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Comparative study of small wastewater treatment technologies under special operation conditions—COMPAS

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ABSTRACT

In rural areas, small wastewater treatment plants (SWWTPs) are a cost-efficient solution to sewage disposal issues. In Europe, SWWTPs 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 10–12 million people are served by decentralized 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 mon 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 study was performed at the Training and Demonstration Centre for Decentralized 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.

Keywords: Small wastewater treatment technologies; Decentralized wastewater treatment; Rural areas; Comparison test; Treatment efficiency; Realistic operating conditions

1. Motivation and objectives

The use of satellite and decentralized approaches for the management of water and wastewater can play an important role in the future of water resources management [1]. That is why more and more decentralized system are developed and installed. All small wastewater treatment systems sold on the European market must be certified to European standard EN 12566-3 [2]. 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,

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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 sponsor of the study "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, those are provided by the manufacturers organized 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 at the Centre Scientifique et Technique du Bâtiment (CSTB) in Nantes. The operation conditions of this French study consisting of a test field with eight SWWTPs, mainly soil filter systems, were identical.

The test program was to be carried out in accordance with EN 12566-3 [2] (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 (not reported in the paper)
- 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.

2. Overview of the 12 small wastewater systems investigated

Under the guidance of a 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 (see Fig. 1). The required floor space of the installation varied from 31 m² (SBR, rotating disc) to 35 m² (constructed wetland). The nominal size of the installations varied from 4 to 9 PE based on a specific nominal hydraulic load of 150 1/(PE·d). More details are given in the complete report [3]. The type of technology determined the sequence of taking the samples in the effluent. 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 to be able to compare with another study at the CSTB, Nantes. There has been done a similar comparison

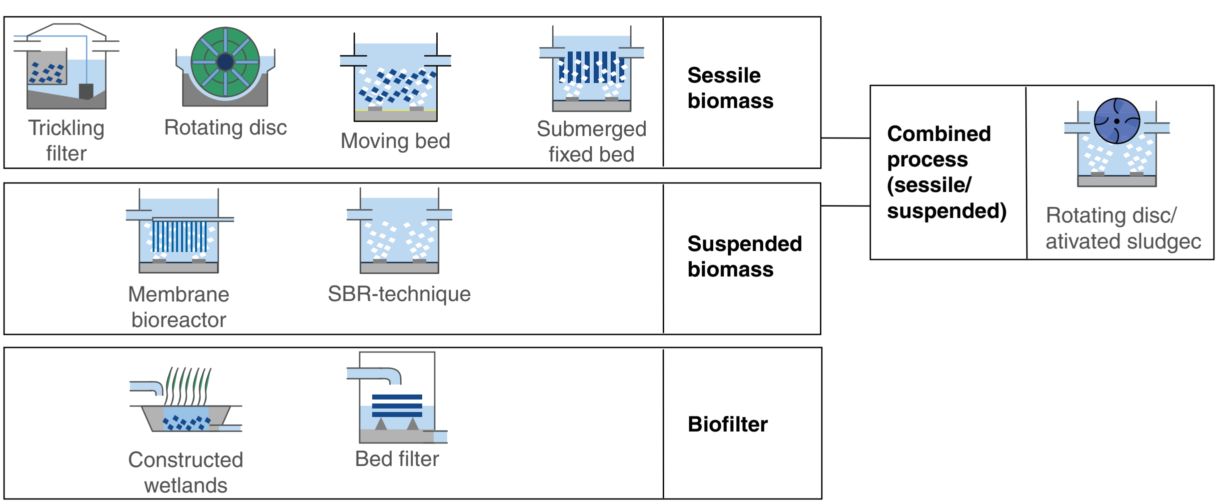

Fig. 1. Processes of the 12 small wastewater systems investigated.

of a little bit different systems and with other test conditions in the North of Germany [4].

3. Test conditions

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 bathtub 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 [2] with increased waste water quantities at intermittent intervals (VEOLIA test program: “Protocole en conditions sollicitantes®”). The charging program is summarized in the following, changes compared to EN 12566-3 [1] are written bold:

- Phase 1: Inoculation: 100% hydraulic and pollution load (seven weeks)
- Phase 2: Obtaining a permanent state with 100% (four weeks)
- Phase 3: Normal operation with a load of 100% (21 weeks)
- Phase 4: Operation with 100% except for three days at the end of the week with 200% (four weeks)
- Phase 5: operation with 200% (three weeks)
- Phase 6: No load (three weeks)
- Phase 7: Normal operation again, except for the last three days of the week with 200% (two weeks)
- Phase 8: Normal operation (four weeks)
- Phase 9: Operation with 50% load (four weeks)
- Phase 10: Operation with normal load (four weeks) with three simulated electric breakdowns of 24 h with 48 h intervals

Phase 3 had to be extended due to an oil accident from a nearby factory, which also affected the test facility. This additional time was needed to allow the systems time to restabilize and to ensure that the further course of testing was not impaired.

Before starting phase 4, manufacturers of the SWWTP were given the opportunity to modify and adapt their systems to the increased hydraulic load conditions.

4. Overview of purification performance

Fig. 2 contains the influent curves and the maximal and minimal concentrations in the effluent of all SWWTPs for entire study period. The mean influent COD concentration was 456 mg/l, with values ranging from 830 mg/l maximum down to 180 mg/l minimum. Overall effluent COD for the respective small wastewater systems ranged from 14 mg/l (minimum) to 741 mg/l (maximum), with mean values ranging from 34 to 196 mg/l. By comparison, the mean effluent COD for Class 1–5 wastewater treatment plants in Germany was only 28 mg/l in 2007 [2]. This suggests a significantly better treatment performance of large WWTPs. All but two of the investigated SWWTPs yielded an average effluent COD below the German and French regulation for small wastewater treatment plants (maximum limit) of a mean 150 and 125 mg/l, respectively.

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).

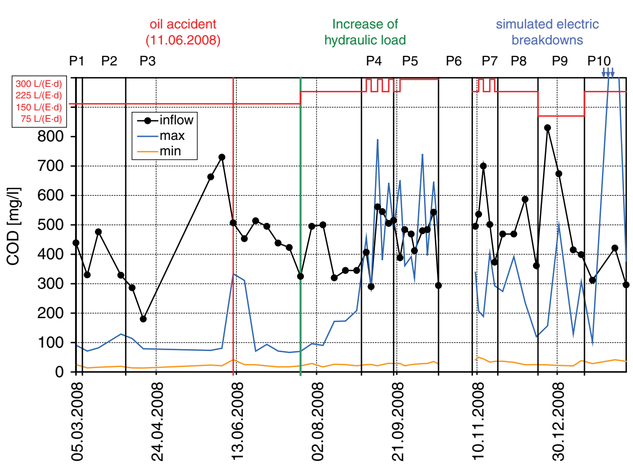

Fig. 2. COD curves for influent and the maximal and minimal effluent of all systems.

Increased effluent COD concentrations (mean 28.6–102.9 mg/l) were detected in the remaining SWWTPs. After Phase 6 (no load), the concentrations stabilized in nearly all SWWTPs. COD peaks were observed directly after system restart, particularly in suspended biomass systems. 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.

Table 1 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 $n = 50$.

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 1,100 mg/l(maximum), with mean values ranging from 5 to 117 mg/l. The maximum effluent value appears only at one SBR-system during the highest hydraulic overloading. This system was not designed for that flow. 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.

The mean influent NH_4-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 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 [5]. Two systems using sessile biomass achieved effluent NH_4-N concentrations <10 mg/l (stabile nitrification).

Due to the lack of guidelines on monitoring parameters for microbiological testing of small wastewater systems without hygienisation, Directive 2006/7/EC of the

Table 1
Mean effluent value and purification efficiency η (calculated over all periods)

System	COD (mean)		SS (mean)		NH_4N-(mean)		Delta *E.coli*
	Effluent	η	Effluent	η	Effluent	η	[log]
	[mg/l]	%	[mg/l]	%	[mg/l]	%	–
mean inflow	456	–	269	–	35	–	–
Limiting Values	150[d]	–	35[e]	–	10[f]	–	
combination rotating disc and activated sludge	196	56	117	53	20	41	0,6
Moving bed	53	88	16	94	9	73	0,8
Rotating disc	78	81	21	91	16	52	0,8
Trickling filter	92	79	29	89	18	47	0,8
Tricling filter (textil material)[a]	–	–	–	–	–	–	0,9
Submerged bed	56	87	11	96	20	44	1,2
Bed filter	60	86	14	95	17	48	1,1
Constructed wetlands	34	92	5	98	12	60	0 MPN/ml (effluent)
filter with coconut material	52	86	13	95	9	54	0,8
Membrane bioreactor	77	83	25	80	19	47	0 MPN/ml (effluent)
SBR I [b,c]	163	82	93	62	23	29	0,8
SBR II with control panel	70	84	20	92	24	34	0,8

a) could not be tested during high-performance work phase due to the process
b) was changed to 4 PE during the 200%-work phase
c) not designed for peak load
d) German limiting value as specified in AbwV
e) French limiting value as specified in "arrêté du 22/6/2007"
f) German limiting value as specified in DIBt group N, not all plants are designed for nitrification

European Parliament and of the Council of 15 February 2006 concerning the management of bathing water quality and repealing Directive 76/160/EEC [6] was consulted for reference. 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*".

5. Power consumption, maintenance, sludge production

Total power consumption rates for the entire study period ranged from 42 to 247 kWh/(PE·a). The bed filter and coco filter systems did not consume any power.

The mean specific sludge mass of all 12 SWWTPs was 36 g/(PE·d). The lowest specific sludge mass (8 g/[PE·d]) was observed in a combined process SWWTP caused by excessive sludge overflow, and the highest value (66 g/(PE·d)) was detected in a sessile biomass system.

The mean total maintenance time for all maintenance work performed during the entire study period ranged from 90 (moving bed) to 150 min (trickling filter). The mean maintenance lasted 111 min.

6. Summary and perspectives

The 12 small wastewater systems installed at the Training and Demonstration Centre for Decentralized 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 [2]. 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 [3] 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 in-creased 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 analyzed 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 hardly degradable substances in the influent which pass through the plants in those cases. In the study in Nantes [7], however, similar peaks were observed during simulated electrical breakdowns in almost all SWWTPs 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*".

Overall, the results of this study support the further establishment of SWWTPs as a permanent solution to decentralized 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 program investigating the effects of specific local conditions for example 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

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