total phosphorus (P_{tot})

The system achieved a mean effluent P_{tot} concentration of 6 mg/L over the entire study period; the maximum concentration was 26 mg/L (see 7.11.7).

7.11.3 Operational and process stability

Process stability was described in terms of compliance with statutory limits for target parameters (*stay below probability*) (Figure 155). The steeper the cure, the more "stably" the system is operating. A stable system maintains steady effluent concentrations in spite of changes in influent concentrations, temperature etc. (see 2.10.9).

The 200 mg/L curve was left out for clarity; in this range, the slopes of the curves were similar.

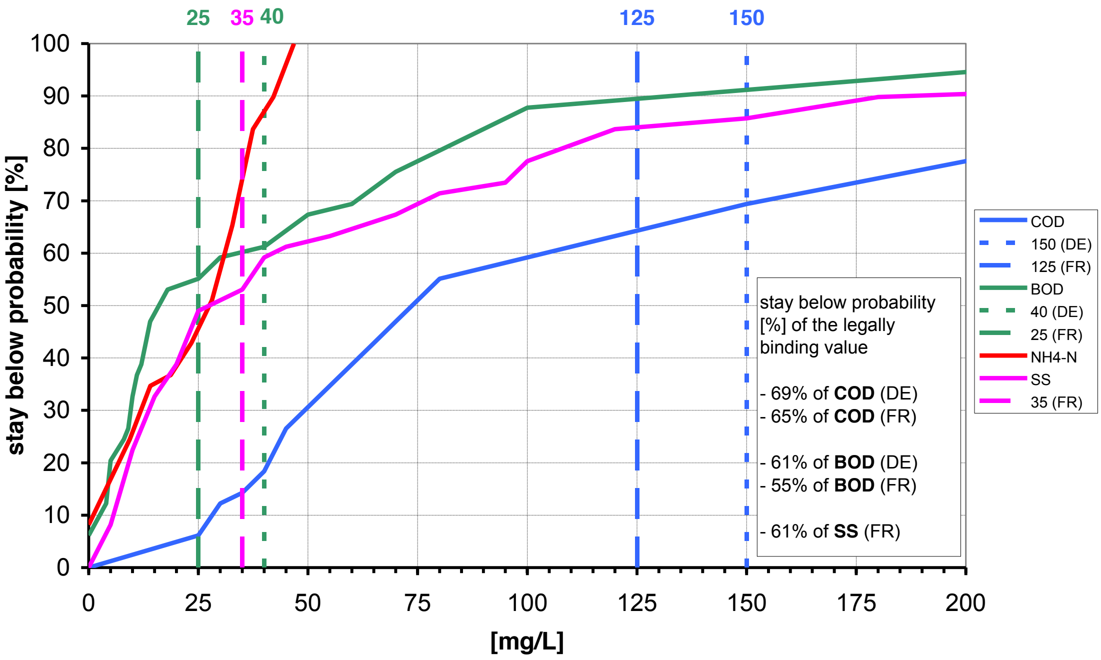

Figure 155: ATB AQUAmax® BASIC – Stay below probability for COD, BOD$_5$, NH$_4$-N and SS

7.11.4 COD and BOD$_5$ elimination

The combined parameters for organic matter were analysed based on the COD curve over the entire study period. The horizontal lines (Figure 156) at 150 mg/L (125 mg/L) represent the German and French maximum limits. The vertical broken line represents the switch from 9 PE to 4 PE on 30 Sep 2008, including the altered hydraulic loading conditions.

The BOD_5 curve shown in Figure 157 is similar to the COD curve. The mean COD/ BOD_5 ratio is 3.2 to 1.

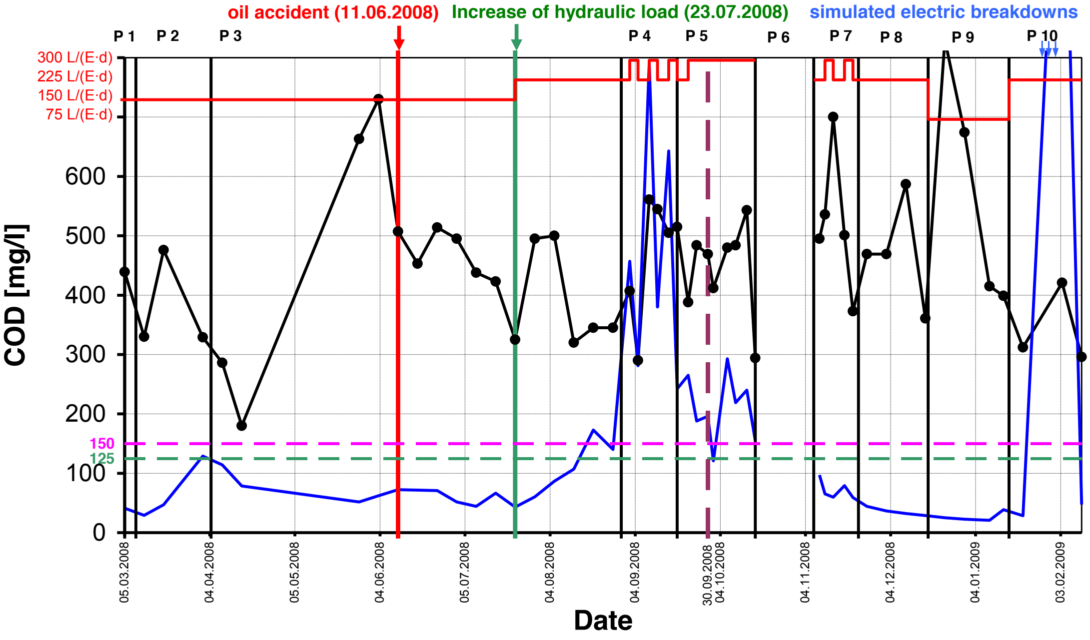

Figure 156: ATB AQUAmax® BASIC – Influent and effluent COD curves

Until 23 Jul 2008, effluent COD concentrations remained below 100 mg/L with few exceptions (Figure 156). The increase during this period occurred towards the end of Phase 2 and was most probably caused by the two-week breakdown of the aeration system since 01 Apr 2008. The fact that the oil accident did not result in any increase in effluent COD levels was presumably due to the fact that the system was thoroughly cleaned and inoculated with activated sludge from an external source.

Before 30 Sep 2008, the investigational system was overloaded by a factor of 1 PE (150 l/d) and four additional bathtub loads (see 5.1.2). During the increased hydraulic loading conditions in Phase 3 (starting on 23 Jul 2008), the system was overloaded by roughly 178%, corresponding to an increase from 50 mg/L to over 200 mg/L by the end of Phase 3. This sharp increase was caused by emergency overflow from the pretreatment tank into the biological reactor (on 13 Aug and 20 Aug 2008) and presumably resulted in the following effects:

- During clear water removal, some settleable solids were rinsed via the emergency overflow from the pretreatment tank into the biological reactor and thus gained entry into the effluent.
- Due to the uncontrolled inflow, hydraulic and pollutant loads in the biological stage rose, thus raising the oxygen demand in the biological reactor. The consequently de-

ficient oxygen content (only 0.1 mg/L at times) prevented adequate biological treatment, thus presumably leading to increased effluent concentrations during this phase.

Due to the further increase in hydraulic load during Phase 4, effluent COD concentrations increased to more than 800 mg/L, which was much higher than the corresponding influent concentrations. In addition, there was a massive drop in sludge volume from about 170 mL/L to less than 30 mL/L, which can be attributed to the loss of sludge due to high inflow (cf. Figure 159, suspended solids curve). The increased inflow resulted in overflow from the pretreatment tank, as evidenced by traces of particles found on the baffles. During the aeration phase, this presumably led to the escape of sludge via the emergency overflow out of the biological reactor and into the effluent. Consequently, the effluent COD concentration at the end of Phase 4 was 250 mg/L although the sludge volume was still very low (20 mL/L). The oxygen content improved during this phase, presumably because the low sludge volume decreased the number of micro-organisms to low levels.

Switching the load to 4 PE on 30 Sep 2008 resulted in an appreciable increase in sludge volume (to about 100 mL/L) within about 10 days. Effluent COD concentrations then decreased to levels below 200 mg/L. During Phase 6 (no load), the sludge volume decreased to about 30 mL/L, which can be attributed to the compression/condensation of sludge and to the fact that the amount of sludge remained constant in spite of the low sludge volume.

From Phase 7 on, the effluent COD problem improved continuously, and concentrations decreased from below 100 mg/L to roughly 20 mg/L by the middle of Phase 9. This improvement was reflected by a higher sludge volume (ca. 300 mg/L) and good oxygen content (ca. 3 mg/L). It is notable that these effluent concentrations were achieved in spite of low wastewater temperatures (below 5°C) and very high effluent loads (more than 800 mg/L in some cases).

Effluent COD concentrations rose to a peak 1.350 mg/L after the simulated electrical breakdowns and returned to values less than 50 mg/L thereafter. This may be caused by an overflow of the primary treatment and an associated entry of sludge in the bioreactor. Also a related overflow of the bioreactor could be envisaged. This hypothesis is supported by the very high end concentration of suspended solids. A further explanation might be the temporary increase of hard-to-degrade substances in the influent, as this phenomenon while in nearly all plants investigated was observed (see 7.11.13).

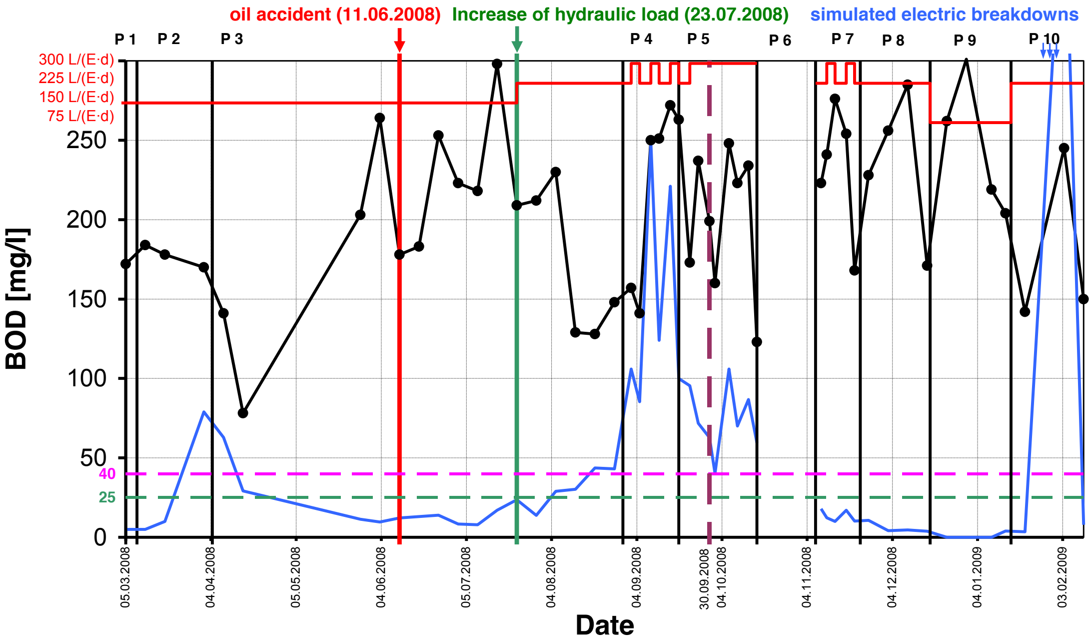

Figure 157: ATB AQUAmax® BASIC – Influent and effluent BOD_5 curves

7.11.5 Nitrogen

Ammonia (NH_4-N)

The course of the NH_4-N curve reflects the course of nitrification (Figure 158). As a biological process very sensitive to changes in process control, nitrification is a useful indicator of the stability of wastewater treatment systems.

Effluent NH_4-N concentrations remained at approximately 10 mg/L until the oil accident, with the only exceptions occurring at the end of Phase 2 and at the beginning of Phase 3. At those times, influent and effluent NH_4-N concentrations were nearly identical. In other words, almost no nitrification occurred. The aeration system malfunction could be the reason for this.

After the oil accident, the system was completely emptied and filled with sludge from an external source, which was presumably a wastewater treatment plant without nitrification. Therefore, no appreciable nitrification was observed under the high hydraulic load up until the end of Phase 5, although the temperatures (mean: 16.5°C) were the highest measured during the entire study period.

After the resting period (Phase 6), effluent NH_4-N concentrations finally decreased to levels below 10 mg/L but rose again to 30 mg/L by the end of Phase 7. Reduced retention time in the system is a possible cause of this short-term rise in NH_4-N concentration. The wastewater might have passed directly from the pretreatment tank into the biological reactor, which was reinforced by the high level alarm.

In Phases 8 and 9, the NH_4-N concentration dropped to levels below 0.5 mg/L, which was probably due to the reduced hydraulic load but might have been caused by replacement of the controller by the manufacturer. This decrease occurred although the wastewater temperatures were extremely low (< 5°C).

The simulated electrical breakdowns induced a short-term increase in effluent NH_4-N concentrations to levels >20 mg/L. This could be due to the aeration system malfunction caused by the electrical breakdowns (see Figure 158: aeration system malfunction on 04 Apr 2008).

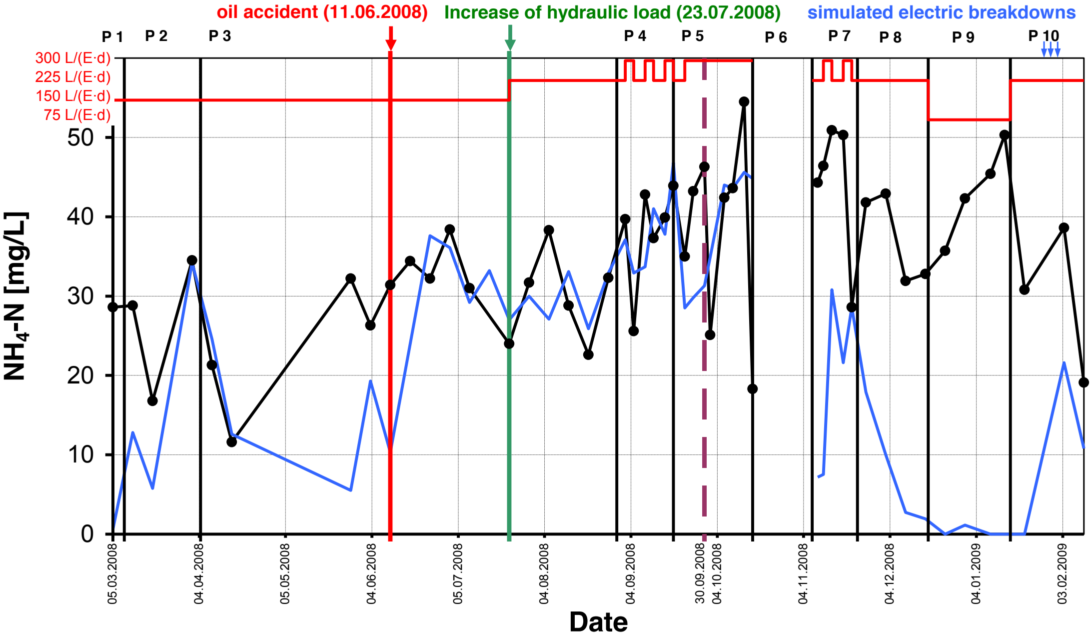

Figure 158: ATB AQUAmax® BASIC – Influent and effluent NH_4-N curves

Inorganic nitrogen

The inorganic nitrogen curve is provided in the Appendix.

The inorganic nitrogen curve ran almost completely parallel to the NH_4-N curve until Phase 5 (see Figure 158). This means that partial denitrification occurred in the presence of sufficient nitrification. Denitrification stopped only after the oil accident, when NH_4-N could no longer be converted into nitrate.

From Phase 8 on, significant denitrification (up to 50%) occurred again and was not diminished by the simulated electrical breakdowns.

7.11.6 Suspended solids (SS)

Until 23 Jul 2008, effluent SS concentrations remained below 35 mg/L with only one exception (Figure 159). The increase during this period occurred towards the end of Phase 2 and was most probably caused by the two-week aeration system malfunction staring on 01 Apr 2008. The oil accident did not cause an increase in effluent SS concentrations presumably due to the thorough system cleaning and sludge exchange in response to the accident.

The increase in nominal hydraulic load at the start of Phase 3 (23 Jul 2008) increased the effluent SS concentration from around 10 mg/L to more than 200 mg/L by the end of Phase 3. This sharp increase can be attributed to emergency overflow from the pretreatment tank into the biological reactor. After a further increase in hydraulic load during Phase 4, effluent SS concentrations initially rose to more than 550 mg/L, which was much higher than the corresponding influent concentrations. By the end of Phase 4, they had decreased to approximately 100 mg/L. Effluent SS concentrations decreased further to <35 mg/L by the middle of Phase 5, around the time at which the system was switched to 4 PE on 30 Sep 2008. From Phase 7 on, effluent concentrations were generally below 35 mg/L and, in some cases, were less than 5 mg/L. The only exception was after the simulated electrical breakdowns, when concentrations rose to a peak 1100 mg/L but later decreased to values below 15 mg/L. (For further details, see 7.11.4)

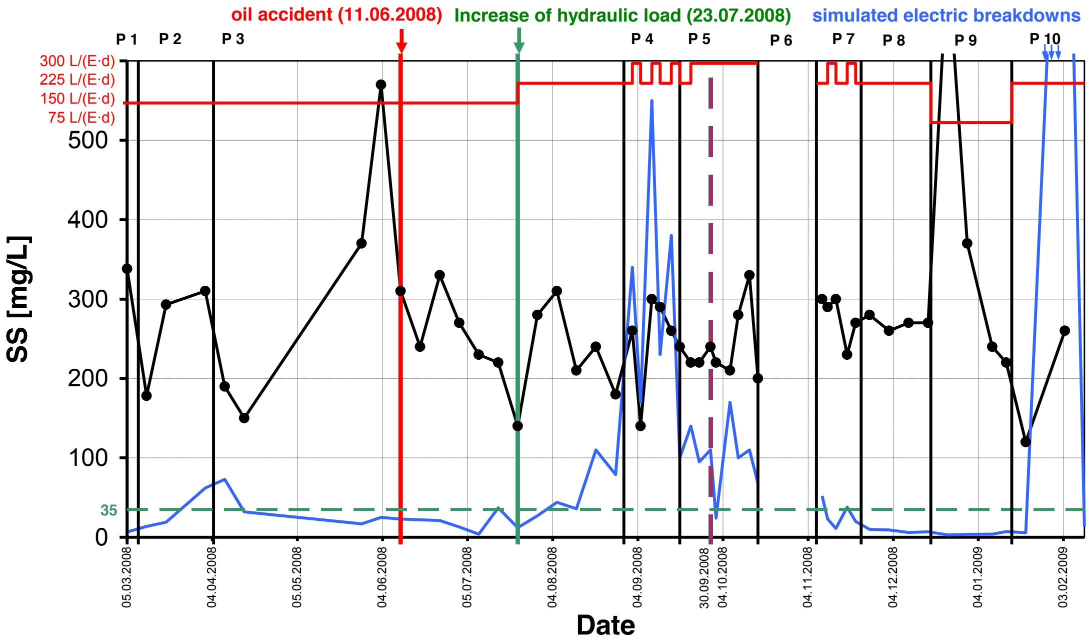

Figure 159: ATB AQUAmax® BASIC – Influent and effluent SS curves

7.11.7 Phosphorus

Comparison with suspended solids concentrations demonstrates that effluent phosphorus concentrations are directly proportional to SS concentrations because bound phosphorous is also eliminated with suspended solids. In this case, phosphorus is not degraded but rather, is "bound" and removed by sludge and eliminated with the eliminated suspended solids.

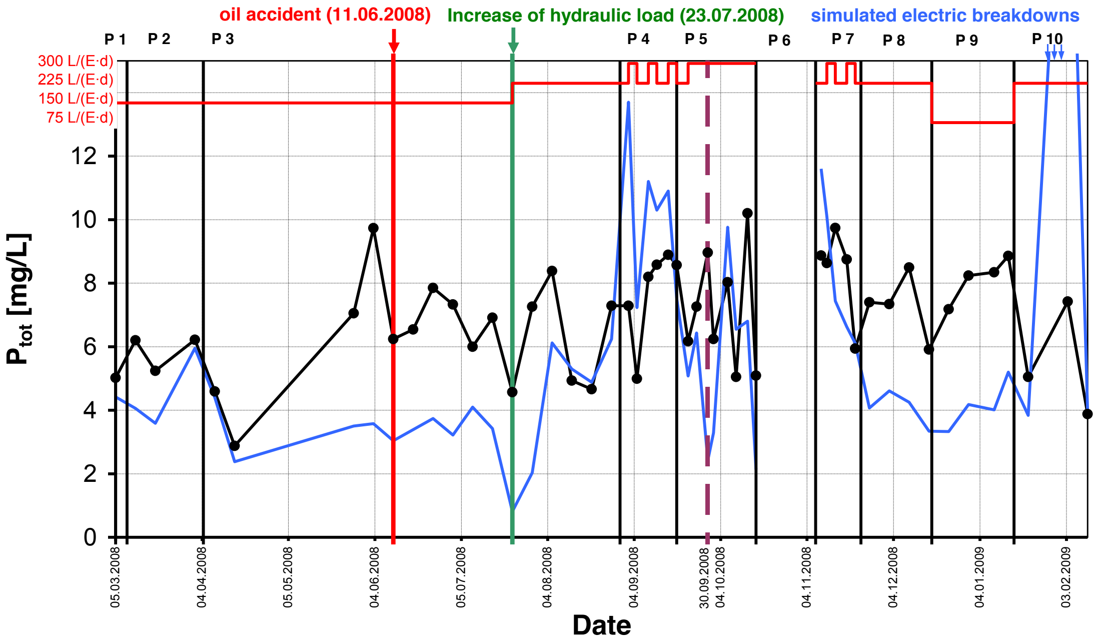

Figure 160: ATB AQUAmax® BASIC – Influent and effluent P_{tot} curves

7.11.8 Degradation rate

Degradation rates for COD, BOD_5, NH_4-N, N_{tot}, P_{tot} and SS are expressed as percentage values (Table 104, Table 105 and Table 106; see 2.9). Negative values mean that influent concentrations were smaller than effluent concentrations. Potential reasons for this are re-dissolution, washout and (back) transformation from the biomass. Measurement error is another potential cause, but checks for measurement error were performed in the course of quality assurance. Table 105 contains data from Phases 1, 2 and 3, during which the system was tested at 100% hydraulic load, and Table 106 contains data from Phases 4, 5 and 7, during which the system was tested under hydraulic overload conditions.

Phosphorus is not eliminated. Instead, it settles in the primary treatment tank or is incorporated in the biomass in the biological stage and is returned with excess sludge to the primary treatment tank.

The mean degradation rate was 62% for COD and 75% for BOD_5. Mean elimination rates were 29% for NH_4-N, 18% for N_{tot}, and 16% for P_{tot}.

Table 104: ATB AQUAmax$^{®}$ BASIC – Degradation rates (%) for COD, BOD_5, NH_4-N, N_{tot}, SS and P during the entire study period

ATB, AQUA max BASIC	η_{COD}	η_{BOD}	η_{NH4-N}	η_{Norg}	η_{P}	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	49	49	49	49	49	48
mean	62	75	29	18	16	62
median	84	93	21	21	24	87
min.	-221	-73	-145	-85	-244	-323
max.	97	100	100	75	82	100

Table 105: ATB AQUAmax$^{®}$ BASIC – Degradation rates (%) for COD, BOD_5, NH_4-N, N_{tot}, SS and P during the 100% phases (Phases 1, 2 and 3)

ATB, AQUA max BASIC	η_{COD}	η_{BOD}	η_{NH4-N}	η_{Norg}	η_{P}	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	19	19	19	19	19	19
mean	60	73	7	16	20	60
median	83	87	5	15	27	83
min.	-41	0	-29	-21	-88	-83
max.	92	96	83	75	82	98

Table 106: ATB AQUAmax$^{®}$ BASIC – Degradation rates (%) for COD, BOD_5, NH_4-N, N_{tot}, SS and P during the overload phases (Phases 4, 5 and 7)

ATB, AQUA max BASIC	η_{COD}	η_{BOD}	η_{NH4-N}	η_{Norg}	η_{P}	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
Number of samples	19	19	19	19	19	19
mean	65	76	26	18	19	68
median	71	75	31	21	24	83
min.	-27	19	-145	-80	-31	-46
max.	95	98	94	65	73	98

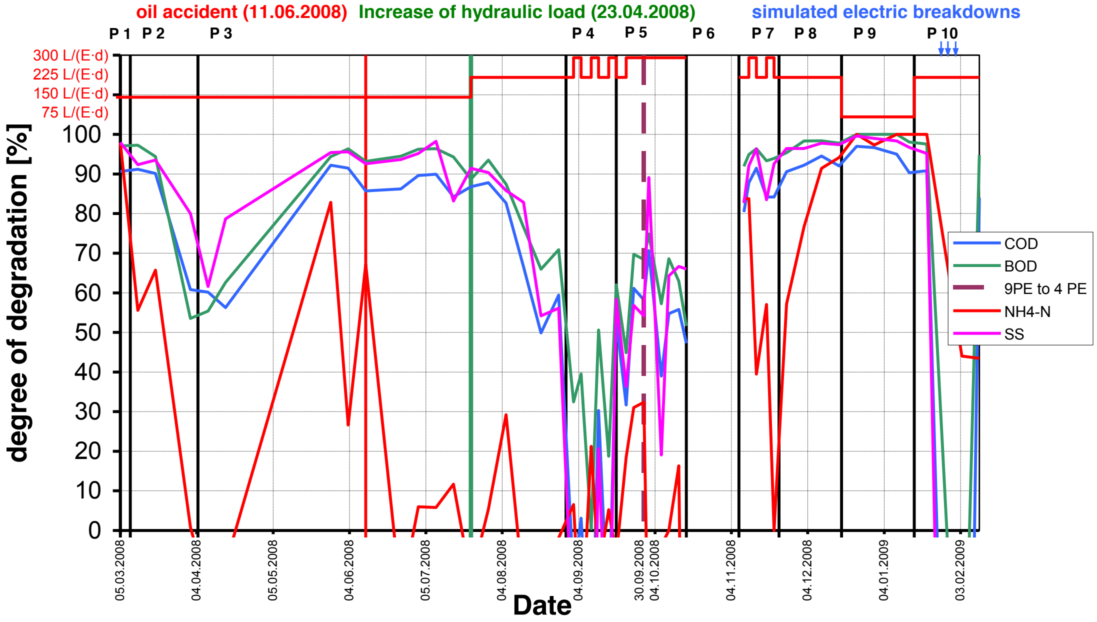

Figure 161: ATB AQUAmax® BASIC – Degradation curves for COD, BOD_5, NH4-N, Ntot, and SS

The COD degradation rate was slightly lower (60%) during nominal load testing (at 9 PE) than during the entire study period because effluent concentrations were increased during Phase 3. Degradation rates during the hydraulic overload phases were also slightly higher because the nominal load was reduced to 4 PE. As shown in the degradation curves (Figure 161), all degradation rates decreased by approximately 40 percentage points (COD, BOD_5 and SS) to more than 90 percentage points (NH_4-N) as a result of the aeration system malfunction.

Regarding NH_4-N, the oil accident brought ammonia degradation to a complete halt. This situation persisted, with few exceptions, until the beginning of Phase 8, when ammonia turnover rose to values above 90% again. Only after the simulated electrical breakdowns did the degradation rate decrease again to levels below 50%.

COD, BOD_5 and SS degradation rates decreased sharply after the nominal influent flow rate was increased from 150 to 225 L/(PE·d). When the pollution load was reduced from 9 PE to 4 PE and during Phase 6 (no load), degradation rates levelled off at more stable levels of over 90% and were not disrupted again until after the simulated electrical breakdowns. COD, BOD_5 and SS degradation rates increased sharply in response to the electrical breakdowns.

More detailed analyses of effluent values are presented in Section 7.11.4.

7.11.9 Power consumption

Power consumption (Figure 162) was classified according to the population-specific hydraulic load (no load, 75, 150, 225, 225+300 and 300 L/(PE·d)); the load corresponded to the nominal population equivalent value (9 PE before 30 Sep 2008 and 4 PE from 30 Sep 2008 on).

Mean power consumption values are given in kWh/(PE·a) (see 2.3). Since power consumption in Phase 6 (no load) was calculated based on the nominal pollution load (4 PE), the estimated specific power consumption may be lower under other hydraulic conditions because the values were calculated as the quotient of measured power consumption and the population equivalent of wastewater flow. At higher loads, the population equivalent is often higher than the nominal population equivalent; consequently, power consumption per inhabitant is lower.

Power consumption was measured as the total power consumed by the system. The following power consumers were included in the calculations:

- Aeration system
- Sludge pump
- Clear water pump

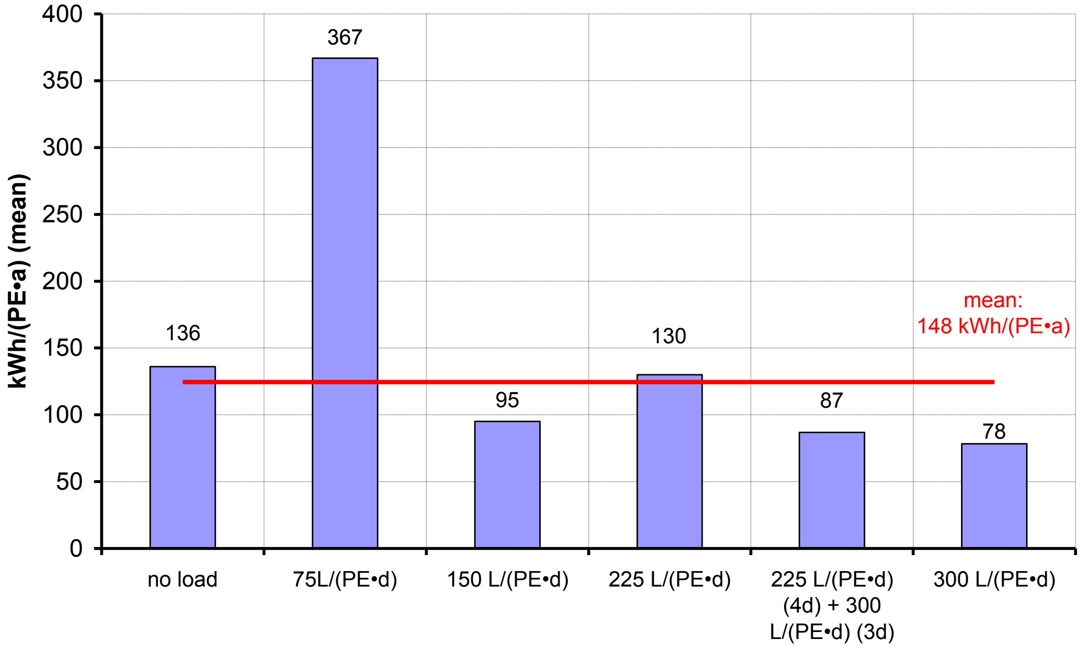

Figure 162: ATB AQUAmax® BASIC – Power consumption

Total power consumption at the plant during the study period was a mean 148 kWh/(PE·a). Calculated based on the average population equivalent of 4.9 PE (based on BOD_5 and the entire study period; see 2.3), this corresponds to a daily power consumption rate of 1.7 kWh/d.

Population-independent consumption was 1.5 kWh/day, as calculated based on zero load power consumption (160 kWh/(PE·a)) at 4 PE during Phase 6 (no load).

7.11.10 Sludge

The sludge volume was estimated based on the measured sludge height and the known container geometry. As such geometry-dependent estimates are relatively imprecise, their power of evidence is limited.

Overall sludge production during the entire study period was 1.05 m³. At a sludge dry matter content of 35.3 g/L (measured), this corresponds to a sludge mass of 36.9 kg.

The specific sludge volume at the calculated actual load of 4.7 PE is 21.5 g TS/E·d.

7.11.11 Operation and maintenance

Figure 163 shows all unusual events occurring over the entire study period while the system was in operation. Hydraulic loads and influent COD concentrations are also shown for better clarity. The diagram shows the course of events over time.

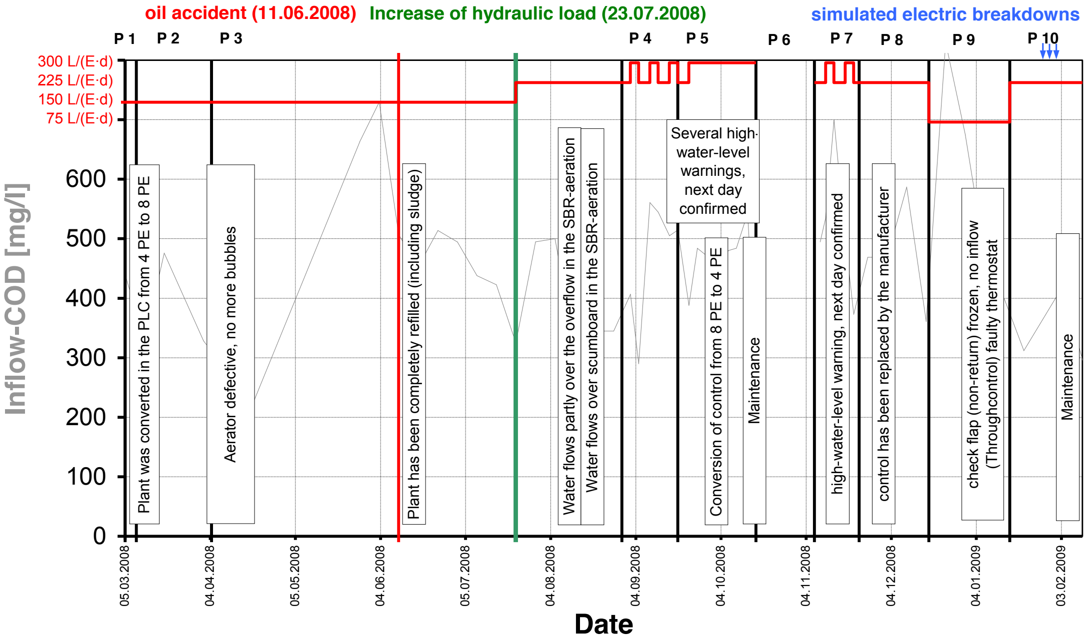

Figure 163: ATB AQUAmax® BASIC – Maintenance log analysis

Maintenance was performed on the following dates:

- 15 Feb 2008
- 14 Oct 2008
- 05 Feb 2008

01 Apr to 14 Apr 2008: An aeration system malfunction occurred due to a worn out pump and blower components.

18 Jun 2008 – 12:00 hrs: After the oil accident, the system was put back into operation and wastewater inflow re-started. The pretreatment tank was filled with wastewater and the biological tank was inoculated with sludge from an external source (volume: 1.5m³). In addition, the coarse filter was retrofitted: a sieve was installed in the emergency overflow, the blower was replaced, and the clear water removal time was changed from 25 minutes to 30 minutes.

13 Aug 2008: The water level in the biological reactor was slightly increased. Some of the wastewater from the pretreatment tank had spilled via the emergency overflow into the biological reactor.

20 Aug 2008: Water from the pretreatment tank spilled over the entire baffle and into the biological reactor.

30 Sep 2008: The control setting was switched from 9 PE to 4 PE.

16 Sep to 19 Nov 2008: There were a total of 7 high water alarms, each of which had to be documented on the next day.

01 Dec 2008: The control unit was replaced by the manufacturer.

06 Jan 2009 – 08:00 hrs until 07 Jan 2009 – 12:00 hrs: Inflow was obstructed due to a frozen non-return check valve. The valve was not part of the standard system equipment but rather, an experimental device. Therefore, the manufacturer ATB was not responsible for this malfunction.

7.11.12 Microbiology

Effluent water samples were collected on three consecutive days and tested for total coliform bacteria, faecal coliform bacteria, intestinal enterococci, salmonella and intestinal nematodes (see 5.4.2). The results of the microbiological analysis are presented in Table 107.

On average of three consecutive days, total coliform bacteria were reduced by 1.4 log steps, faecal coliform bacteria by 0.8 log steps, intestinal enterococci by 2.1 log steps and salmonella by around 2.2 log steps. In intestinal nematodes, there was an avarage reduction of 1 egg/L.

It can generally be assumed that the number of faecal coliform bacteria undergoes a one- to two-log reduction per treatment stage (compare DWA, 1998). This was almost achieved by this plant with a mean of 0.8-log reduction.

As expected, effluent microbiological quality did not meet bathing water quality standards.

Table 107: ATB AQUAmax® BASIC – Microbiological analysis

Date		1 Dec 08			2 Dec 08			3 Dec 08			Mean
		[MPN/ mL]	[log]	Δ [log]	[MPN/ mL]	[log]	Δ [log]	[MPN/ mL]	[log]	Δ [log]	Δ [log]
Total coliform bacteria	Influent	930,000	5.97	3.61	390,000	5.59	1.21	430,000	5.63	1.00	1.4
	Effluent	230	2.36		24,000	4.38		43,000	4.63		
Faecal coliform bacteria	Influent	150,000	5.18	2.81	240,000	5.38	1.00	73,000	4.86	0.23	0.8
	Effluent	230	2.36		24,000	4.38		43,000	4.63		
Intestinal enterococci	Influent	43,000	4.63	2.67	93,000	4.97	2.00	93,000	4.97	2.00	2.1
	Effluent	91	1.96		930	2.97		930	2.97		
Salmonella	Influent	2,100	3.32	- 2)	750	2.88	0.43	46,000	4.66	3.12	2.2
	Effluent	< 0.3	- 2)		280	2.45		35	1.54		
		[Eggs/L]		Δ [Eggs]	[Eggs/L]		Δ [Eggs]	[Eggs/L]		Δ [Eggs]	Δ [Eggs]
Intestinal nematodes	Influent	<1		0	13 1)		13	<1		0	4
	Effluent	<1			<1			<1			

1) statistical uncertainty in determination of the egg counts

2) 0 MPN/ml in effluent, no log reduction determined

"< 1" is assumed to be zero

"<0.3" is assumed to be zero

7.11.13 Comparison of test results with reports and literature data

Chemical oxygen demand

According to the manufacturer's specifications (see 4.14.9), the system should achieve effluent COD concentrations of < 100 mg/L in 24-hour composite samples, in accordance with DIBt effluent class C requirements (Table 2). Measured concentrations were below 100 mg/L in 59% of cases. In addition, they were below the manufacturer's specification of 100 mg/L in 74 % of cases during nominal load phases 1, 2, and 3.

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 65 mg/L in the 100% phase, which is comparable to the mean 77 mg/L (100% load) achieved by the system up until 23 Jul 2008. The overall mean effluent COD concentration achieved by the system was much higher (163 mg/L).

Considering that the average effluent COD concentration of SBR systems in practice was determined to be 143 mg/L (STRAUB 2008), the mean 163 mg/L achieved by this system is slightly higher than the reference average.

In a test series in *Dorf Mecklenburg*, Germany (JIROUDI 2005), the SBR system used there (6 PE, 26 measurements) achieved a mean effluent COD concentration of 50 mg/L, which is much lower than that achieved by the investigational system. In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 1.087 mg/L (223 mg/L - 2.128 mg/L, 135 measurements).

According to FLASCHE 2002, 15 SBR systems achieved a mean effluent COD concentration of 43.8 mg/L, which is slighty below the mean 92 mg/L achieved by the AQUAmax Basic system.

According to BOLLER 2004, 136 SBR systems yielding 249 measurement values achieved a mean effluent COD concentration of 102 mg/L, which is far higher than the mean 77 mg/L achieved by the AQUA max Basic system.

Biological oxygen demand in five days

According to the manufacturer's specifications (see 4.14.9), the system should achieve effluent BOD_5 concentrations of < 25 mg/L in 24-hour composite samples, in accordance with DIBt effluent class C requirements (Table 2). Measured concentrations were below 25 mg/L in 55% of cases. In addition, they were below the manufacturer's specification of 25 mg/L in 63% % of cases during nominal load phases 1, 2, and 3.

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 12 mg/L in the 100% phase. The mean concentration achieved with the investigational system up until 23 Jul 2008 was generally higher (approx. 22 mg/L at 100% load). Therefore, the overall mean effluent BOD_5 concentration achieved by the test system over the entire study period (50 mg/L) was much higher than the reference average.

Considering that the average effluent BOD_5 concentration of SBR systems in practice was determined to be 22 mg/L (STRAUB 2008), the mean 50 mg/L achieved by this system is roughly twice as high as the reference average.

In a test series in *Dorf Mecklenburg*, Germany (JIROUDI 2005), the SBR system used there (6 PE, 10 measurements) achieved a mean effluent BOD_5 concentration of 11 mg/L, which is much lower than that achieved by the investigational system. In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 598 mg/L (160 mg/L - 960 mg/L, 136 measurements).

According to FLASCHE 2002, 15 SBR systems achieved a mean effluent COD concentration of 4.3 mg/L, which is slighty below the mean 22 mg/L achieved by the AQUAmax Basic system.

Ammonia (NH_4-N)

According to the manufacturer's specifications stating that the system "is also tested for stronger German effluent requirements (Class D)" (see 4.14.9), the system should achieve effluent NH_4-N concentrations of < 10 mg/L in composite samples, in accordance with DIBt effluent class D requirements (Table 2). Measured concentrations were below 10 mg/L in 24% of cases. In addition, they were below the manufacturer's specification of 10 mg/L in 16% of cases during nominal load phases 1, 2, and 3.

The reference value, calculated as the average of 51 SWWTPs with nitrogen elimination tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 5 mg/L in the 100% phase. The investigational system did not reach this low effluent concentration until after the switch to 4 PE at 75% load, when concentrations were far below this level. The mean effluent NH_4-N concentration over the entire study period was 23.1 mg/L; this value corresponds approximately to the mean concentration across Phases 1-3 (23 mg/L at 100% load) and is much higher than the reference average.

Considering that the average effluent concentration of SBR systems in practice was determined to be 21 mg/L (STRAUB 2008), the mean 23.1 mg/L achieved by AQUAmax BASIC is slightly higher than average but also includes data for measurements at water temperatures below 12°C (cf. STRAUB 2008).

In a test series in *Dorf Mecklenburg*, Germany (JIROUDI 2005), the SBR system used there (6 PE, 20 measurements) achieved a mean effluent NH_4-N concentration of 1 mg/L, which is much lower than that achieved by the investigational system. In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 72 mg/L (24 mg/L - 114 mg/L, 137 measurements).

According to FLASCHE 2002, 15 SBR systems achieved a mean effluent COD concentration of 4.3 mg/L, which is slighty below the mean 23.1 mg/L achieved by the AQUAmax Basic system in the 100% phase.

Suspended solids

According to the manufacturer's specifications (see 4.14.9), the system should achieve a suspended solids (SS) concentration of < 75 mg/L in random samples, in accordance with DIBt Class C requirements (Table 2). Measured concentrations were below 75 mg/L in 69% of cases. In addition, they were below the manufacturer's specification of 75 mg/L in 89% of cases during nominal load phases 1, 2, and 3.

The reference value, calculated as the mean of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 25 mg/L in the 100% phase, which is slightly less than the effluent concentration achieved by the AQUAmax BASIC system (mean 34 mg/L) across Phases 1-3. The mean effluent SS concentration achieved by the system over the entire study period (93 mg/L) was much higher than the reference average.

Considering that the average effluent SS concentration of SBR systems in practice was determined to be 57 mg/L (STRAUB 2008), the mean 93 mg/L achieved by this system is higher than the reference average.

Suspended solids were not investigated in the test series in *Dorf Mecklenburg* (JIROUDI 2005).

Simulated electrical breakdowns

The increases in effluent concentrations observed during the simulated electrical breakdowns (Figure 156, Figure 157, Figure 158 and Figure 159) may be directly attributable to the electrical breakdowns themselves independent of increased influent concentrations or the presence of hard-to-degrade substances. In a comparison study in Nantes (VIGNOLES, CAUCHI, 2009), similar peaks were observed during simulated electrical breakdowns in almost all plants independent of whether they required electricity or not. The researchers in Nantes also could not find a plausible explanation for this phenomenon. This issue requires further research.

Power consumption

Daily power consumption of the investigational system was found to be 1.7 kWh/d (mean of values for 4 PE und 9 PE since the switch was made approximately half-way through the test period), which is slightly higher than the average 1.4 kWh/d nominal power consumption specified by the manufacturer (see 4.14.9).

The reference value, 0.25 kWh/(PE·d), calculated as the average power consumption of 23 SBR systems tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is slightly lower than the mean 0.35 kWh/(PE·d) achieved by the investigational system at 9 PE and 4 PE combined. The individual values were 0.19 kWh/(PE·d) at 9 PE and 0.5 kWh/(PE·d) at 4 PE. Power consumption rates for the SBR systems tested at the PIA test facility in Aachen ranged from approximately 0.1 kWh/(PE·d) to 0.75 kWh/(PE·d). Power consumption of the investigational system is thus mid-range.

In a test series in *Dorf Mecklenburg* (JIROUDI 2005), the annual power consumption rate of the SBR system used there (6 PE) was 96 kWh/(PE·a), corresponding to a daily power consumption of 1.6 kWh/d, which is comparable to that of the investigational system.

Sludge

Based on the data in DWA, 2003 a total solids concentration of approximately 70 g/(PE·d) was expected. According to our measurements, the actual load was 21.5 g/(PE·d), which is below the expected load. Reasons for this could be that the influent load was lower and/or because the mineralization rate was increased, that is, because more biomass than usual was converted and released as CO_2 and/or because sludge was washed out (see effluent SS concentrations in Figure 159).

Microbiological parameters

The investigational system reduced effluent faecal coliform bacteria counts to roughly 230 to 43,000 per 100 ml. This is comparable to the reference average for SBR systems, a mean 32,000 per 100 ml with a range (minimum-maximum) of 93 to 120, 000 per 100 ml (STRAUB ET AL. 2008). The investigational system had an average log reduction of 0.8 log steps. This is well below the log reduction of 1.5 log steps by STRAUB ET AL. 2008.

In a test series in *Dorf Mecklenburg* (JIROUDI 2005), the SBR system used there (6 PE) reduced total coliform bacteria to $3.6 \cdot 10^6$/100 mL and faecal coliform bacteria to $1.8 \cdot 10^6$/100 mL, which is much higher than that achieved by the investigational system. The investigational system had an average log reduction of 1.4 log steps. This corresponds roughly the faecal coliforms log reduction of 1.5 log steps by JIROUDI 2005.

7.11.14 Summary

The investigational system was operated at a load of 9 PE before 30 Sep 2008. From 30 Sep 2008 on, the system was operated at 4 PE at the request of the manufacturer due to the occurrence of overflow.

Analysis of the COD, BOD_5 and SS curves shows that the investigational system had problems operating under the increased hydraulic load conditions. After the oil accident, no appreciable nitrification occurred until after the resting phase (from Phase 7 on).

Biological degradation came to a nearly complete standstill due to the breakdown of the aeration system in the initial phase of testing.

Treatment efficiency of the investigational system was generally good to satisfactory except during malfunctions and simulated electrical breakdowns (see below). During the malfunctions, treatment efficiency was insufficient or completely lacking. System malfunctions consisted of the breakdown of the aeration systems and the frequent occurrences of high water levels, which at times spilled over the baffles. This resulted in the wash-out of sludge. However, it must be considered that the system was tested at nearly 235% the nominal hydraulic load.

The measured power consumption corresponded to the manufacturer's specifications.

7.12 Mall – SanoClean XL

7.12.1 Loading conditions

Mall GmbH installed the SanoClean XL system, which has a design capacity of 4 PE and was loaded accordingly. The nominal BOD_5 load according to authorisation is 240 g/d.

The nominal hydraulic load is 600 L/d. The system was also tested with 200-litre bathtub discharges 5 times a week corresponding to approx. 114 l/d (see Chapter 5.1.2). According to authorisation, the system should be able to handle haudraulic loads of 600 L/d.

The system was operated under the following influent loadings level:

Befor 23 July 2008[1]:	2.6 $PE_{BOD,60}$
23 Jul 2008 until before 27 Aug 2008:	3.1 $PE_{BOD,60}$
Overall mean (across entire study period):	3.4 $PE_{BOD,60}$

Therefore, the system achieved a 86% capacity at the nominal pollution load of 6 PE relative to influent BOD_5.

The manufacturer specifies minimum and maximum volumes for both the pretreatment tank and the biofilm reactor. The corresponding resident times were therefore 1.3 to 2.1 days for the pretreatment tank and 1.1 to 1.9 days for the SBR reactor. The overall resident times for the entire system were 2.4 to 4.0 days (average 3.2 days) (see 2.6)

7.12.2 Statistical overview of results

Table 108 and Table 109 show the results of the statistical analysis for the entire study period, including the number of samples, the mean, median, minimum (min) and maximum (max) values, the statutory limits in France (FR) and Germany (DE) (see Chapters 2.2.1.1 and 2.2.1.2), and the rate of compliance of effluent COD, BOD_5, SS, NH_4-N, N_{tot} and P_{tot} with the statutory limits (*stay below probability*). Mean, median, minimum and maximum values as well as the statutory limits in France (FR) and Germany (DE) are expressed in units of mg/L. The number of samples is a dimensionless parameter. The rate of compliance with statutory limits (*stay below probability*) is given in percent.

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[1] See Chapter 5.1.2: Due to the low influent concentrations, testing under increased hydraulic load conditions (150%) was discontinued in order to increase the influent load.

Table 108: Mall SanoClean XL – Statistical analysis of COD, BOD_5 and SS

Mall, Sano Clean XL	COD		BOD			SS	
	In	**Out**	**In**	**Load (real)***	**Out**	**In**	**Out**
	[mg/l]	[mg/l]	[mg/l]	[E]	[mg/l]	[mg/l]	[mg/l]
number of samples	50	50	50	50	50	49	50
mean	456	70	207	3,4	14	269,0	19,9
median	469	63	215	3,2	11	260,0	14,0
min.	180	25	78	1,0	3	120,0	3,2
max.	830	187	301	5,8	57	730,0	93,0
legally binding value (DE / FR)		**150 / 125**			**40 / 25**		**-- / 35**
stay below of legally binding value (DE)		96%			94%		
stay below of legally binding value (FR)		94%			88%		84%

* Load (real): See 2.3

Table 109: Mall SanoClean XL – Statistical analysis of nitrogen and phosphorus

Mall, Sano Clean XL	NH_4-N		N_{tot}		P_{tot}	
	In	**Out**	**In**	**Out**	**In**	**Out**
	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]
number of samples	50	50	50	49	50	50
mean	35,1	23,7	47,4	34,8	7,0	4,5
median	34,8	32,8	46,5	36,1	7,3	4,2
min.	11,6	< 0,5	19,8	11,9	2,9	1,6
max.	54,5	48,1	71,6	76,0	10,2	11,0
legally binding value (DE / FR)		**-- / --**		**-- / --**		**-- / --**
stay below of legally binding value (DE)						
stay below of legally binding value (FR)						

Chemical oxygen demand (COD)

The system achieved a mean effluent COD of 70 mg/L over the entire study period; the maximum concentration was 187 mg/L. Measured COD levels were below the German statutory limit of 150 mg/L (Chapter 2.2.1.1) in 96% of cases, and were below the French statutory limit of 125 mg/L (Chapter 2.2.1.2) in 94% (3 measurements). In other words, the measured levels exceeded the German limit in 2 cases and exceeded the French limit in 3 cases. Thus, the system meets the German and French effluent standards for COD in the vast majority of cases.

Biological oxygen demand (BOD_5)

The system achieved a mean effluent BOD_5 of 14 mg/L over the entire study period; the maximum concentration was 57 mg/L. Measured BOD_5 levels were below the German statutory limit of 40 mg/L in 94% of cases, and were below the French statutory limit of 25 mg/L in

88 %. The measured levels exceeded the German limit in 3 cases and exceeded the French limit in 6 cases. Thus, the system meets the German and French effluent standards for BOD_5 in the majority of cases.

Suspended solids

The system achieved a mean effluent suspended solids concentration of 20 mg/L over the entire study period; the maximum concentration was 93 mg/L. Measured SS concentrations were below the French statutory limit of 35 mg/L in 84% of cases, and they exceeded the French limit in 8 cases (see 7.12.6). Thus, the system met the French effluent standards for suspended solids in the majority of cases. There are no statutory limits for SS concentrations in Germany.

Nitrogen

- **Ammonia (NH_4-N):**
  The system achieved a mean effluent NH_4-N concentration of 23.7 mg/L over the entire study period; the maximum concentration was 48.1 mg/L.
- **Total nitrogen (N_{tot})**:
  The system achieved a mean effluent N_{tot} concentration of 35 mg/L over the entire study period; the maximum concentration was 76 mg/L.

Total phosphorus (P_{tot})

The system achieved a mean effluent P_{tot} concentration of 4.5 mg/L over the entire study period; the maximum concentration was 11 mg/L (see 7.12.7).

7.12.3 Operational and process stability

Process stability was described in terms of compliance with statutory limits for target parameters (*stay below probability*) (Figure 164). The steeper the curve, the more "stable" the system is operating. A stable system maintains steady effluent concentrations in spite of changing influent concentrations, temperatures, etc (s. Chapter 2.10.9).

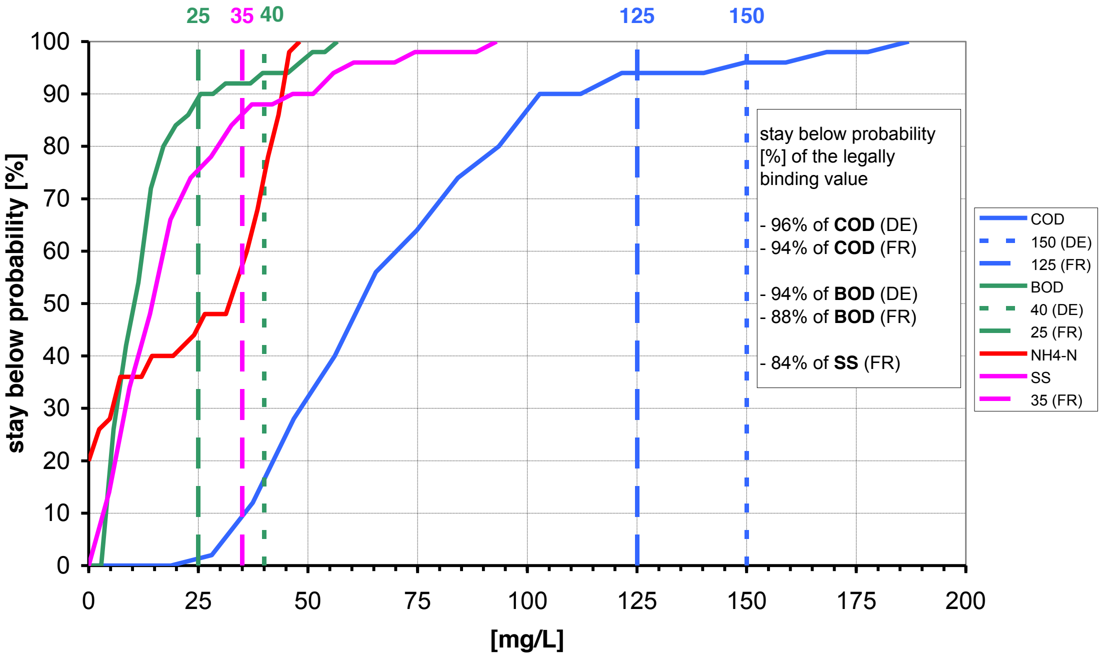

Figure 164: Mall SanoClean XL – Compliance with statutory limits for COD, BOD$_5$, NH$_4$-N and SS

7.12.4 COD and BOD$_5$ eliminationl

The two organic matter parameters were analysed based on the COD curve over time for the entire study period. The horizontal lines (Figure 165) at 150 mg/L (125 mg/L) represent the German and French statutory limits.

The BOD$_5$ curve was comparable to the COD curve (Figure 166). The mean COD/ BOD$_5$ ratio was 5 to 1.

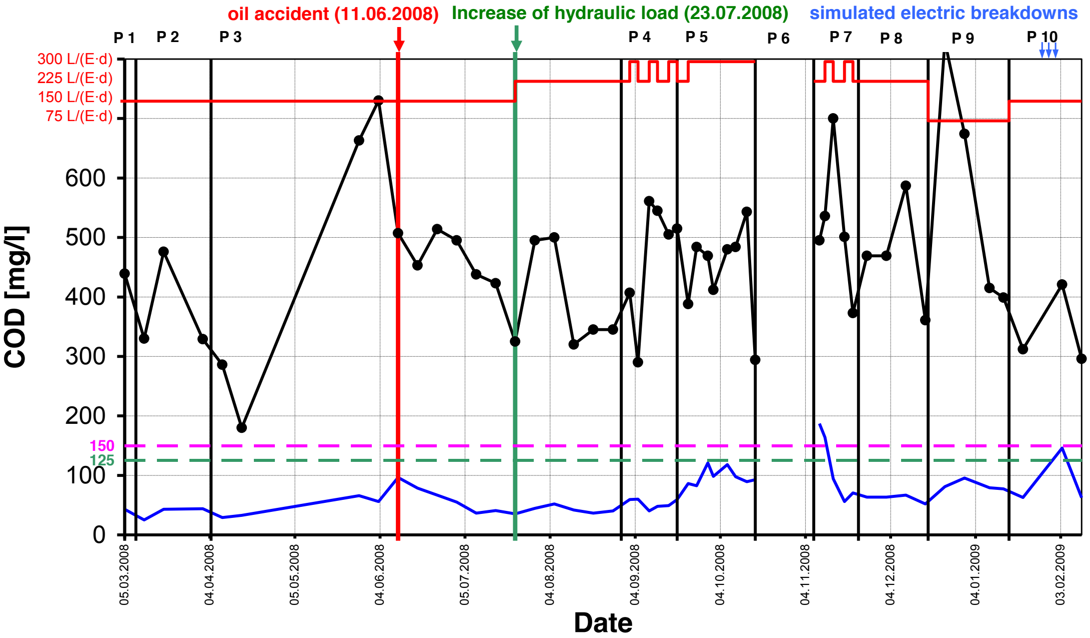

Figure 165: Mall SanoClean XL – Influent and effluent COD curves

Effluent COD concentrations remained below 100 mg/L with few exceptions (Figure 165). The oil accident resulted in a slight increase in effluent COD. COD concentrations returned to baseline levels within about 14 days although no countermeasures were taken apart from cleaning of the primary treatment. The increased hydraulic load conditions in Phase 3 had no measurable effect on COD concentrations. Intermittent 200% hydraulic load increases on 3 days per week also did not result in any elevation of effluent COD levels. However, the continuous four-week 200% increase in hydraulic load (Phase 5) led to a two-fold increase in effluent COD concentrations, which still remained clearly below the 150 mg/L level.

After completion of Phase 6 (3 weeks without load), COD concentrations rose to the highest level (187 mg/L) but returned to normal (to about 70 mg/L) by the middle of Phase 7. This is presumably due to increased biomass removal following the system re-start.

The short-term increase in effluent COD levels observed after the re-start following the simulated electric break downs could be due to a temporary increase in hard-to-degrade substances in the influent because this phenomenon was observed at the same time in nearly all of the SWWTPs studied (see 7.12.13).

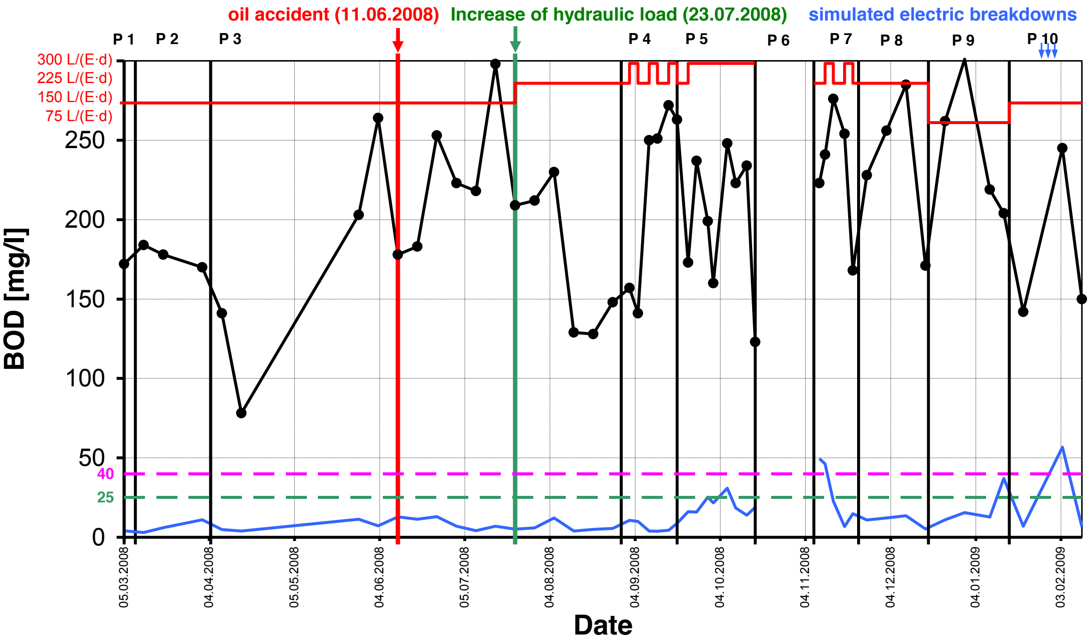

Figure 166: Mall SanoClean XL – Influent and effluent BOD_5 curves

7.12.5 Nitrogen

Ammonia (NH_4-N)

The course of the ammonia curve reflects the course of nitrification (Figure 167). As a biological process very sensitive to changes in process control, nitrification is a useful indicator of changes in wastewater treatment systems.

From 23 July 2008 on, effluent NH_4-N concentrations rose sharply (from approx. 0 mg/L to 20 mg/L) in response to an increase in hydraulic load from 150 L/(PE·d) to 225 L/(PE·d) although temperatures were the warmest of the entire test period (a mean 19.7°C during Phase 4). During this time, the system measured oxygen concentrations of 1 to 2 mg O_2/L, which should be sufficient for biological processes. From Phase 4 on, ammonia concentrations remained around 40 mg/L, due to the shorter residence time.

No significant nitrification occurred during the remaining test period. From Phase 8 on, this can be attributed to temperatures below 12°C to 5°C.

After 23 July 2008, effluent NH_4-N concentrations ran roughly parallel to the influent concentrations and from Phase 4 on, no further significant nitrification occurred.

The poor nitrification can therefore be attributed to the increased hydraulic loads and low wastewater temperatures from Phase 8 on.

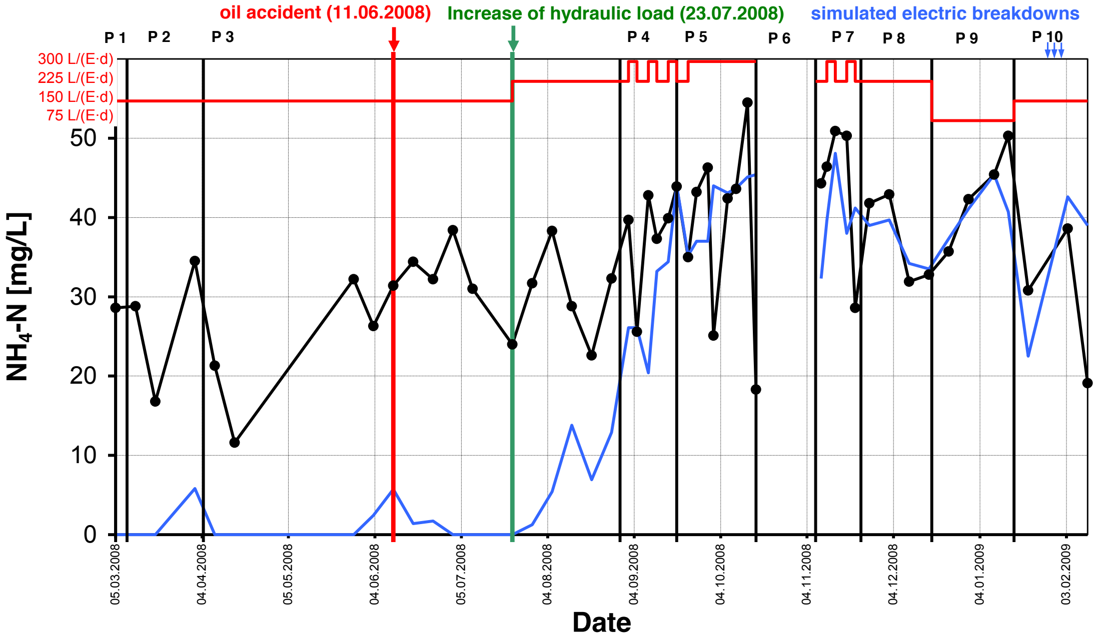

Figure 167: Mall SanoClean XL – Influent and effluent NH_4-N curves

Inorganic nitrogen

The inorganic nitrogen curve is provided in the Appendix.

Inorganic nitrogen concentrations ranged from 10 to 20 mg/L until the end of Phase 3. These concentrations were 5 to 10 mg/L below the influent concentrations. As the prevailing NH_4-N concentrations were predominantly very low, one can assume that partial denitrification occurred (approx. 25-75%). From Phase 4 on inorganic nitrogen concentrations rose to a peak 50 mg/L and later remained at a mean concentration of about 40 mg/L, which was approximately equal to the effluent NH_4-N concentrations. No further significant denitrification occurred.

After hitting a peak 64.7 mg/L during Phase 7 (after the resting phase without hydraulic load), the effluent concentration normalized at roughly 40 mg/L within about 10-14 days.

7.12.6 Suspended solids

The suspended solids concentration generally remained relatively constant at very low levels less than 25 mg/L (Figure 168). In Phase 5 (300 L/(E·d)), there were two peaks of up to

50 mg/L. An increased sludge volume (up to 360 ml/l) during this period can explain the two peaks.

After the resting phase (Phase 6), the maximum concentration of 93 mg/L normalized within about 7 days. The initial elevation can be attributed to partial wash-out of biomass during the resting phase.

Concentrations briefly exceeded the 35 mg/L limit again during Phases 9 and 10. During Phase 9, this might have been attributable to the extremely high concentration of suspended solids in the influent (730 mg/L). During Phase 10, the increase may have been caused by the simulated electric break downs (see Chapter 5.1.1) or a hard-to-degrade substance in the influent, both of which result in biomass death and backflow. This is suspected because similar peaks occurred at almost all of the SWWTPs and is also detectable in the influent COD and BOD_5 concentrations (Figure 165 and Figure 166).

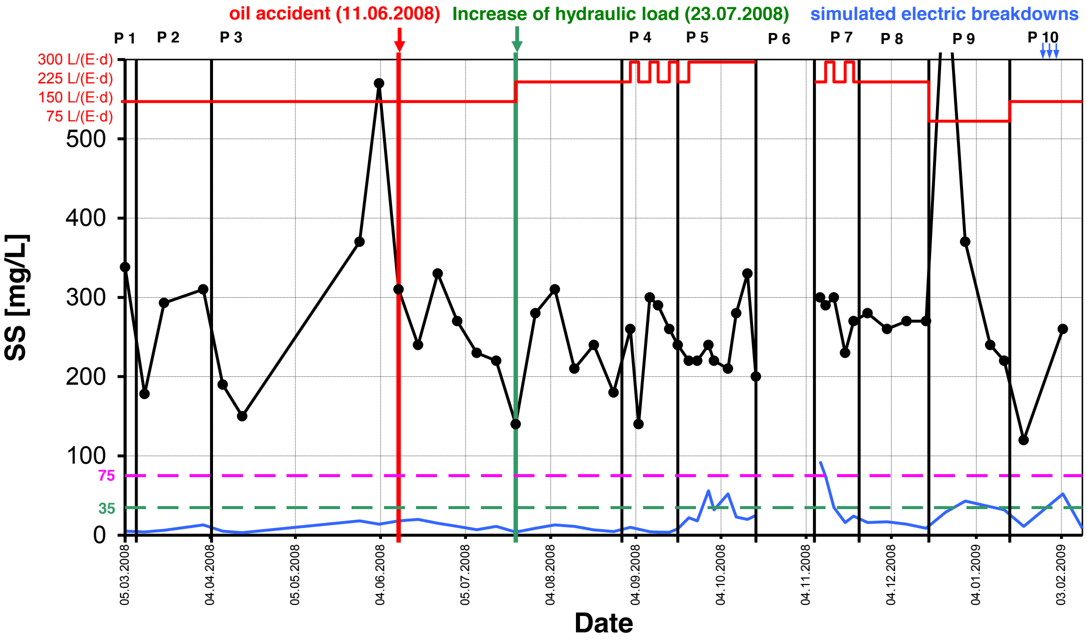

Figure 168: Mall SanoClean XL – Influent and effluent SS curves

7.12.7 Phosphorus

During the entire study period, the phosphorus elimination rate was low and hydraulic load-independent (Figure 169). Effluent phosphorus concentrations ran parallel to the influent concentrations, but generally with a slight time-delay. The > 10 mg/L peak induced by solids after Phase 6 (no hydraulic load) decreased within 2 weeks to a mean effluent concentration of about 4 mg/L.

Comparison with suspended solids concentrations demonstrates that effluent phosphorus concentrations are directly proportional to SS concentrations because bound phosphorus is also eliminated with suspended solids. Therefore, phosphorus is not degraded but rather "bound" and removed by sludge.

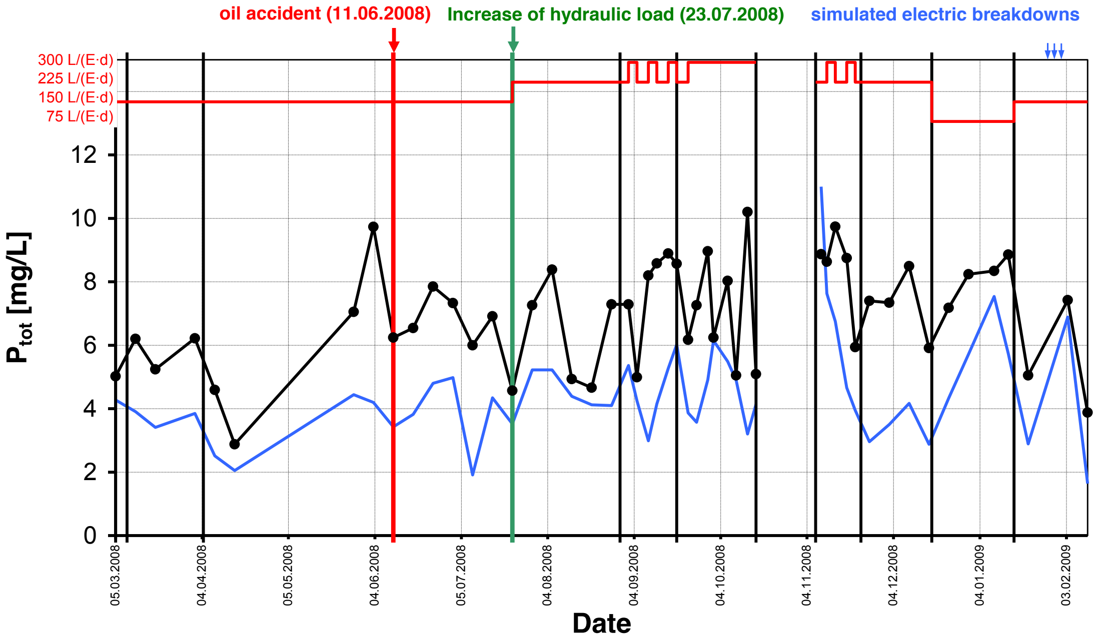

Figure 169: Mall SanoClean XL – Influent and effluent P_{tot} curves

7.12.8 Degradation rate

Degradation rates for COD, BOD_5, NH_4-N, N_{tot}, P_{tot} and SS are expressed as percentage values (Table 110, Table 111 and Table 112; cf. 2.9). Negative values mean that influent concentrations were smaller than effluent concentrations. Potential reasons for this are re-dissolution, washout and conversion/re-conversion from biomass. Measurement error is, of course, another potential cause, but checks for measurement error were performed in the course of quality assurance. Table 111 contains data from Phases 1, 2 and 3, during which the system was tested at 100% hydraulic load. Table 112 contains data from Phases 4, 5 and 7, during which the system was tested under hydraulic overload conditions.

Phosphorus is not eliminated. Instead, a fraction settles during primary treatment or is incorporated in the biomass and moves on with the excess sludge to primary treatment.

The mean degradation rate was 84% for COD and 93% for BOD_5. Mean elimination rates were 34% for NH_4-N, 26% for N_{tot}, and 35% for P_{tot}.

Table 110: Mall SanoClean XL- Degradation rates (%) for COD, BOD_5, NH_4-N, N_{tot}, SS and P during the complete period

Mall, Sano Clean XL	η_{COD}	η_{BOD}	η_{NH4-N}	η_{N-tot}	η_{P}	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
number of samples	50	50	50	49	50	49
mean	84	93	34	26	35	92
median	86	95	22	31	37	95
min.	62	77	-148	-82	-24	69
max.	93	98	100	71	69	99

Table 111: Mall SanoClean XL- Degradation (%) for COD, BOD_5, NH_4-N, N_{tot}, SS und P during the 100%-Phases (Phase 1, 2 and 3)

Mall, Sano Clean XL	η_{COD}	η_{BOD}	η_{NH4-N}	η_{N-tot}	η_{P}	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
number of samples	20	20	20	20	20	20
mean	89	96	90	48	36	96
median	90	97	98	50	37	97
min.	81	93	52	30	11	92
max.	92	98	100	71	68	99

Table 112 : Mall SanoClean XL- Degradation (%) für COD, BOD_5, NH_4-N, N_{tot}, SS und P during the Overload-Phases (Phase 4, 5 and 7)

Mall, Sano Clean XL	η_{COD}	η_{BOD}	η_{NH4-N}	η_{N-tot}	η_{P}	η_{SS}
	[%]	[%]	[%]	[%]	[%]	[%]
number of samples	19	19	19	19	19	19
mean	81	91	-2	10	31	89
median	81	92	11	16	32	92
min.	62	78	-148	-82	-24	69
max.	93	98	52	54	69	99

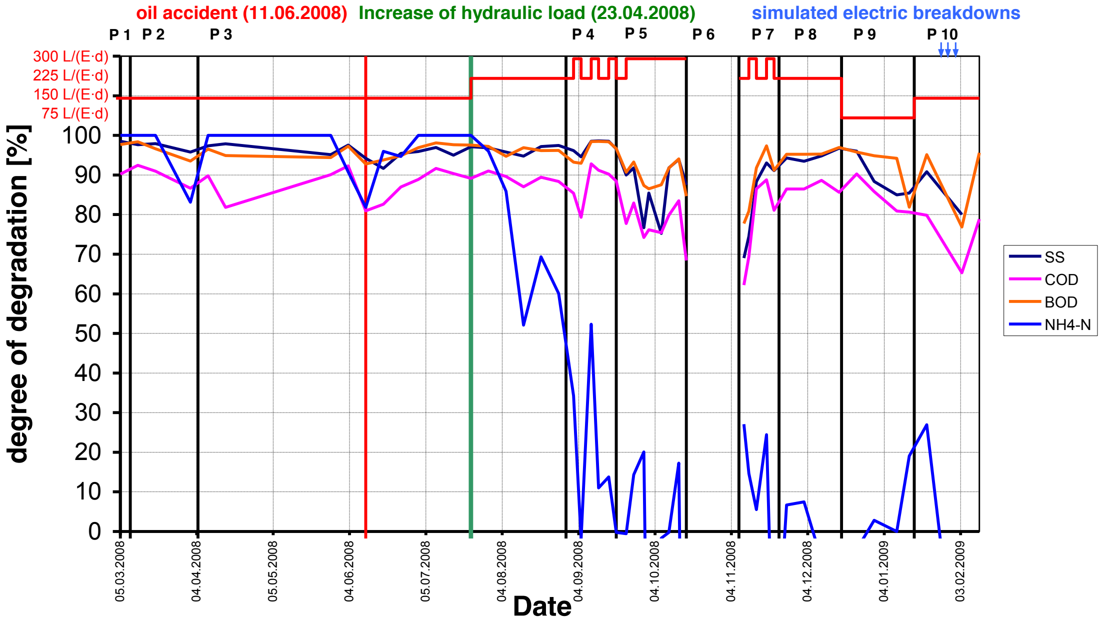

Figure 170: Mall SanoClean XL- Degradation curves for COD, BOD_5, NH4-N and SS

The COD degradation rate was slightly higher (89%) during the nominal load testing than during the entire study period (84%) which was due to the reduced hydraulic load. Degradation rates during the hydraulic overload phases tend to be lower. The lowest COD elimination rate was observed during Phase 6 (no load). As indicated by the degradation curves in Fig. 168, NH_4-N degradation rates decreased sharply after influent flow was raised from a nominal 150 L/(PE·d) to 225 L/(PE·d).,

Degradation rates for all parameters decreased by about 10 percentage points during hydraulic overloading (Phase 5) and breaks (after Phase 6 and during Phase 10: simulated electric break down), but returned to average levels within a few days.

A more detailed analysis of effluent levels has been presented in Section 7.12.4.

7.12.9 Power consumption

Power consumption (Figure 171) was classified according to the population-specific hydraulic load (no load, 75, 150, 225, 225+300, 300 L/(PE·d)); the load corresponded to the nominal population equivalent value (4 PE).

Mean power consumption values are given in kWh/(PE·a) (see 2.3). Since power consumption in Phase 6 (no load) was calculated based on the nominal pollution load (4 PE), the estimated specific power consumption may be lower under other hydraulic load conditions because the values were calculated as the quotient of measured power consumption and the population equivalent of wastewater flow. At higher loads, the population equivalent is often higher than the nominal population equivalent; consequently, power consumption per inhabitant is lower.

Power consumption was calculated as the sum of all power consumed by the system. This includes the following individual power consumers:

- Feed pump
- Sludge return pump
- Clearwater separation system
- Aerator

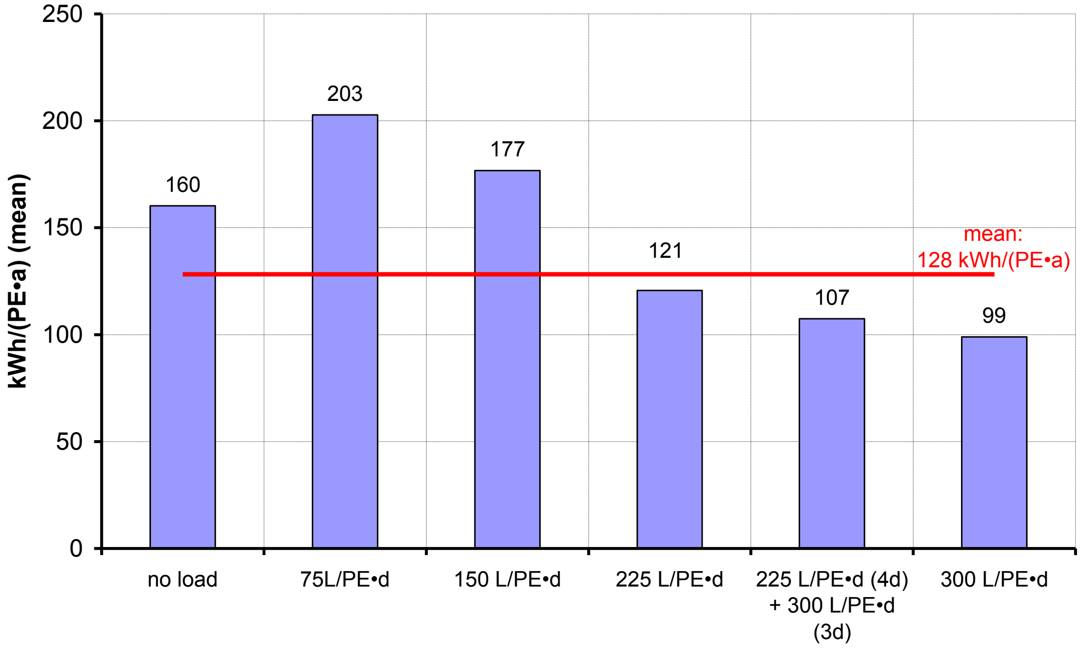

Figure 171: Mall SanoClean XL – Power consumption

Total power consumption at the plant during the study period was a mean 128 kWh/(PE·a). Calculated based on the average population value of 3.4 PE (based on BOD_5), this yields a daily power consumption rate of 1.2 kWh/d (see 2.3).

Population-independent consumption, or zero load power consumption at 4 PE during Phase 6, was 160 kWh/(PE·a) or 1.8 kWh/d.

7.12.10 Sludge

The sludge volume was estimated based on the measured sludge height and the known container geometry. As such geometry-dependent estimates are relatively imprecise, their power of evidence is limited.

Sludge production was 2.51 m³ during the entire study period. This corresponds by a sludge dry matter content of 32.8 g/L (measured) to a sludge mass of 82.44 kg.

The specific sludge volume at the calculated actual load of 3.4 PE is 67.2 g dry matter/E·d.

7.12.11 Operation and maintenance

Figure 172 shows all unusual events occurring over the entire study period while the system was in operation. Hydraulic loads and influent COD concentrations are also shown for better illustration of data. The diagram shows the course of events over time.

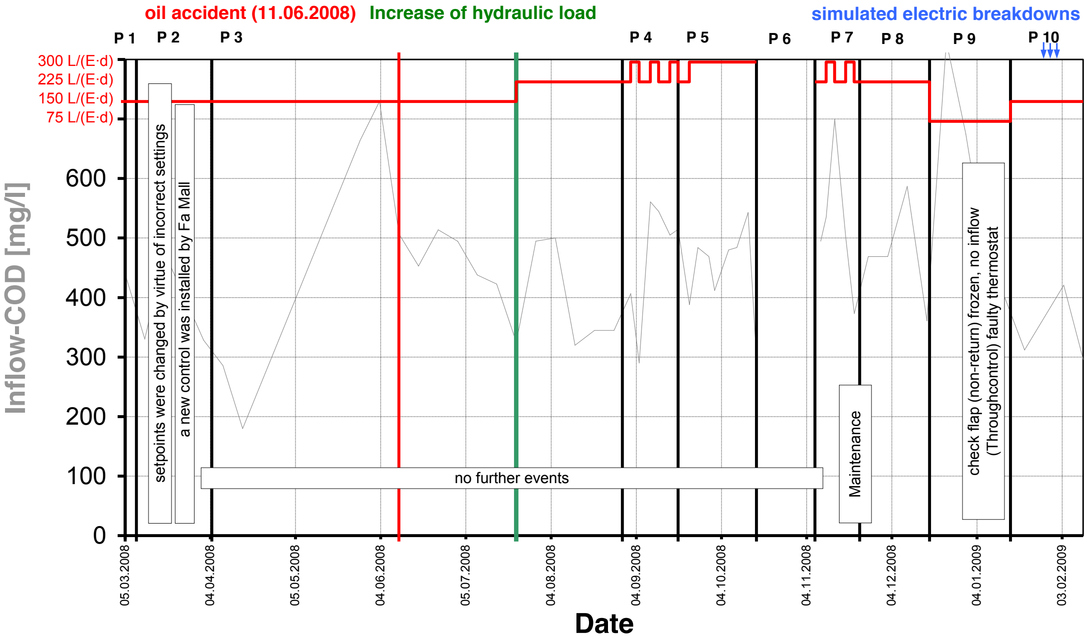

Figure 172: Mall SanoClean XL - Maintenance log analysis

On 9 May 2008 and on 2.11.2008 the entire system was maintained.

On 20 Mar 2008, the nominal value was changed because it had been set at the wrong level. On 27 Mar 2008, Mall GmbH installed a new control unit. On 11 Jun 2008, the influent was switched off from 08:00 to 18:00 hrs due to the oil accident.

From 06 Jan 2009 08:00 hrs until 07 Jan 2009 12:00 hrs, inflow was obstructed due to a frozen non-return check valve. The valve was not part of the standard system equipment but belonged to the test field. Therefore Mall was not responsible for this malfunction.

7.12.12 Microbiology

Effluent water samples were collected on three consecutive days and tested for total coliform bacteria, faecal coliform bacteria, intestinal enterococci, salmonella and intestinal nematodes (see 5.4.2). The results of the microbiological analysis are presented in Table 113.

On average of three consecutive days, total coliform bacteria were reduced by 1.2 log steps, faecal coliform bacteria by 0.8 log steps, intestinal enterococci by 1.3 log steps and salmonella by around 1.6 log steps. An increase in influent and effluent salmonella counts was observed on 2 Dec 2008. However, because influent and effluent samples were collected simultaneously, the time required for wastewater to flow from one point of the system to another was not taken into account. This may have been a factor.

In intestinal nematodes, there was an avarage reduction of 2 eggs/L. On some days, there was an increase, although this may be explained by statistical uncertainty in the determination of the number In addition, the simultaneous sampling in the influent and effluent did not consider the time lag during the system passage.

It can generally be assumed that the number of faecal coliform bacteria undergoes a one- to two-log reduction per treatment stage (compare DWA, 1998). This was almost achieved by this plant with a mean of 0.8-log reduction.

As expected, effluent microbiological quality did not meet bathing water quality standard

Table 113: Mall SanoClean XL – Microbiological analysis

Date		1 Dec 08			2 Dec 08			3 Dec 08			Mean
		[MPN/ mL]	[log]	Δ [log]	[MPN/ mL]	[log]	Δ [log]	[MPN/ mL]	[log]	Δ [log]	Δ [log]
Total coliform bacteria	Influent	930,000	5.97	1.82	390,000	5.59	0.96	430,000	5.63	1.00	1.2
	Effluent	14,000	4.15		43,000	4.63		43,000	4.63		
Faecal coliform bacteria	Influent	150,000	5.18	1.03	240,000	5.38	1.41	73,000	4.86	0.23	0.8
	Effluent	14,000	4.15		9,300	3.97		43,000	4.63		
Intestinal enterococci	Influent	43,000	4.63	0.66	93,000	4.97	2.00	93,000	4.97	1.59	1.3
	Effluent	9,300	3.97		930	2.97		2,400	3.38		
Salmonella	Influent	2,100	3.32	1.86	750	2.88	-0.17	46,000	4.66	3.23	1.6
	Effluent	29	1.46		> 1,100	3.04		27	1.43		
		[Eggs/L]		Δ [Eggs]	[Eggs/L]		Δ [Eggs]	[Eggs/L]		Δ [Eggs]	Δ [Eggs]
Intestinal nematodes	Influent	<1		-3	13 1)		12	<1		-3	2
	Effluent	3 1)			1			3 1)			

1) statistical uncertainty in determination of the egg counts

"< 1" is assumed to be zero

">1,100" is assumed to be 1,100

7.12.13 Comparison of test results with reports and literature data

Chemical oxygen demand

According to the manufacturer, the system achieves COD concentrations of < 75 mg/L in random samples (see 4.15.9). The values specified by the DIBt (German Institute for Construction Engineering) are 90 mg/L maximum for random samples and 75 mg/L maximum for composite samples (Table 2). Measured concentrations were less than 75 mg/L in 64% of all cases and less than 90 mg/L in 78%.

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 65 mg/L in the 100% phase, which is comparable to the mean 70 mg/L achieved by SanoClean XL over the entire study period in spite of the stricter test conditions.

Considering that the average effluent concentration of SBR systems in practise was determined to be 143 mg/L (STRAUB 2008), the mean 70 mg/L achieved by SanoClean XL is much lower than the reference average.

In a test series performed in *Dorf Mecklenburg*, Germany (JIROUDI 2005), the SBR system used there (6 PE, 26 measurements) achieved a mean effluent COD concentration of 50 mg/L, which is lower than the values achieved by the investigational system. In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 1.087 mg/L (223 mg/L - 2.128 mg/L, 135 measurements).

According to FLASCHE 2002, 15 SBR systems achieved a mean effluent COD concentration of 43.8 mg/L, which is clearly below the mean 70 mg/L achieved by the SanoClean XL system.

According to BOLLER 2004, 136 SBR systems yielding 249 measurement values achieved a mean effluent COD concentration of 102 mg/L, which is far higher than the mean 70 mg/L achieved by the SanoClean XL system.

Biological oxygen demand in five days

According to the manufacturer, the system achieves a BOD_5 concentration of < 15 mg/L in composite samples (4.15.9), which corresponds to the DIBt data (Table 2). Measured BOD_5 concentrations were below 15 mg/L in 74% of cases.

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 12 mg/L in the 100% phase, which is comparable to the mean 14 mg/L achieved by SanoClean XL over the entire study period.

Considering that the average effluent concentration of SBR systems was determined to be 22 mg/L (STRAUB 2008), the mean 14 mg/L achieved by SanoClean XL is slightly lower than the reference average.

Considering that the average effluent concentration of SBR systems in practise was determined to be 22 mg/L (STRAUB 2008), the mean 14 mg/L achieved by SanoClean XL is much lower than the reference average.

In a test series performed in *Dorf Mecklenburg*, Germany (JIROUDI 2005), the SBR system used there (6 PE, 10 measurements) achieved a mean effluent BOD_5 concentration of 11 mg/L, which corresponds to the mean 14 mg/L achieved by the SanoClean XL system. In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 598 mg/L (160 mg/L - 960 mg/L, 136 measurements).

According to FLASCHE 2002 15 SBR systems achieved a mean effluent BOD_5 concentration of 4.3 mg/L, which is clearly below the mean 14 mg/L achieved by the SanoClean XL system.

Ammonia

According to the manufacturer, the system achieves an NH_4-N concentration of < 10 mg/L in composite samples (4.15.9), which corresponds to the DIBt data (Table 2). Measured NH_4-N concentrations were below 10 mg/L in 36% of cases.

The reference value, calculated as the average of 51 SWWTPs with nitrogen elimination tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 5 mg/L in the 100% phase. During this time (Phases 1 to 3, until 23 July 2008), concentrations achieved by SanoClean XL were lower than the reference average. However, the mean effluent concentration for the entire test period (23.7 mg/L) was far higher than the reference average.

Considering that the average effluent concentration of SBR systems in practice was determined to be 21 mg/L (STRAUB 2008), the mean 23.7 mg/L achieved by SanoClean XL is slightly higher than average but includes data for measurements at water temperatures below 12°C (cf. STRAUB 2008).

In a test series performed in *Dorf Mecklenburg*, Germany (JIROUDI 2005), the SBR system used there (6 PE, 20 measurements) achieved a mean effluent NH_4-N concentration of 1 mg/L, which is clearly below the mean 23.7 mg/L achieved by the SanoClean XL system. In this test series performed in Dorf Mecklenburg, Germany the mean influent COD concentration is approximately 72 mg/L (24 mg/L - 114 mg/L, 137 measurements).

According to FLASCHE 2002 15 SBR systems achieved a mean effluent NH_4-N concentration of 2.8 mg/L, which is clearly below the mean 23.7 mg/L achieved by the SanoClean XL system.

Suspended solids

According to the manufacturer, the system achieves a suspended solids concentration of < 50 mg/L 10 mg/L in random samples (4.15.9), which corresponds to the DIBt data (Table 2). Measured concentrations were below 50 mg/L in 90% of cases.

The reference value, calculated as the average of 51 SWWTPs tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is approximately 25 mg/L in the 100% phase, which is higher than the mean 20 mg/L achieved by SanoClean XL over the entire study period.

Considering that the average effluent concentration of SBR systems in practice was determined to be 57 mg/L (STRAUB 2008), the mean 20 mg/L achieved by SanoClean XL is much lower than the reference average.

The test series performed in *Dorf Mecklenburg*, Germany (JIROUDI 2005) no measurement values for suspended solids are available.

Simulated electric break downs

The increase in effluent concentrations observed during the simulated electric breakdowns (Figure 165, Figure 166, Figure 167 and Figure 168) may be directly attributable to the electrical breakdowns themselves independent of increased influent concentrations or the presence of persistent substances. In a comparison study carried out in Nantes (VIGNOLES, CAUCHI, 2009), similar peaks were observed during simulated electric breakdowns in (almost) all plants independent of whether they required electricity of not. The researchers in Nantes could not find a plausible explanation for this phenomenon. This issue requires further research.

Power consumption

Power consumption of the SanoClean XL was found to be 1.2 kWh/d, which corresponds to the average 1.1kWh/d nominal power consumption specified by the manufacturer. The reference value, calculated as the average power consumption of 23 SBR systems tested at the PIA test facility in Aachen, Germany (DORGELOH 2008), is 0.25 kWh/(PE·d) and thus slightly lower than the mean 0.35 kWh/(PE·d) achieved by SanoClean XL. Power consumption rates for the SBR systems tested at the PIA test facility in Aachen ranged from approximately 0.1 kWh/(PE·d) to 0.75 kWh/(PE·d). By comparison, SanoClean XL is a medium power consumption system.

In a test series performed in *Dorf Mecklenburg*, Germany (JIROUDI 2005), the annual power consumption rate of the SBR system used there (6 PE) was 96 kWh/(PE·a). This corresponds to 1.6 kWh/d and is thus slightly above the rate of the SanoClean XL system

Sludge

Based on data in DWA, 2003 a total solids concentration of approx. 70 g/(PE·d) was expected. Based on our measurements, the actual load was 67.2 g/(PE·d), which is below the expected load. This could have occurred because the influent load was lower and/or because the mineralization rate was increased, that is, because more biomass than usual was converted and released as CO_2.

Microbiological efficancy

The system achieved effluent faecal coliform bacteria counts of roughly 10,000 to 43,000 per 100 ml. This is comparable to the reference average for SBR systems, a mean 32,000 per 100 ml with a range (minimum-maximum) of 93 to 120, 000 per 100 ml (STRAUB ET AL. 2008). The investigational system had an average log reduction of 0.8 log steps. This is well below the log reduction of 1.5 log steps by STRAUB ET AL. 2008.

In a test series performed in *Dorf Mecklenburg* (JIROUDI 2005), the SBR system used there (6 PE) reduced the total coliform bacteria to $3.65 \cdot 10^6$/100 mL and faecal coliform bacteria to $1.83 \cdot 10^6$/100 mL, which clearly exceeds the values measured by SanoClean XL system. The investigational system had an average log reduction of 1.2 log steps. This is below the faecal coliform faecal coliforms log reduction of 1.5 log steps by JIROUDI 2005.

7.12.14 Summary

The system was operated at a mean load of 3.4 PE over the entire study period. Effluent COD concentrations (mean 70 mg/L) remained below 150 mg/L (except 2 indicated values) and below 125 mg/l (except 3 indicated values) during the entire study period, even at a hydraulic load of 200%. Higher concentrations did not occur except when restarting the system after the zero load phase (period without hydraulic load).

Effluent solids concentrations were predominantly less than 35 mg/L (mean 19.9 mg/L). However, effluent solids concentrations of around 50 mg/L were observed on two occasions during the 200 % hydraulic load test phase and once after restarting the system after the zero load phase.

On the whole, the treatment performance of SanoClean XL proved to be very stable. No system malfunctions occurred during the study period.

The actual power consumption corresponded to the nominal power consumption specified by the manufacturer.

Chapter 8

Summary and Perspectives

All small wastewater treatment systems sold on the European market must be certified to European standard EN 12566-3. As such, they all meet uniform minimum requirements for operating safety and treatment efficiency. In addition, the system must also meet any additional national or regional standards applicable. However, these minimum requirements say little about the efficiency, stability, and ease of maintenance of an SWWTP under real operating conditions although this information would be of particular interest, not only to consumers but also to wastewater service providers. Moreover, the available SWWTPs come with a wide range of different technologies. The results of this study are therefore of particular importance, especially for the Veolia Water Group, because the public gladly rely on the professional competence and independent advice of Veolia's regional companies. The services provided range from consulting and planning, construction, upgrading and retrofitting to commissioning, maintenance, financial support and promotion of wastewater treatment systems.

The COMPAS study was undertaken as a first step in filling this information deficit. The twelve small wastewater systems installed at the Training and Demonstration Centre for Decentralised Sewage Treatment (BDZ) facility in Leipzig, Germany represent the wide range of technical solutions available for small-scale wastewater treatment problems, including SWWTPs with sessile biomass, different types of soil filters, suspended biomass membrane bioreactors, and sequencing batch reactors. In the COMPAS study, these state-of-the-art small wastewater systems were evaluated and compared under realistic operating conditions far more stringent than those associated with the EU certification or design approval procedures. To better reflect local conditions, the test conditions used for assessment of the small wastewater systems investigated in COMPAS were more stringent than those specified in EN 12566-3. The effects of additional loads attributable to guests and regular bath water discharges, low-flow conditions occurring during vacation and holiday periods and electrical power outages were simulated in appropriately designed test phases.

The results of the COMPAS provide useful data on the performance characteristics of the different small wastewater systems, including their treatment efficiency, effluent concentrations, technical requirements, sludge accumulation and power consumption rates, etc. Data gathered in this study will make it possible to identify the most reliable small wastewater treatment systems.

Because influent concentrations at 100% design load were in the lower ranges for "standard European wastewater", as specified in EN 12566-3, the nominal hydraulic load was increased to 150%. Relative COD ratios, or the ratio of COD concentration to that of other parameters, were consistent with the reference values.

Chemical and physical parameters in the influent and effluent of the SWWTPs analysed each week. In addition, three samples were collected for microbiological analyses, the results of which served as the basis of a treatment efficacy assessment.

Nearly all of the SWWTPS reduced effluent COD and TSS to concentrations below the German and French statutory limits. Some of the SWWTPs did not exhibit stable operation. Some of the systems with suspended biomass developed problems under high hydraulic load conditions.

In almost all of SWWTPS studied, increases in effluent concentrations of the target parameters during simulated electrical breakdowns could be attributed to the electrical breakdowns themselves or to the presence of hard-to-degrade substances in the influent. In the study in Nantes (VIGNOLES, CAUCHI, 2009), however, similar peaks were observed during simulated electrical breakdowns in almost all WWTPs independent of whether they operated using electricity or not. The researchers in Nantes also could not find a plausible explanation for this phenomenon. This issue requires further investigation.

Only those SWWTPs with targeted hygienisation systems achieved the rating of "excellent bathing water quality for coastal waters and transitional waters", as determined based on the parameters "intestinal enterococci" and "Escherichia coli".

Table 114: Results of the statistical analysis, sorted in order of increasing effluent COD concentration

System	**mean Effluent**			
	COD	**SS**	**NH_4-N**	**Δ E. coli**
	[mg/l]	[mg/l]	[mg/l]	[log]
mean inflow	**456**	**269**	**35**	
Limiting values	**150** 1)	**35** 2)	**(10)** 3)	
Aquamatic – STM 5	196	117	20	0,6
Bergmann – BIO-WSB®-N	53	16	9	0,8
Klargester – BioDisk BA	78	21	16	0,8
Nordbeton – Biofilter KP253 PAL	92	29	18	0,8
PREMIER TECH – Ecoflex™ *) **)	45	9	8	0,9
HUBER - 3K PLUS®	56	11	20	1,2
Lauterbach-Kießling – BKF 4	60	14	17	1,1
UFZ - PKA Typ UFZ C+H 4 E	34	5	12	Effluent: 0 MPN/ml
PREMIER TECH – Ecofix® Typ STB 500	52	13	9	0,8
Busse – MF Typ MF-HKA4	77	25	19	Effluent: 0 MPN/ml
ATB – AQUA max BASIC **) ***)	163	93	23	0,8
Mall – SanoClean XL	70	20	24	0,8

*) could not be tested during high-performance work phase due to the process

**) was changed to 4 PE during the 200%-work phase

***) not designed for peak load

1) German limiting value as specified in AbwV

2) French limiting value as specified in "arrêté du 22/6/2007"

3) German limiting value as specified in DIBt group N, not all plants are designed for nitrification

Overall, the results of this study support the further establishment of small wastewater treatment plants as a permanent solution to decentralised wastewater treatment problems in rural areas. The data from this study make it possible to compare the treatment efficacy, stability, and ease of maintenance of different small wastewater treatment systems under realistic operating conditions and provide further insight into the planning and operation of such systems.

An additional research programme investigating the effects of specific local conditions in Germany should be performed in the future. Examples include:

- Extreme underload conditions (e.g. 1 PE)
- Holiday apartment conditions (changing loads, summer and winter periods)
- Effects of disinfectants
- Effects of household cleaning agents
- Effects of medications

Chapter 9

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Annex A

Catchment Area KA Leutzsch

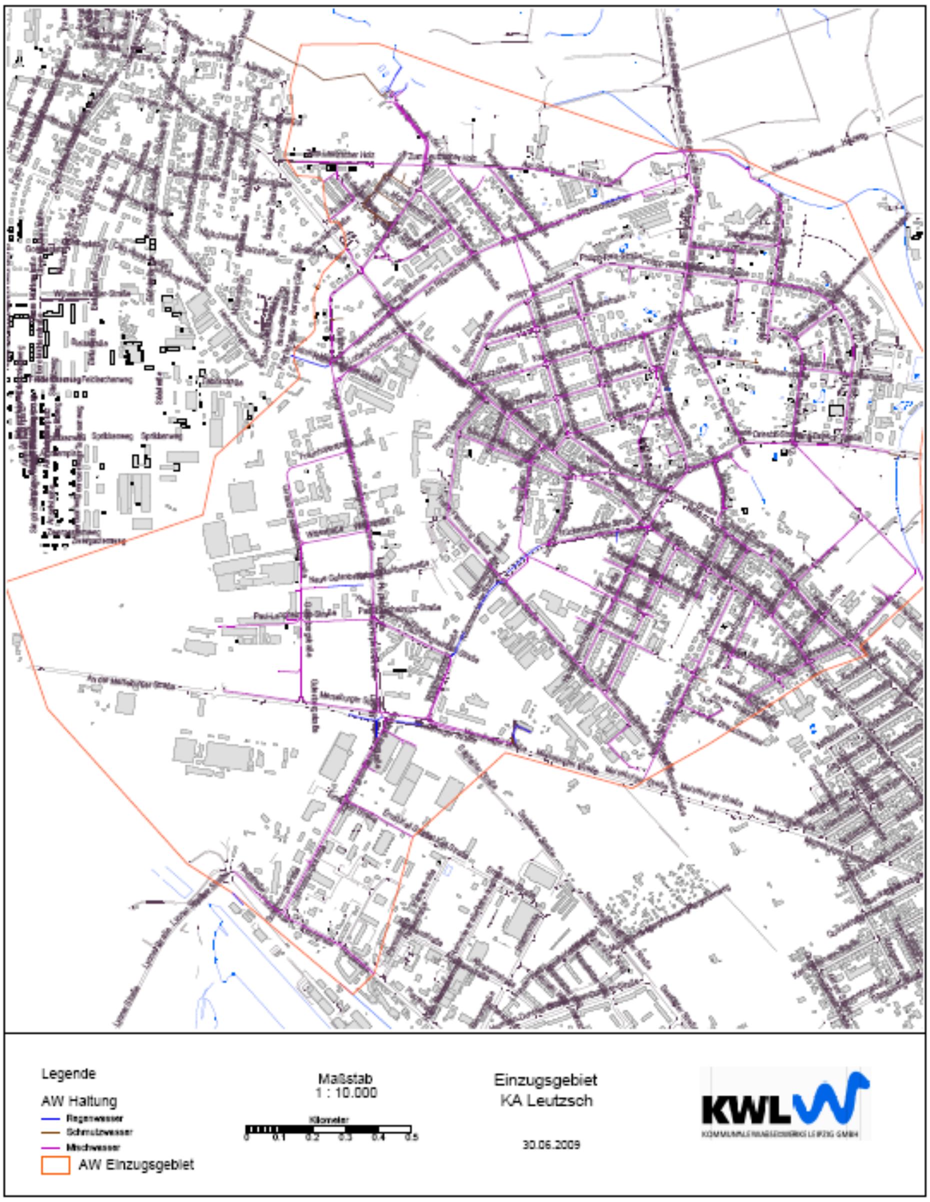

Figure 173: Catchment Area KA Leutzsch

Annex B

Listing of Results in Table Form

See enclosed CD-Rom.

Annex C

Sludge list ATV-DVWK-M 368

Table 115: Raw sludge accumulation and quality as a function of different treatment processes

Verfahren / Betriebsbedingungen	Schlammart	Schlammanfall und -beschaffenheit			
		TR-Gehalt [% TR]	TR-Fracht [g /(E·d)]	oTR/TR [-]	Volumen [l /(E·d)]
Vorklärung:	Primär-schlamm				
$t_{A,VK}$ = 0,5 h 1a)		2 - 8	30 1)	0,67	1,0
$t_{A,VK}$ = 1,0 h 1b)	PS	2 - 8	35 1)	0,67	1,2
$t_{A,VK}$ = 2,0 h 1c)		2 - 8	40 1)	0,67	1,4
Belebungsverfahren (T = 15 °C)	Überschuss-schlamm				
C-Elimination (BSB$_5$+ ggf. Denitrifikation)					
t_{TS} = 5 d, $t_{A,VK}$ = 0,5 h	ÜS$_B$	0,7	46,3 1) 2)	0,75	6,7
t_{TS} = 5 d, $t_{A,VK}$ = 1,0 h		0,7	41,1 1) 2)	0,75	5,9
t_{TS} = 5 d, $t_{A,VK}$ = 2,0 h		0,7	35,8 1) 2)	0,75	5,1
t_{TS} = 10 d, $t_{A,VK}$ = 0,5 h		0,7	42,0 1) 3)	0,72	6,0
t_{TS} = 10 d, $t_{A,VK}$ = 1,0 h		0,7	37,3 1) 3)	0,72	5,3
t_{TS} = 10 d, $t_{A,VK}$ = 2,0 h		0,7	32,4 1) 3)	0,72	4,6
t_{TS} = 15 d, $t_{A,VK}$ = 0,5 h		0,7	39,3 1) 4)	0,70	5,6
t_{TS} = 15 d, $t_{A,VK}$ = 1,0 h		0,7	34,8 1) 4)	0,70	5,0
t_{TS} = 15 d, $t_{A,VK}$ = 2,0 h		0,7	30,2 1) 4)	0,70	4,3
t_{TS} = 25 d (Stabilisierungsanlage)		0,7	56,2 1) 3)	0,65	8,0
Nitrifikation		Praktisch keine ÜS-Mehrproduktion feststellbar			
Denitrifikation infolge externer C-Quellen	ÜS$_{DEN,ECQ}$				
Methanol (ß =1,35)		1,0	5,7 5)	> 0,95 6)	0,57
Ethanol (ß = 1,35)		1,0	8,8 5)	> 0,95 6)	0,88
Essigsäure (ß = 1,35)		1,0	5,9 5)	> 0,95 6)	0,59
Biol. P-Elimination	ÜS$_{BIO-P}$		2,75 7)	< 0,05 7)	
Biofilmverfahren					
Tropfkörper (C-Elimination/Nitrifikation)		Schlammanfall und -beschaffenheit bei Biofilmverfahren ergibt sich unter Berücksichtigung der jeweiligen Betriebsparameter analog zum Belebungsverfahren			
Tauchkörper	ÜS$_{BF}$				
Fließbettreaktoren					
Simultanfällung (SF)	Fällschlamm				
Eisensalz	ÜS$_P$				
ß = 1,0; ΔSF ≈ 50 %			2,5 8)		
ß = 1,0; ΔSF ≈ 100 %			5,0 8)		
ß = 1,5; ΔSF ≈ 50 %			3,8 8)		
ß = 1,5; ΔSF ≈ 100 %			7,6 8)		
Aluminiumsalz					
ß = 1,0; ΔSF ≈ 50 %			2,0		
ß = 1,0; ΔSF ≈ 100 %			4,0		
ß = 1,5; ΔSF ≈ 50 %			2,95		
ß = 1,5; Δ SF ≈ 100 %			5,90		
Flockungsfiltration (FF)	Fällschlamm				
Eisensalz (ß = 1,5; ΔP_{ges} ≈ 100 %)	ÜS$_{FF}$		7,5		

1. AFS- bzw. BSB$_5$-Frachten im Rohabwasser werden mit typischen Werten von 70 g TR/(E·d) bzw. 60 g BSB$_5$/ (E·d) angesetzt.

1a) Typische Eliminationsraten: ΔAFS = 43 %, ΔBSB$_5$ = 16,7 %

1b) Typische Eliminationsraten: ΔAFS = 50 %, ΔBSB$_5$ = 25,0 %

1c) Typische Eliminationsraten: ΔAFS = 57 %, ΔBSB$_5$ = 33,3 %

2. Bei einer Bemessungstemperatur von 10 °C nimmt die Überschussschlammproduktion um rund 4 % zu.

3. Bei einer Bemessungstemperatur von 10 °C nimmt die Überschussschlammproduktion um rund 5,5 % zu.

4. Bei einer Bemessungstemperatur von 10 °C nimmt die Überschussschlammproduktion um rund 6 % zu.

5. Die mit externen C-Quellen zu denitrifizierende NO3-N-Fracht ΔNO3-N wird mit 8 g/(E·d) angesetzt (z.B. nach vollständiger Nitrifikation); bei geringeren ΔNO3-N-Frachten verringert sich der Überschussschlammanfall anteilmäßig,

6. Der Gehalt an abfiltrierbaren Stoffen im Ablauf der Nachklärung wird mit TSE = 20 mg/l angesetzt.

7. Die mit Bio-P zu eliminierende P-Fracht ΔPBIO-P wird unter Berücksichtigung einer P-Zulauffracht von 1,8 g/(E · d), der P-Elimination in der Vorklärung von ca. 0,25 g/(E·d) ($t_{A, VK}$ = 1,0 h; $P_{x,PS}$ = 0,7 %), der P-Inkorporation in Überschussschlamm (t_{TS} = 15 d; $P_{x,ÜS}$ = 1,7 %) von rund 0,59 g/(E·d), einer Ablauffracht von 0,2 g P g/(E·d) mit 0,96 g P/(E·d) angesetzt.

8. Die Pges-Fracht im Zulauf der biologischen Stufe wird unter Berücksichtigung einer P-Zulauffracht von 1,8 g/(E·d), der P-Elimination in der Vorklärung von ca. 0,25 g/(E·d) und durch Inkorporation in den biologischen Überschussschlamm von rund 0,59 g/(E·d) = 1,16 g/(E·d) angesetzt.