Performance of very small wastewater treatment plants with pronounced load variations

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Abstract The operation of very small biological wastewater systems is strongly influenced by the patterns of wastewater generation. The absence of people in the connected building(s) during holidays or off-season leads to a system underload, other circumstances however may lead to an overload. Experiments have been carried out to display the effects of no-feed conditions on activated sludge biomass and its microbial activity during a 24 hour period after re-feeding. The decrease of the biomass during idle periods can be modelled by a first order equation. The initial specific oxygen uptake rate (OUR) of the remaining biomass decreased with the duration of the preceding no-feed sequence. Four different laboratory-scale treatment plants were operated to demonstrate the system performance when re-started after a break period of 24 and 52 days respectively. The effluent concentration after a break of 52 days had not been sufficient as compared to the discharge requirements given by German laws. In addition a full scale trickling filter was monitored, while the connected building accommodated a maximum of 40 guests interrupted by times with no guest at all. Conclusions are drawn from the experimental results and from literature, giving some hints on how to manage the impacts of varying loads at very small wastewater treatment plants.

Keywords Activated sludge; biomass decay; idle conditions; moving bed biofilm reactor; oxygen uptake rate; rotating bio contactor; trickling filter

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Introduction

Approximately 10% of the population in Germany discharge their wastewater to decentralised wastewater treatment systems. The percentage goes up 30% in certain federal states particular in Eastern Germany. It has been calculated that about 20% of the total COD emissions from WWTP effluents can be attributed to decentralised systems (Flasche, 2002).

The management of very small wastewater treatment systems has become an important issue in Germany, since simple septic tanks (see Schweizer, 1983) are insufficient for a proper wastewater treatment. A biological upgrade is essential. Treatment systems, which are marketed in Germany usually bear a proof label from the German Institute for Bautechnik (DIBt), which will be assigned after a successful one-year-test. The impact of a 14 day break is nowadays assessed due to a recent refinement of the testing procedure. However, the load variations may dominate and the breaks may be of extended duration in some cases.

From the microbiological point of view, it is important to know about the impact on the total biomass and its activity during idle periods (Urbain *et al.*, 1993; Morgenroth *et al.*, 2000). It determines the treatment capacity of the system in terms of microbiological turn over rates. Beside this, non-biological effects like settling, adsorption on flocs, dilution and hydrolysis play an important role in wastewater treatment. The performance

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of a complete treatment system cannot be predicted on the base of microbiological turn over rates only. Consequently the system response (Vasel and Jupsin 2003) has been part of the experiments in addition to lab-scale investigations.

Four laboratory-scale treatment plants with a design capacity of 0.1 P.E. each were operated to demonstrate the system performance of a trickling filter (TF), a rotating biological contactor (RBC), an activated sludge- (AS) and a moving bed biofilm system (MBBR) when re-started after a break period of 24 and 52 days respectively. Moreover, the performance of a full scale trickling filter with a design capacity of 20 P.E. was monitored over a period of 85 days, while the connected building (a youth hostel in the Northern Black Forest, Germany) accommodated a maximum of 40 guests interrupted by times with no guest at all.

Materials and methods

Chemical parameters (COD, NO_3-N) were measured with test kits LCK 314 and LCK 339 (Dr. Lange). *Total suspended solids (TSS)* and *volatile suspended solids (VSS)* were measured according to DIN 39409 H2. *Storage of sludge:* Activated sludge was taken from WWTPs in Blankenloch and Berghausen, Germany. It was stored in 10 L Plexiglas cylinders and aerated. Evaporation was compensated by the addition of pure water. Samples were taken for measuring OUR after adding substrate and for SS determination. *Oxygen uptake rates (OUR)* were measured by using an oxygen probe (Greisinger electronic - GMH 3610) and a data logging computer programme (Greisinger EBS9M)). Sludge samples were mixed with substrate to assure an initial VSS and COD content in the range of 1 g/L each. Samples were taken in Karlsruhe-flasks and a sequence of aeration (15 minutes) and oxygen consumption (15 minutes) was applied by using a timer device. Phases of oxygen consumption have been taken for calculation of OUR. Tests were carried out over six weeks using three substrate solutions, i.e. (1) a glucose solution (2) a yellow-water (urine) solution (3) and a brownwater solution (suspended feces). Substrates were taken from a common stock, which had been prepared at the beginning of the experiments and was frozen in icecube trays until use.

Laboratory scale WWTPs were designed for 0.1 P.E. each. Design data are given in Table 1. Wastewater was pumped from a sanitary sewer in a residential area in Eggenstein-Leopodshafen (near Karlsruhe, Germany) at a rate of 10–20 L/d each. The influent COD was 1165 mg/L on average. Experimental breaks were applied when the WWTPs showed stable conditions. During break-times aeration was applied one minute per 15 minutes, as was the trickling filter pump and the disk motor of the RBC in order to keep the biofilms alive. Re-feeding started after 24 and 52 days without inflow.

The *full scale trickling filter* consisted of a three-chamber settling basin (8 m^3), a trickling filter with stone package (5.5 m^3) and a secondary settling tank (4.2 m^3). Prior to the investigation an internal recycle from the secondary settling tank to the head of the trickling filter had been implemented. Beside this, an external recycle from the secondary settling to the first chamber of the settling tank was taken in operation (Figure 1). Samples were taken from the final effluent and from the effluent of the primary settling tank. Samples were frozen until being taken to analysis.

Results

Biomass decay

Changes of the organic content of the stored sludge are displayed in Figure 2 along with an exponential regression function. The exponential constants of -0.0197 and $-0.0258\,d^{-1}$ represent the decay rate. The decay rate constants are within the scope of values from literature. According to Metcalf and Eddy (1991) the range is from

Table 1 Design data of the laboratory-scale WWTPs

	AS	MBBR	RBC	TF
Primary settling (L)	16	16	16	16
Reactor / trough (L)	32	32	32	40L TF; 32L trough
Secondary settling (L)	16	16	16	16
Biomass or area/volume for attached growth	64 gTSS	3,2 m^2 Biolox 10* (5 L)	3 m^2 12 disks	40 L RFK 50 L*
				

*Carrier media manufactured by Rauschert Verfahrenstechnik GmbH, Germany; AS-activated sludge, MBBR-moving bed biofilm reactor, RBC-Rotating bio contactor, TF-Trickling filter

Figure 1 (a) Scheme of the trickling filter; (b) Youth hostel Raumünzach (Black Forest, Germany); (c) Distribution of internal water recycle

$-0.025\,d^{-1}$ to $-0.075\,d^{-1}$. Results from Coello Oviedo *et al.* (2002) indicate a constant of $-0.06\ d^{-1}$. It should be noted, that the sludge has been stored under aerobic conditions, which are supposed to have a significantly higher decay rate (due to the activity of protozoa) as compared to anaerobically stored sludge (Batla and Gaudy, 1965; Lopez and Morgenroth, 2002).

OUR after re-feeding

Specific cumulated oxygen uptake rates are displayed in Figure 3. OUR was maximum when yellow water has been added as substrate. This can be attributed to the activity of nitrifying bacteria. Carbon substrates (glucose, brown water) showed a lower uptake. Although the biomass without preceding storage always exhibited the highest OUR, a lack of consistency has been observed, since the sludge with the most extended storage duration (six weeks) did not always represent the lowest activity.

However, initial oxygen uptake reflected the duration of the preceding storage time. Figure 3a shows the relative uptake within the first two hours after substrate was added. The degression with storage time became indistinct within 24 hours (Figure 4b).

It can be concluded that the sludge almost regained its specific activity within 24 hours. This finding is of importance for the assessment of idle conditions: it can be stated that the major task for operating very small WWTPs during breaks is keeping the mass of biomass so that its activity will recover within a short term period.

Performance of the laboratory-scale systems

Table 2 shows the average performance data during steady state conditions. The influent taken from a sanitary sewer exhibited high COD concentrations leading to high loading

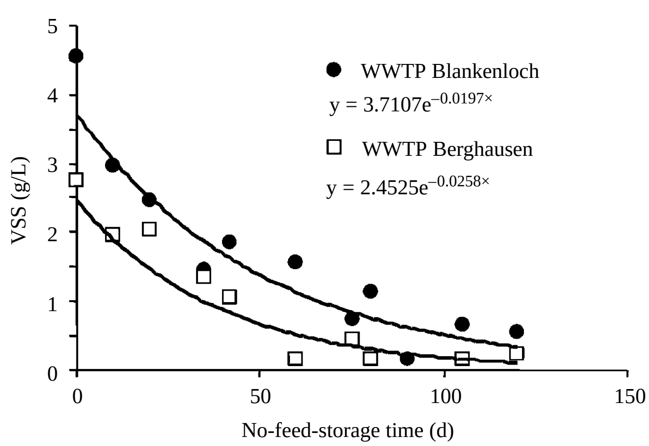

Figure 2 Decrease of VSS of two different stored sludges

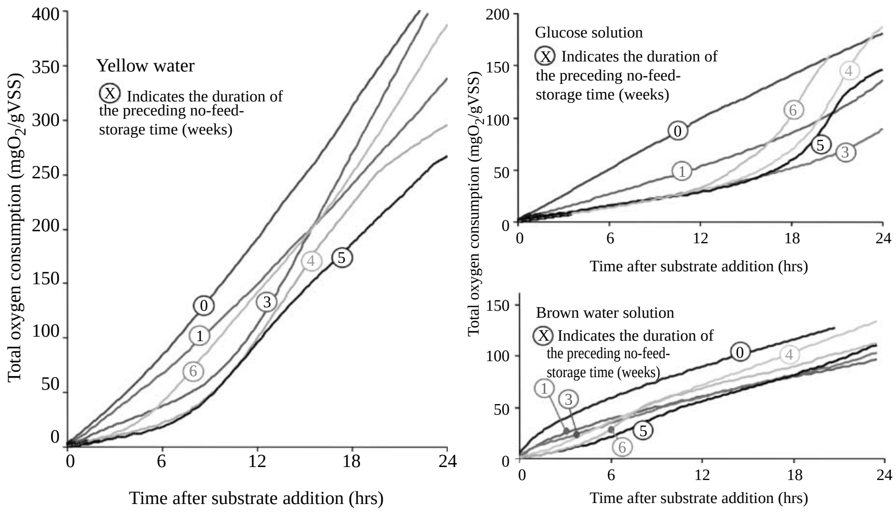

Figure 3 Total oxygen consumption with respect to the preceding no-feed storage time, substrate and time after substrate addition

rates for the treatment systems, thus nitrification occurred to a limited extent only. However, COD-elimination was reasonable and experimental breaks were applied.

The effluent COD dropped below 100 mg/L during break conditions, except for the activated sludge system in the second experimental run. Re-feeding the systems caused an increase of the effluent COD with maximum values in the range of 160 mg/L after the 24 days-break and values up to 260 mg/L after the 52 days-break (Figure 5).

The feed pump was accidentally set to 20L/WWTP·d during the second re-start, followed by a pump clogging after three days, which disabled further feeding. Design feeding of 10 L/WWTP·d was reconstituted at the sixth day after re-start. Even though the effluent quality was worse as compared to the steady state conditions, COD elimination was in the range of 80%. The COD requirements for wastewater at the point of discharge of 150 mg/L as defined by German Water Regulations may be exceeded after a 24 days break, whereas a break of 52 day ultimately leads to an unacceptable effluent quality.

Although it was intended by the experiments to work out some kind ranking of appropriate systems for varying load conditions it has to be stated, that the results seem too

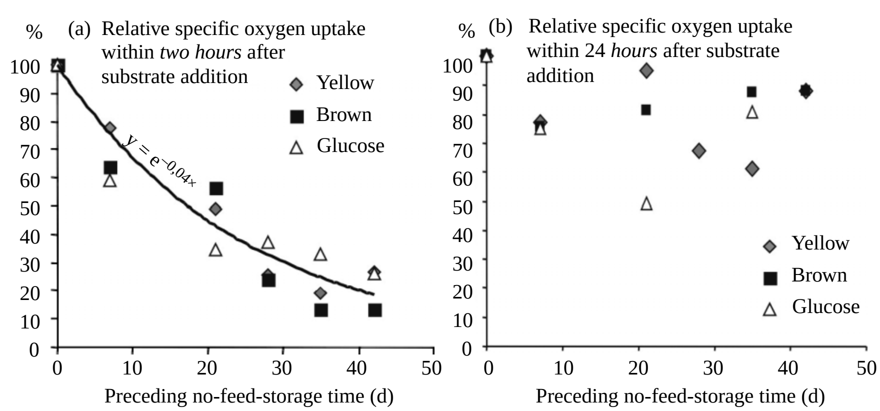

Figure 4 Relation of the oxygen uptake of sludge from the storage container (0 weeks = 100%) within two and 24 hours respectively

Table 2 Performance of the laboratory scale WWTP during steady state conditions

	Loading rates	COD (mgO_2/L)			Nitrate (mgN/L)			Total Nitrogen (mgN/L)		
		n	Ave.	Std. Dev.	*n*	Ave.	Std. Dev.	*n*	Ave.	Std. Dev.
Influent	11.7 gCOD/d each	16	1165		–	–	–	8	98.7	11.2
RBC	2.0 $gCOD/m^2d$	16	133	32.4	8	33.2	16.3	4	78.3	9.3
MBBR	1.9 $gCOD/m^2d$	16	109	29.4	8	25.3	5.6	4	63.2	18.9
AS	0.09 gCOD/gSSd	16	122	22.1	8	15.6	5.9	4	54.2	14.1
TF	291 $gCOD/m^3d$	8	98	29.6	8	45.3	22.6	4	85.3	11.4

fuzzy for supporting any similar statement, since all investigated systems worked in the same range and all systems showed some variations hard to explain.

Performance of a full-scale trickling filter under load variations

Figure 6 displays the performance data of the trickling filter along with the number of accommodated guests and the outside air temperatures. The differences of COD measured at the final effluent and the effluent of the primary settling tank appeared very low. This finding is due to the recycle line from the secondary to the primary settling tank and the subsequent dilution.

Even though the recycle line brings nitrate into the primary settling tanks, it could hardly be detected there. This indicates that the primary settling tank serves as a denitrification reactor. Nitrate could only be detected in the settling tank when the building was closed and the carbon feed ceased.

These observations demonstrate, that the settling tank cannot be considered as a sole physical treatment unit, but also as an upstream denitrification plug flow reactor unit. Although there are no limitations (for very small WWTPs in Germany) on discharging nitrogen, it should be noted that an enhanced denitrification process goes hand in hand with COD removal and saves energy for aeration.

Figure 6 shows that the interim breaks did not affect the overall performance, since COD effluent concentrations were well below 150 mg/L. However, the maximum break duration has been 14 days only (end of November). Therefore the result is in accordance with the laboratory-scale experimental data. It should be noted, that the trickling filter is designed for a maximum capacity of 20 P.E., whereas it served 40 P.E. sometimes.

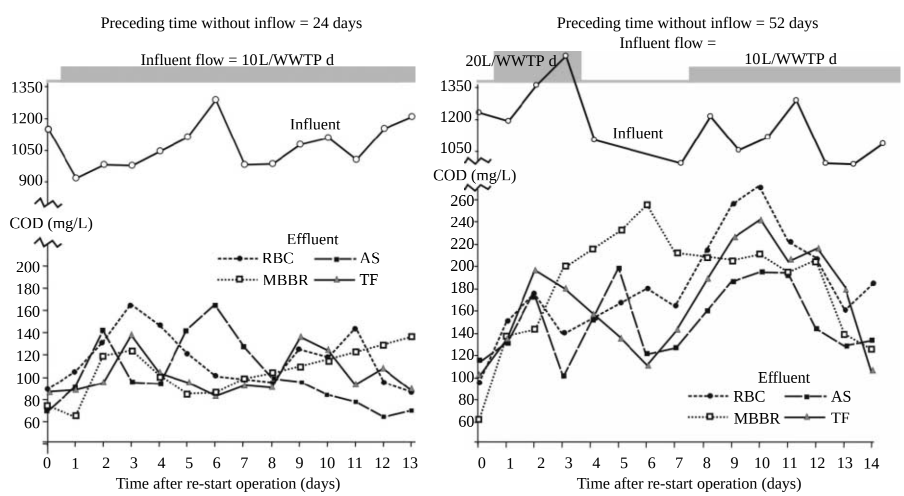

Figure 5 Performance of the laboratory-scale WWTPs after preceding breaks of 24 and 52 days respectively

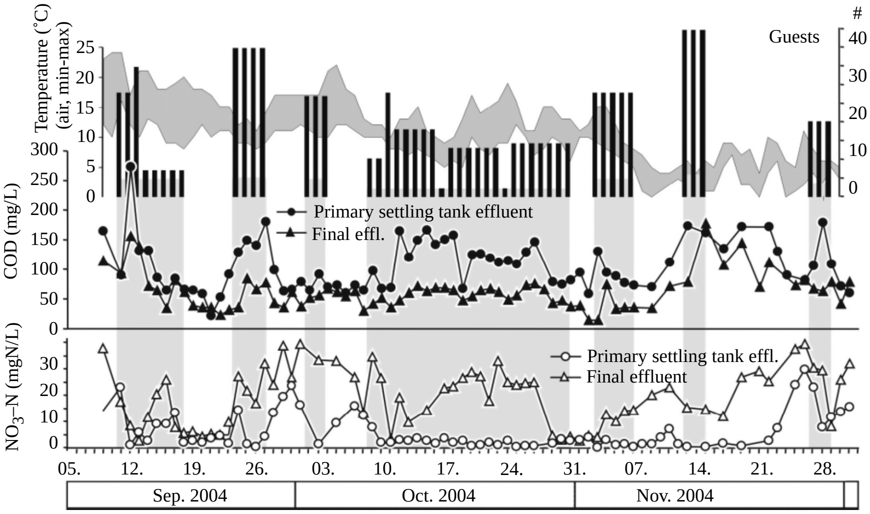

Figure 6 COD, nitrate, temperature and accommodation of a youth hostel trickling filter from early September to early December 2004

Summary and conclusions

It can be stated, that the loss of biomass significantly affects the treatment capacity of a biological system whereas the specific activity – measured as OUR – recovers within a reasonable time. However, biomass decay does not start immediately after the feed ceases. The performance data of the youth hostel trickling filter demonstrate that residual substrates provide further feed for the bacteria, particularly when water is recycled through the system. For practical reasons it is interesting to know how long a system can stay idle without affecting the treatment efficiency. The answer will not be uniform, since it depends on the specific boundary conditions, such as process scheme, temperature, regular loading, buffering capacity and more. Moreover, the definition of a sound treatment in terms of effluent limits is not uniform throughout the countries of their application.

Anyway, the following benchmark data can be summarised from the experiments and from literature data as an approach.

- The Alpenverein states on its internet homepage a startup time for a trickling filter of 12 days after an extended off-season (Alpenverein, 2000)
- Begert and Müller (1976) investigated the impact of a 70 days break on an activated sludge laboratory scale system. They concluded a re-start-time of 7 days, which could be shortened to three days, when primary sludge was filled into the reactor at the beginning of the break.
- The displayed laboratory-scale experimental results can be interpreted in a way, such that a 24 days break highlights the maximum break time without exceeding the COD limit of 150 mg/L during re-start. A break time of 52 days required a start-up in the range of 1–2 weeks.
- No impact must be expected when the break time is in the range of 14 days. This conclusion is supported by the performance of the youth hostel trickling filter and by investigations from Barjenbruch and Al Jiroudi (2004) in the context of the testing procedure for very small WWTPs for the assignment of a proof label and by early experiments from Hörler and Pracek (1964).
- Measures for managing breaks may either aim at keeping the total biomass or at regenerating the loss.

- As indicated by Begert and Müller (1976) and other researchers (i.e. Loosdrecht and Henze, 1999) the biomass decay is lowered under anaerobic conditions (due to the diminished activity of protozoa). Thus suspended systems such as AS or MBBR should not be aerated during breaks.
- A delayed biomass decay can be accomplished with sufficient buffering capacity, such as storage and/or settling tanks and a recycle line through the system.
- A carbon source of high concentration (sugar, methanol …) may be added a week in advance of the re-start to regenerate the loss of biomass by natural growth.
- The biomass loss may be compensated with excess sludge of a municipal WWTP.

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