Performance of the biological nitrogen and phosphorus removal in four large WWTPs in Germany

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Abstract In this paper the design data, flow sheets, operating results and running experiences of four municipal wastewater treatment plants are presented. The size of these plants varies between 95,000 and 830,000 people equivalents. Different activated sludge systems running with cascades and simultaneous nitrification/denitrification are practised in these plants. The data of these different plants are compared.
Keywords Dimensioning data; running experiences; simultaneous nitrification/denitrification; cascade; municipal wastewater;biological removal of nitrogen and phosphorus

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Introduction

Because of recent regulations in the Federal Republic of Germany and in the countries belonging to the European Union and also due to increasing eutrophy in both North Sea and Baltic Sea, the most imminent ecological problems are the elimination of oxygen consuming carbon compounds and the reduction of nutrient salt loads. Since the end of the 1970s, several methods have been developed to biologically eliminate nitrogen and phosphorus from the wastewater. Parallel to an increase to the performance of wastewater treatment plants, the minimum requirements for the effluent quality of wastewater treatment plants were raised. The effluent data must be met in Germany in the qualified peak sample (see Table 1).

In the following, the operation experiences of four municipal wastewater treatment plants with different sizes between 95,000 and 830,000 people equivalents, and with different operation methods are presented. This includes the major dimensioning parameters and the achieved effluent data.

Wastewater treatment plant at Hildesheim

The extension of the wastewater treatment plant at Hildesheim by a biological stage with nitrification, denitrification and biological phosphorus removal was conceived in 1982/1983. At this time, practical experiences with full scale plants for biological phosphorus

Table 1 Minimum requirements for the effluents from municipal wastewater treatment plants in the FRG and the EU,(*) for “sensitive areas”, (**) “normal areas”, (***) required for the average value of one year

Minimum requirements FRG (peak sample)					
Size [peop. equiv.]	**COD [mg/l]**	**BOD [mg/l]**	**NH_4–N [mg/l]**	**Nmin.[mg/l]**	**Ptot. [mg/l]**
10,000–100,000	90	20	10	18	2
>100,000	75	15	10	18	1
Requirements EU-Standards (24 h-mixed-sample)					
Size [peop. equiv.]	**COD [mg/l] (**)**	**BOD [mg/l] (**)**	**NH_4–N [mg/l]**	**Ntot. [mg/l] (*), (***)**	**Ptot. [mg/l](*), (***)**
10,000–100,000	125 or 75%	25 or 70–90%	–	15 or 70–80%	2 or 80%
>100,000	125 or 75%	25 or 70–90%	–	10 or 70–80%	1 or 80%

Table 2 Dimensioning data, (#)=for return sludge denitrification

	Lines 1–2 (running since 1987)	**Lines 3–4 (running since 1997)**
Aeration tank	V=2×7,100 m^3=14,200 m^3	V=2×10,650 m^3=21,300 m^3
	6 mammoth rotors per tank	17 mammoth rotors per tank
	288 kg O_2/h per tank	918 kg O_2/h per tank
Anoxic tank (#)	V_{anox}=2×625=1,250 m^3	V_{anox}=2×938=1,875 m^3
Anaerobic tank	V_{an}=2×875=1,750 m^3	V_{an}=2×1.312=2,624 m^3
Secondary clarifier	V=2×3,360=6,720 m^3	V=2×6,450=12,900 m3
	A=2×1,018=2,036 m^2	A=2×1,565=3,130 m^2
	Effluent through submerged pipes	Effluent through submerged pipes

Table 3 Load data of the wastewater treatment plant at Hildesheim for the operation with 4 lines in 1998 (average data)

	Operation 1998 (4 lines)	**Dimensioning (4 lines)**
Q	34,786 m^3/d	37,500 m^3/d
MLSS	2.5 g/l	3.0
COD	19,762 kg/d	–
BOD	10,011 kg/d	9,500 kg/d
$N_{tot.}$	1,647 kg/d	2,025 kg/d
$P_{tot.}$	283 kg/d	375 kg/d
Sludge loading	0.07 kg BOD/(kg MLSS*d)	0.05 kg BOD/(kg MLSS*d)

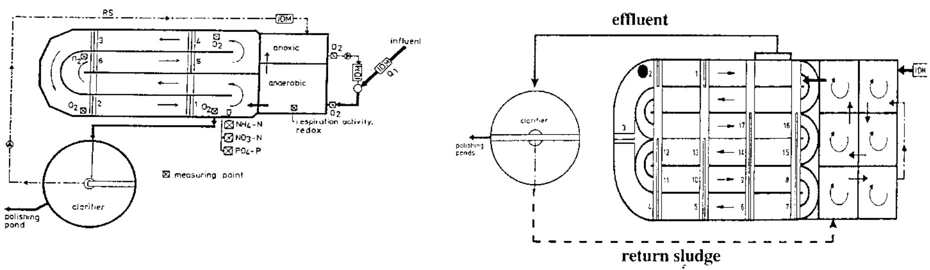

Figure 1 Flow sheet of the two types of lines (left=running since 1987, right=running since 1997) at the wastewater treatment plant at Hildesheim

removal were available only from plants in South Africa, where, as a rule, the wastewater is rather concentrated, that is the sedimented BOD ranges from 300 to 400 mg/l. In contrast, in Hildesheim one can expect concentrations below 100 mg BOD/l on rainy days or with high amounts of sewer infiltration water. The plant is run using the ISAH-process, the main asset of which is that the return-sludge is denitrified in a separate anoxic tank in order to prevent any possible impairing of the phosphate removal through return nitrate. If necessary, additional substrate can be fed from the anaerobic tank. Of the four lines planned for the activated sludge plant, two were built and started in July 1987 (Figure 1 left side), in order to use operation experiences for the construction of the other two (Figure 1, right side), which are both running since 1997 (see Tables 2 and 3 for dimensioning and load data).

For the analysis period (1998), excellent effluent data for the parameters P_{total} and $N_{mineral}$ could be achieved. The low effluent values for P_{total} result almost entirely from the achieved biological phosphorus elimination. Because of the excellent operation results, the owners will for 1999 declare to the controlling authorities lower monitoring results

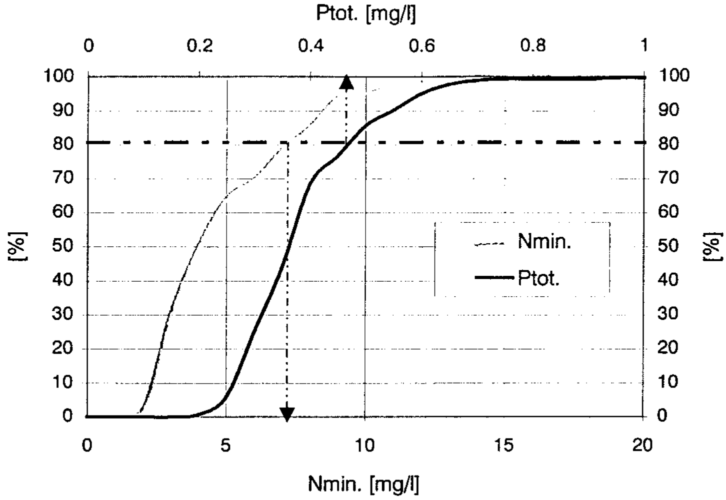

Figure 2 Cumulative frequency for the parameters $N_{mineral}$ (NH_4–N+NO_3–N) and P_{tot} in the effluent of the secondary clarifiers at the WWTP at Hildesheim as daily average 1–9/1998

compared with the demands presented in Table 1, which would allow for considerable financial savings in the area of wastewater levy.

Wastewater treatment plant at Husum

The wastewater treatment plant at Husum is conspicuous for the exceptionally wide seasonal variation of loads, which is due to the impact of tourism and to the fact that major parts of the wastewater come from an abattoir. These factors had to be considered for the dimensioning of the operation methods of the plant:

- municipal share of the city of Husum: 25,000 inhab. equiv.;
- tourism and abattoir: up to 136,000 inhab. equiv.

For the biological elimination of phosphorus, the CISAH-process (Combined ISAH) was used. This process combines biological elimination of phosphorus with the main stream method (ISAH-process) with an optional precipitation of bitstreams from the anaerobic tank for the biological removal of phosphorus (see Table 4).

Based on the good conditions, which are favourable for the elimination of both nitrogen and phosphorus (C_{BOD}=1.318 mg/l, BOD/P=84.9), it was possible to achieve excellent effluent data for the parameters nitrogen (NH_4–N+NO_3–N) and P_{tot}. It was possible to entirely dispense with any precipitation in the bypass flow. The carbon loads are considerably higher than those found in earlier data evaluations, which is due to the production extension and restructuring of the connected abattoir during the year 1996 (see Figure 3 and Table 5).

Table 4 Dimensioning data and flow sheet of the WWTP in Husum

Aeration tank	V=2×5,500 m=11,000 m^3
	6 mammoth rotors per tank
	360 kg O_2/h per tank
	V_{anox}=650 m^3
	V_{an}=650 m^3
Secondary clarifier	V=2×3,300=6,600 m^3
	A=2×700=1,400 m^2
	Effluent through submerged pipes

Table 5 Average day loads in the influent of the wastewater treatment plant at Husum in 1998 in comparison to the dimensioning data, (*)=no data available

		Operation data 1998	Dimensioning data
Q	m^3/d	6,794	13,000
BOD	kg/d	9,681	6,600
COD	kg/d	17,903	– (*)
NH_4–N	kg/d	275	– (*)
$N_{tot.}$	kg/d	592	1,320
$P_{tot.}$	kg/d	103	200
MLSS	g/l	5.6	5.0
Sludge loading	kg BOD/(kgMLSS×d)	0.15	0.12

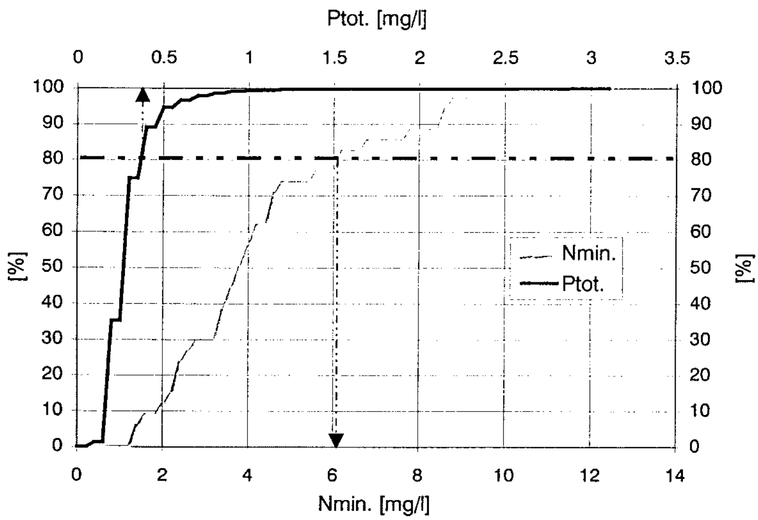

Figure 3 Cumulative frequency of the parameter $N_{mineral}$ (NH_4–N+NO_3–N) and P_{tot} in the effluent of the secondary clarification of the wastewater treatment plant at Husum from 1995 to 8/1998

Wastewater treatment plant of the AV Holtemme

The wastewater treatment plant of the Waste Water Association Holtemme (AV) at Wernigerode has been in operation since December 1995; it is currently in the first construction stage of the first extension phase. The cascade denitrification as operation method is used. In contrast to tanks with thorough mixing, the cascade method has the advantage that it allows higher biomass contents in the first tank, which leads to volumes which are accordingly lower. Actually it is run without preliminary clarification and external fermentation; however, in a second construction stage the plant is to be extended by preliminary clarification and an anaerobic sludge stabilisation unit to be suitable for 95,000 inhab. Finally, the plant will be dimensioned for 125,000 inhab. (2nd extension phase), which will include the construction of a storage tank for untreated water to even out the influent.

Table 6 Dimensioning data

Aeration tank AT	V_{aerob}=3×5,100 m^3=15,300 m^3
	V_{anox}=3×2,700 m^3=8,100 m^3
Bio-P-tank	V=3×2×400 m^3=2,400 m^3
RS-Deni-tank	V_i=3×400 m^3=1,200 m^3
Secondary clarification	V=3×3,688 m^3=11,064 m^3
	A=3×938 m^2=2,814 m^2

aeration tank AT	V_{aerob} = 3 □ 5.100 m³ = 15.300 m³
	V_{anox} = 3 □ 2.700 m³ = 8.100 m³
Bio-P-tank	V = 3 □ 2 □ 400 m³ = 2.400 m³
RS-Deni-tank	V_i = 3 □ 400 m³ = 1.200 m³
secondary clarification	V = 3 □ 3.688 m³ = 11.064 m³
	A = 3 □ 938 m² = 2.814 m²

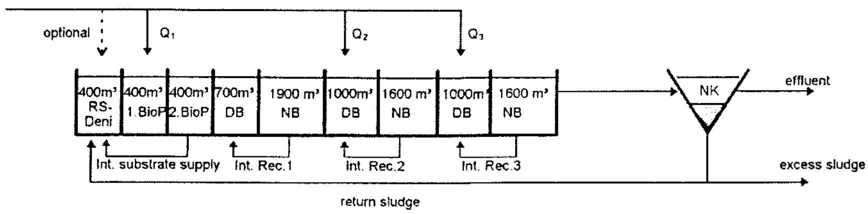

Figure 4 Flow sheet of the aeration unit of the wastewater treatment plant of AV Holtemme (1 line)

Table 7 Load data of the wastewater treatment plant of AV Holtemme for the first extension phase (95,000 inhab., with preliminary clarification), and monitoring data

	Operation data (average)	**Dimensioning data**	**Monitoring data**	
Influent AT	**Loads**	**Loads**	**Concentrations**	**Remarks**
COD	6,115 kg/d	10,768 kg/d	75 mg/l	–
BOD	2,517 kg/d	5,153 kg/d	13 mg/l	–
NH_4–N	307 kg/d	773 kg/d	6 mg/l	Temp.>12°C
N_{tot}	474 kg/d	1,064 kg/d	13 mg/l	Temp.>12°C
P_{tot}	89 kg/d	244 kg/d	2 mg/l	
Q	10,874 m³/d	16,000 m³/d (#)		
		1,990 m³/h (##)		

#=Dry weather, ##=storm water flow

In regard to aeration tank and secondary clarification, the plant is designed as a three line plant. The cascade consists of three units with nitrification and denitrification (see Figure 4). Three internal recycling streams effect the return of the nitrate. The biological P-Elimination unit works similarly to the ISAH-process; separate substrate input for the denitrification of the nitrate in the return sludge is possible by addition of one bitstream from the influent. The recycling ratio between the second Bio-P-tank and the tank for the denitrification of return sludge is about 40% of the average amount of influent water. The tank for the denitrification of return sludge is able to eliminate up to 6 $mgNO_3$/l. The influent can be distributed by a well tank with adjustable lip in the area of 100% to Q_1 (system with thorough mixing) down to 40%, 32%, 28% to Q_1, Q_2, and Q_3.

The demands on nitrogen ratios in the effluent are comparatively high. The entire volume of the three-stage cascade plant was reduced by 17% (28,000 m³ to 23,400 m³) in comparison to a method with completely mixed tanks. The average contents of MLSS of the cascade of 3.6 g/l is 0.6 g/l higher than that of a system with completely mixed tanks. The factored anoxic volume is approximately 35% of the entire volume. The Bio-P-tanks are designed for an entire contact period of 1.2 h (for $Q_{dry\ weather}$). Thus, the volume of the Bio-P-tanks amounts to 2400 m³, that is per line two tanks with 400 m³ each. For the tank for the denitrification of return sludge, the volume is also 400m³ per line with a contact period of 1 h. The monitoring data could easily be kept in the year 1997. The elimination degree was 80% for N_{tot} and 92% for P_{tot} (see Tables 6 and 7 for line showing and load data, and Figure 5 for results).

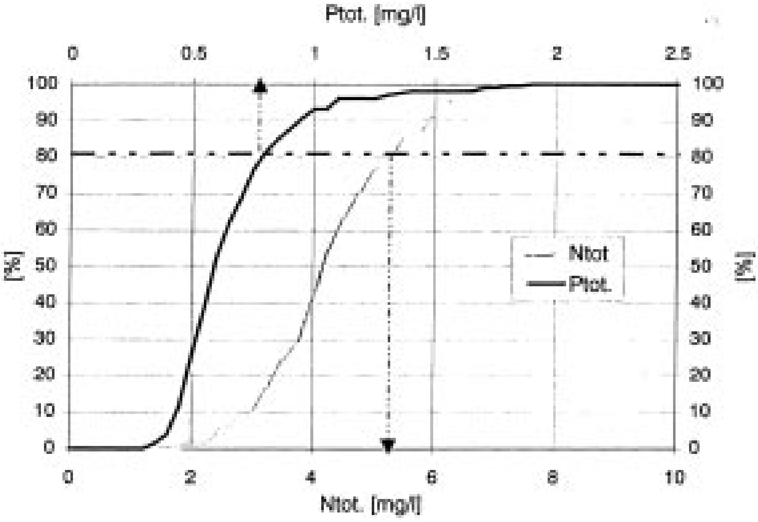

Figure 5 Cumulative frequency for the parameters N_{tot} and P_{tot} in the effluent of the secondary clarifiers at the wastewater treatment of the AV Holtemme as daily average of the year 1998

Wastewater treatment plant of Bremen-Seehausen

In 1989, the municipal wastewater treatment plant at Bremen Seehausen consisted of a preliminary clarification plant topped with a two-stage activated sludge plant; because of the high work load, nitrification could not be achieved. The limits for phosphorus could be observed by constructing a dosing station for precipitation agents in 1989. In order to observe the demanded limits in regard to the parameters nitrogen and phosphorus, the plant had to be extended (see Figure 6).

For reasons of space and economy, the extension of the wastewater treatment plant had to be designed in a way that the existing two-stage activation plant could be smoothly integrated into the new plant. The new aeration plant was initially dimensioned for 50% of the influent according to the German wastewater guideline A 131, and then extended following the ISAH-process described above. The dynamic simulation of this option showed that due to the reduced work load the old plant was only able to nitrify; denitrification was not possible. As a result, the nitrate values in the effluent of the entire plant would have continued to be high. This would have impaired the chances to observe the demanded limits, and it could have led to denitrification in the secondary clarification unit, a phenomenon which might have led to loss of biomass. In order to still reach the demanded clarification performance for the combination of the two plants, several extension options were designed for the old plant via dynamic simulation; the different options were compared in regard to their degradation performance. Considering the saving potential inherent in using the old parts of the plant, the most favourable option was the reconstruction of the old plant as one-stage plant. The tank of intermediate clarification of the former two-stage plant was now used as tank for secondary clarification of the new part of the plant. Thus, it was possible to do without further tanks for secondary clarification. The old plant was redesigned as one-stage plant for nitrification/denitrification and built in cascade form. Additional measures for nitrogen reduction could thus be dispensed with (see Table 8 for operation data Figure 7 for results).

Energy aspects

One major part of the operation costs of municipal wastewater treatment plants are the energy costs, which are mainly accrued by the biological stage. According to Grünebaum *et al.*,1996, the ratio is 15–25%, and approximately three quarters of the total amount of electrical energy of

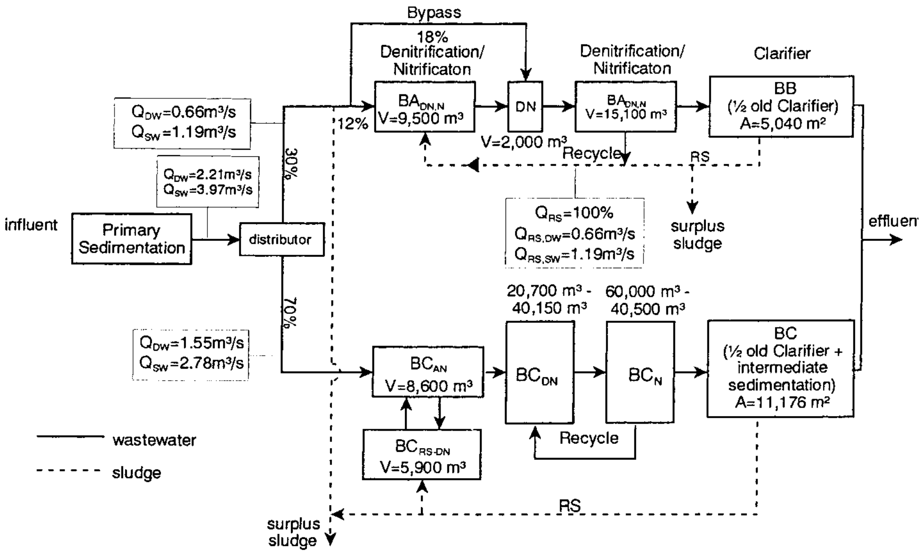

Figure 6 Flow sheet of the wastewater treatment plant at Bremen-Seehausen, accepted extension option [HARTWIG, KRUSE/1996]

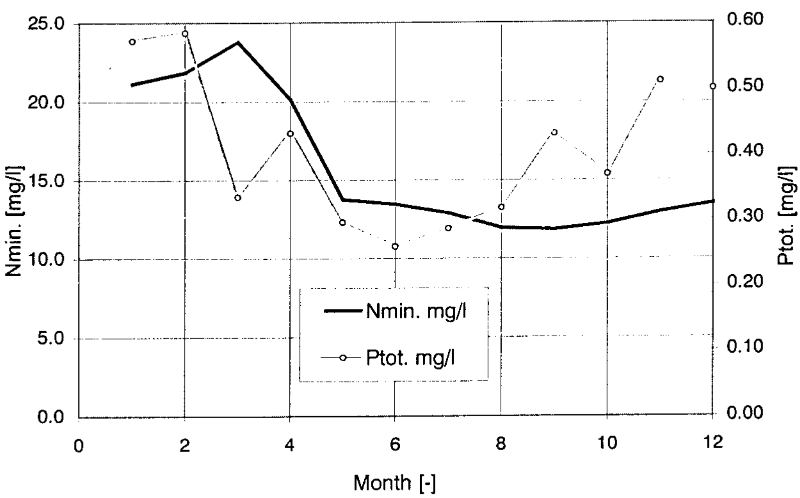

Figure 7 Concentrations of the parameters $N_{mineral}$ and P_{tot} during the year 1997 as monthly average value

Table 8 Operation data of the wastewater treatment plant at Bremen-Seehausen, (#) no data available

	Dimensioning	**Operation data 1997**
$Q_{dry\ weather}$	143,000 m^3/d	103,394 m^3/d
$Q_{storm\ water}$	14,300 m^3/h	– (#)
	Effluent of the primary clarifier	Influent of the primary clarifier
BOD	45,000 kg/d	49,813 kg/d
N_{tot}	11,000 kg/d	7,505 kg/d
P_{tot}	2,300 kg/d	1,148 kg/d
MLSS (Average of both plants)	3.4	3.3–3.5

Table 9 Energy consumption and production of three WWTPs, (#)=no energy production

Plant	Hildesheim (1998)	Husum (1998)	Bremen-Seehausen (1997)
External sources [kWh/a]	2,710,000	1,879,420	10,537,212
Production [kWh/a]	2,880,945	– (#)	12,168,762
Total consumption [kWh/a]	5,590,945	1,879,420	22,705,974
Q [m^3/a]	12,696,890	2,479,880	45,936,200
BOD-Load [kg BOD/a]	3,654,015	3,533,829	18,181,600
People equivalent	167,000	161,000	830,217
[kWh/P.E.×a]	33	12	27
[kWh/kg BOD]	1.5	0.5	1.3
[kWh/m^3]	0.4	0.8	0.5

the WWTP is consumed by the biological stage [Bohn 1997]. Parameters to describe the treatment efficiency of any biological wastewater treatment plant are the load or people specific energy consumption amounts, which in Table 9 are shown for three of the four WWTPs. The parameters of the plants at Bremen and Hildesheim have comparable dimensions, which is mainly due to the fact that their influent situations are similar. Conspicuous are the considerably different dimension of the parameters of the WWTP at Husum, in particular in regard to the load specific and ensuing people specific values. The comparison with the water-amount specific value, which is relatively high, shows that this distortion is mainly due to the unusual influent conditions (BOD/N of 84.9) caused by the high ratio of industrial wastewater, which leads to a situation where the ratio of the aeration energy used up by the energy for nitrification is considerably lower than with the other two examined WWTPs.

Conclusions

This report presents the different operation procedures of four municipal wastewater treatment plants in the North of Germany, the analyses of the available dimensioning and operation results compared with the specific energy consumption. The plants at Hildesheim and Wernigerode have relatively low loads. In both cases, it was possible to reach effluent values considerably below the required minimum demands. The wastewater treatment plant at Husum is conspicuous for the high degree of wastewater coming from food processing factories, which makes for high elimination degrees for the parameters nitrogen and phosphorus due to the high sludge production. Cascade plants make it possible to work with high MLSS-contents and to reduce the return of activated sludge at the same nitrogen elimination degree. The operation concept of the WWTP in Bremen-Seehausen, developed with the assistance of dynamic simulation calculations, is an example of integrating old plant components in a plant rebuild. For the plants with similar influent situations, there result similar values in regard to the energy utilisation.

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