Benchmarking of BAF Plants:
Operational Experience on 40 Full scale installations in Germany

M. Barjenbruch, TU Berlin, Inst. of Civil Engineering, Dept. of Urban Water Management, TIB1-B16, Gustav-Meyer-Allee 25, D-13355 Berlin (matthias.barjenbruch@tu-berlin.de)
Tel.: +49 / (0) 30 / 314 72246; Fax: +49 / (0) 30 / 314 72248

For some years, bio-filtration has been used in municipal wastewater treatment as a relatively new method. Within a German DWA research project, the method of benchmarking was used to compile and scientifically evaluate performance data and operation experiences with this technology on municipal wastewater treatment plants in Germany. This report presents selected partial results from the project. Generally, it becomes apparent that bio-filters as supplementary technology allow for additional improvements in regard to the COD and nitrogen effluent values. Bio-filtration is a compact method which combines biological purification processes with the filtration process. Apart from sound results in regard to the operation costs, operational problems (MSR technology, filter material losses) are described. In terms of energy balances, dimensions of the biological main stages can be compared to other biological purification methods. In regard to the sludge production, further research is necessary.

Keywords: Biofilter, energy consumption, large scale experiences, operational results, purification performance,

Introduction

The usage of bio-filtration in municipal wastewater treatment has increased in recent years. Currently, about 40 plants with different purposes are in operation in Germany. As this technology is a relatively new method, within a ATV-DVWK research project the method of benchmarking was used to compile and scientifically evaluate performance data and operation experiences with this technology on municipal wastewater treatment plants.
The central aim was to determine sound benchmarking values for the evaluation of different biofilter systems compared to other method. The data compilation was done with the help of a qualified questionnaire project. One other crucial element was the direct exchange of experiences with the operation staff, during which the definition of the frame conditions was done as well. Following that, the compiled data were verified, specific benchmark values were created for different part-processes, and internal rankings were arranged. In the following, selected partial results of the method will be discussed.

Bio-filtration procedure

Function

According to DIN EN 1085 (1997), biological filters are defined as “bio-film reactors with a fixed bed of granular material as filling in which filtration and biological degradation happen in combination”. Thus, the processes of biological wastewater treatment (degradation of carbon compounds, nitrification, and denitrification) and the filtration effects for the removal of suspended solids happen parallel in one reactor. As a rule, phosphorous is eliminated through chemical precipitation either preliminarily or downstream.
The fine granular carrier material (maximum ∅ up to 8 mm) retains both the surplus sludge produced during the biological conversion processes and the suspended solids contained in the wastewater influent. This process technology allows to dispense with secondary clarification. However, the bio-filters alone can generally not with sufficient certainty reach the suspended solids contents which are usual in classical flocculation filtration.

The most important characteristic of biofilter plants is that the volumetric conversion performances are up to 10 times higher than plants with suspended biomass can reach. This means that the demand for reactor volume and plant space is considerably lower which results in a correspondingly lower demand of reactor volume and plant space. Moreover, another advantage is the avoidance of bulking sludge.

Construction types and operation modes

On principle, the construction of biofilters resembles that of granular media filters (e.g. suspended floor perforated with nozzles, backwashing technology, filter container, modular design, etc.). Additionally, aeration implements are installed for the aerobic degradation processes, and dosage units for carbon supply are provided for the denitrification. Pumps, blowers for backwashing and a backwashing water storage tank are necessary particularly for systems which are discontinuously backwashed. Biofilters can be classified according to different criteria, depending on their design and their operation mode:

- Upflow filters ⇔ Downflow filters
- Submerged filters ⇔ Dry bed filters
- Density of the materials ρ < resp. > 1,0 g/cm³
- Continuously backwashed ⇔ discontinuously backwashed

As the process air is generally led into the filter material from below, upflow filters work with a co-current aeration, whereas downflow filters – except the dry filters – work with an reverse flow aeration.
Filter types which do not have any direct aeration of the filter bed, but in which the wastewater is aerated only preliminarily, can also be counted to the biological filters, even though their biological capacity is limited by the O_2-saturation concentration.
For reasons of backwash technology, bio-filter plants predominantly have a modular design. Most of the bio-filtration systems available on the market are company-specific developments with the main parts being protected by patent rights. An overview of the most common systems was compiled in the report of the German DWA-Work Report AG 2.6.4 (2000); please note, however, that some manufacturers do not have their respective products on offer anymore.

Development and current spreading of bio-filtration in Germany

Bio-filters developed from the “classical” wastewater filtration, which has been used industrially in Germany since as early as 1977 (first plant in Darmsheim), and from bio-film technology, which has its origins in the trickling filter technology.
At the beginning of the 1980s, both methods were combined for the first time in France, using modified rapid sand filters as main biological stage for wastewater treatment, with air being injected into the lower part of the filter bed. Later, bio-filters were built for the advanced wastewater treatment (residual nitrification, residual denitrification). The latest development stage in regard to municipal wastewater is the utilisation for full biological treatment with complete nitrogen elimination. The first plant of this type was started in 1990 in St.Jean d'Illac/(France near Bordeaux); in Germany, the first industrial main stage was initiated on the wastewater treatment plant at Herford in 1998.
In the following, those process concepts are described with flow sheets in which bio-filters have hitherto been used in Germany.

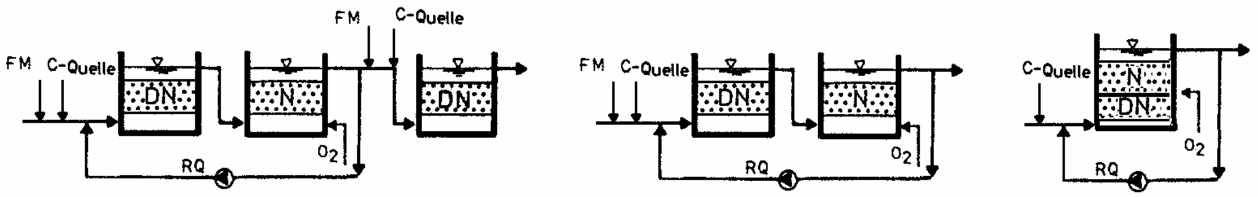

Figure 1: Biofilter as main biological stage (COD elimination, denitrification/nitrification after pre-treatment)

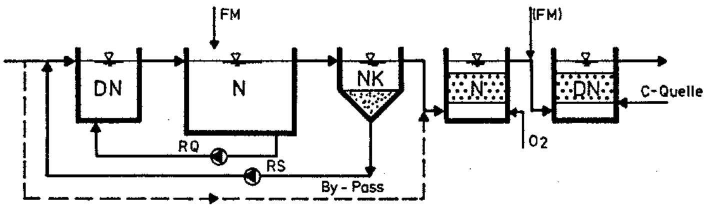

Figure 2: Usage of biofilters as second biological stage (nitrification and denitrification)

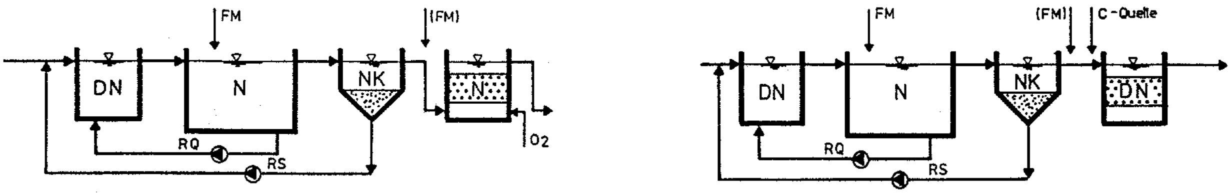

Figure 3: Usage of biofilters for (residual) nitrogen conversion; (residual) nitrification (left) or (residual) denitrification (right) in a downstream stage

Currently, more than 180 municipal wastewater filters are in operation in Germany. About 20% of these are designed as biological filters. With a total connection rate of approx. 10 million inhabitants, the wastewater from about 6 % of all connected PEs runs through some type of bio-filtration Figure 4 shows the usage frequency of the bio-filters in regard to their different application options in the wastewater treatment processes.
With more than 30 %, most bio-filters are used for secondary denitrification, with some of these plants running denitrification only in the months of May to October. The dimensioning size of bio-filters comprises all dimensions of wastewater treatment plants, reaching from the WTP at KA Hagen with 750 PE (main biological stage) to the WTP at Frankfurt-Niederrad with 1,2 million PE (downstream denitrification) and the WTP at Köln-Stammheim with 1,45 million PE (downstream residual nitrification). In Germany, areas of 5 m² to 113 m² for the single cells were designed. The largest single cell realised world-wide has an area of 173 m^2 (Geneva). The variation range of the total filter area of the municipal bio-filters in Germany goes from 14 m² to 3.500 m². The filter height reaches from 1,1 m for steel-enforced concrete tanks to 6,6 m for high-grade steel tanks.

Because of their compact, space-saving design and their high automation degree, bio-filters have also found a considerable place in industrial wastewater treatment. Dry filtration plants are known from the treatment of brewery wastewater and from the food and paper industries. Upflow bio-filters are mainly used in the paper industry, albeit mostly only for the degradation of carbon compounds and the removal of suspended solids. Further applications are known from the chemical industry and the mineral oil industry.

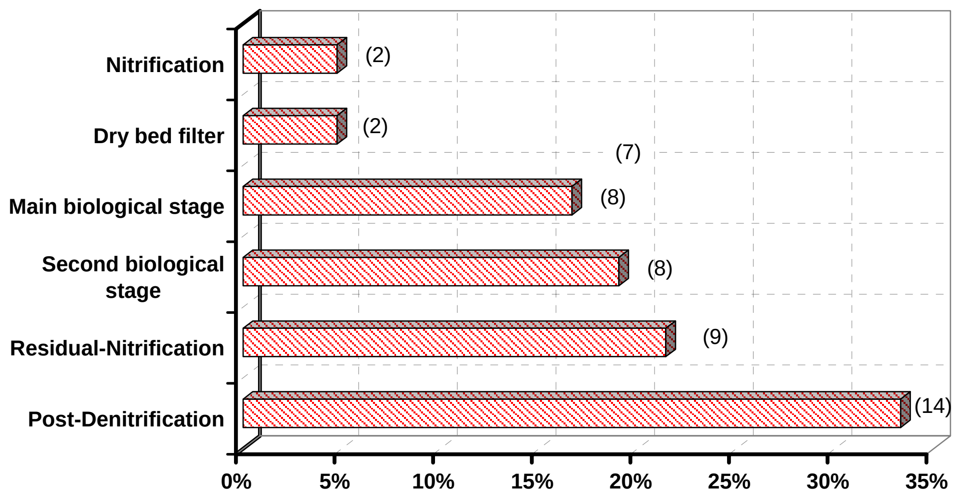

Figure 4: Distribution of bio-filters in municipal wastewater treatment in Germany in regard to their application purposes (total of 42, absolute numbers in brackets; date 12/2005)

Operation experiences

Purification performance

In order to estimate the purification performances and the achievable effluent concentrations, Table 1, gives the influent and effluent concentrations (as a rule annual means) of the respective bio-filters, arranged according to their application area.

Table 1: Average influent and effluent concentrations of municipal bio-filters

[mg/l]	COD_{in}	COD_{out}	NH_4-N_{in}	NH_4-N_{out}	NO_3-N_{in}	NO_3-N_{out}	$P_{tot,in}$	$P_{tot,out}$	TSS_{in}	TSS_{out}
Main biological stage (6 plants)	359	39	41.8	0.8	1.4 [1)]	7.8	3.1 [3)]	0.3	100 [3)]	12
Second biological stage (8 plants)	43	31	10.2	1.5	13.5 [2)]	6.1	1.0	0.4	44	11
Nitrification (2 plants)	88	53	36.4	0.9	1.0 [3)]	23.0 [3)]	1.2 [3)]	0.6 [3)]	38 [3)]	10 [3)]
Residual nitrification (11 plants)	42	31	2.5	0.5	5.3	7.0	0.8	0.3	11	5
Post denitrification (13 plants)	34	29	0.3	0.2	13.1	6.6	1.5	0.5	19	4

[1)] influent entire plant

[2)] Influent DN (partly calculated via the nitrifying ratio)

[3)] This value is but one example

The determined influent values can serve as dimensioning aid for future bio-filters, giving information about “what values do I have to reckon with? which loads can the filters deal with?”. The effluent values gain insights into the average values reached in practice; however, one has to keep in mind that the plants do mainly not achieve their maximum capacities, but are partly limited, for instance because of lower load periods or controlled target effluents, which means that bio-filters do at times work “with the brakes on”.

The achievable volumetric conversion performances are influenced by the specific wastewater composition, the temperature, the chosen method, the carrier material, the application purpose, etc. Compared to the activation method, under favourable conditions bio-filters reach considerably higher conversion performances.

Figure 5 presents the average nitrification capacity in relation to the NH_4-N-volumetric load of 15 nitrifying bio-filters from different application areas as examples. In the observed load range, the nitrification ratio achieved is almost 100% for all plants, with one exception in the second stage which contains only the winter operation and for which toned-down monitoring values apply (25 mg NH_4-N/l).

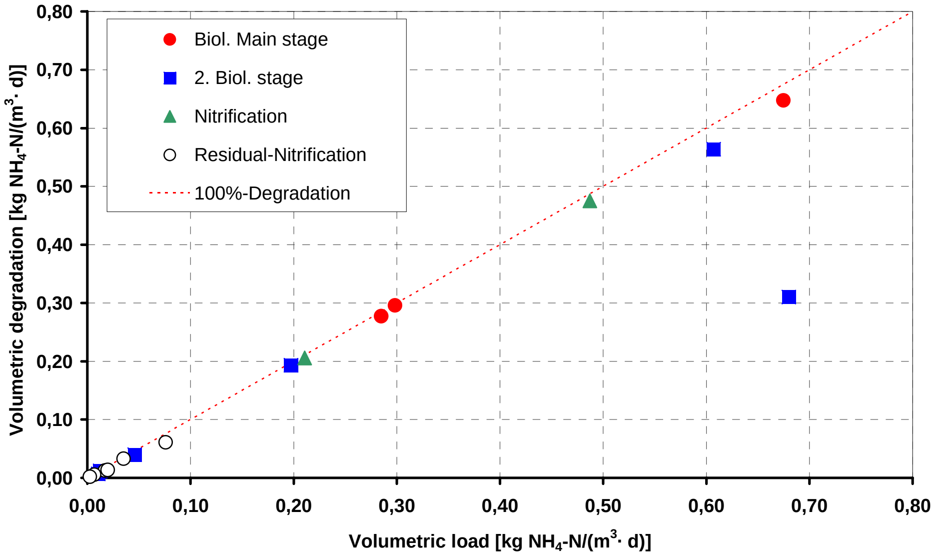

Figure 5: Average nitrification performance in dependence on the NH_4-N-volumetric load

In regard to denitrification, bio-filters show different performances, depending on the additional dosage of external substrate. Some filters achieve a conversion performance of almost 100%, other plants are at “limited” nitrate conversion purposefully set for NO_3-N effluent values adapted to the discharge permission. The external carbon source used is almost technical methanol.
The P-Elimination happens mainly in preliminary treatment stage, even though 63% of the plants are technically equipped to run phosphorous precipitation directly in or before the bio-filter.

Backwashing and filter running times

The filter running times are highest in the aerated filters for nitrification with up to 72 h, the reasons being lower loads and the slightly increased solids output. As a rule, one tries to achieve an operation with daily rinsing. Which rinsing methods are used is partly determined by the application of the respective bio-filter. For the denitrification filters, mainly through-flow or the so called flap backwashing is used, whereas nitrification filters are mostly backwashed in through-flow mode. Continuously washed bio-filters are used as well.
The backwashing water amounts related to the influent water amount vary between 8% and 14% for single-stage plants and between 15% and 33% for multi-stage bio-filters. Related to the installed filter area, the specific average value determined for the backwashing mode with flap was 6 $m^3/(m^2$ and washing process); for the through flow backwashing a slightly higher amount of 7 $m^3/(m^2$ and washing process) was found.

Energy demand

As technically controllable parameter, the energy demand will be discussed in the following predominantly in contrast to other biological wastewater treatment methods. The energy demand is mainly determined by the operation of the process air blowers (only for bio-filters with nitrification), the rinsing, and the influent pumps. The comparison with other methods presented in Figure 6 shows that the population-specific energy demands are lower; however, one has to keep in mind that most bio-filters only fulfil one of several wastewater treatment tasks.

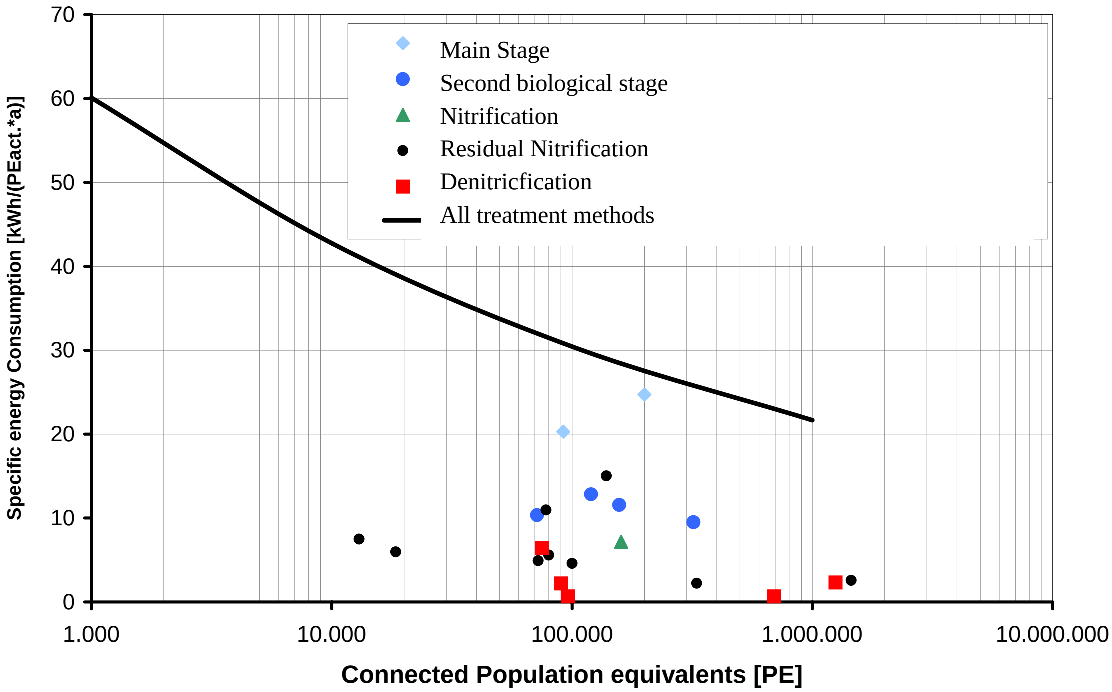

Figure 6: Specific energy demand in relation to the connected PEs and in comparison to other methods

The MURL (1999) states an energy demand for the activation of approx. 16 to 29 kWh/(PE·a) related to the number of connected inhabitants. These values are considerably lower than those determined by BARJENBRUCH (1997) for the bio-filter Nyborg (Denmark) of 40 kWh/(PE·a) to 60 kWh/(PE·a). Compared to the current energy demands of the main stages shown in Figure 6 (20 kWh/(PE·a) to 25 kWh/(PE·a), there results a corresponding dimension between activation plants and bio-filters. To compare the methods, the data of ROTH (1998) should serve, who for trickling filters found a range of 33,8 - 38,8 kWh/(PE·a) and for submerged beds values from 20,3 to 51,2 kWh/(PE·a). Generally, however, only few energy data of bio-filters as main stages are available, all of them referring to new plants.

Sludge production

In bio-filters, the major part of the solids in the backwash water is theoretically determined by the washed-out biomass, which corresponds to the surplus sludge production. For the calculation of the sludge production, representative measurements of the DS contents in the rinsing water are necessary, which is particularly difficult because the DS contents changes considerably in the course of the rinsing. This problem makes further research highly necessary, especially in regard to the detailed determination of the values for the activation method.

Table 2 presents an overview of data from reference literature.

Table 2: Comparison of surplus sludge production data /BARJENBRUCH and BOLL (2000) (supplemented)/

Spec SS production	Dimension	Method, reference literature
0,53 - 1,27	kg DS/kg $BOD_{eli.}$	Activation (ATV A 131 (2000))
0,75 (average)	kg DS /kg BOD_5	Trickling filter (ATV A 262 (2000))
0,4 – 0,6	kg DS /kg $COD_{eli.}$	BIOSTYR Nyborg, (C+N+DN) (Barjenbruch, (1997))
0,4/0,44	kg DS /kg $COD_{eli.}$	Aerobic Upflow/Downflow BAF (Pujol et al., 1992)
0,32 (average)	kg DS /kg $COD_{eli.}$	BIOFOR (C+ N) Bougy-Fechy-Perroy
0,4 – 0,8	kg DS /kg NO_3-$N_{eli.}$	Activation method (DN)[1)] (EPA, (1993))
0,55	kg DS / kg NO_3-$N_{eli.}$	DYNA-Sand (DN) [1)] (Barjenbruch et al. (1998))
0,17	kg DS /kg NO_3-$N_{eli.}$	Practical value downstream denitrification (estimated)

[1)] downstream denitrification

Operation failures

One has to differentiate between technical failures caused by the breakdown of conventional technology also used for other methods and disturbances which are specific to bio-filter systems.
Technical failures occur mainly with the MSR technology (35% of the days with failures), the pumps (28% of the days with failures), and the fittings (21%). The disturbances with the pumps were mainly due to the fact that often the optimal adjustment to the actually produced water amounts failed. The major failure source with the MSR technology was the operation of on-line measuring instruments, mainly because of the high maintenance efforts.
B*io-filter-specific operation failures* comprise all problems of the operation process (Figure 7 (21 bio-filters)) which were not caused exclusively by technical implements.

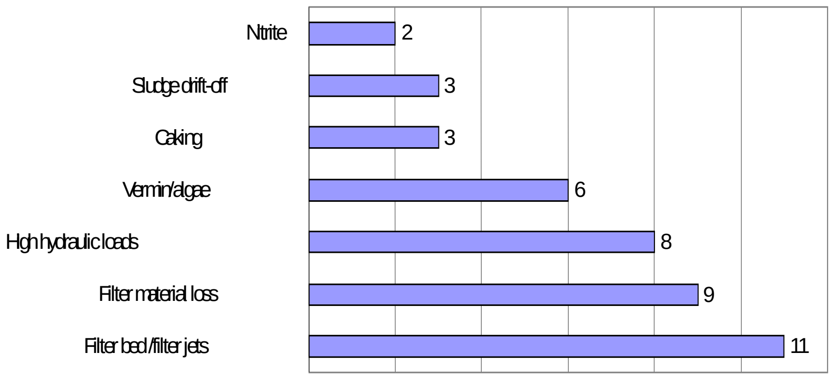

Figure 7: Disturbances of the operation process (absolute numbers)

In regard to the loss of filter material, the data vary from 0,8 to 7,5% per year. The average loss lies at approx. 3%/a, which corresponds to the manufacturers' information of 2% to 4% /HUBELE (1995)/ and other investigations /BARJENBRUCH (1997)/. Clogging and clotting of the material did in a few cases lead to considerable operation disturbances. Problems with increased nitrite emergence might occur with downstream denitrification.
The complete covering of bio-filters may lead to a deterioration of the gas exchange. Especially an accumulation of carbon dioxide was observed. Furthermore, in some plants a particular kind of foam appeared, which in uncovered bio-filters was emitted by wind. This foam is probably protein-containing foam similar to the spray of the ocean surf.

Operation costs

The operation costs of the bio-filters are comprised of (average percentage in brackets):

- Material costs (25%): Costs for external substrates, precipitation agents, plus lubrication agents and auxiliaries
- Energy costs (23%): Pumps, blowers, dosage implements, and fittings
- Personnel costs (21%): Operation, servicing, maintenance, and repairs
- Residue disposal costs (14%): Costs for sludge treatment and disposal
- Maintenance costs (9%): Personnel costs, material costs, and costs for external labour
- Other costs (8%): general administration costs, mail and telephone fees, costs for vehicles, costs for laboratory and office material, protective clothes, etc.

The determined wastewater-specific operation costs vary - depending on the application area – between 2,3 Cent/m³ and 10 Cent/m³. THØGERSEN and HANSEN (2000) found in the practical comparison to an activation plants operation costs which were approx. 15% higher, with sludge disposal and maintenance not considered.

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