



**TÍTULO DEL TRABAJO**

**PLANTED SOIL FILTERS FOR WASTEWATER TREATMENT ACCORDING TO  
NEW GERMAN GUIDELINE "DWA A-262"**

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### SUMMARY

The German guideline A-262 on constructed wetlands from 1998 has been completely revised recently and will be published in 2005. Because of continuously rising standards for discharge into sensitive watersheds great efforts have been made to improve the efficiency of natural like systems for wastewater treatment by means of planted soil filters.

This guideline refers to vertical and horizontal flow systems using sand as filter medium. The key factors for design and operation are discussed. The main issue of the guideline is to prevent the systems from overloading. In most cases a minimum surface area of 4 m<sup>2</sup> per person is recommended for vertical flow systems regarding German climate. For further nitrogen removal recirculation from vertical flow filter to anaerobic pre treatment can be calculated. Phosphorus removal is a matter of filter media and periodical exchange may be necessary.

### KEY WORDS

Constructed Wetlands, Subsurface Flow, Biofilter, Sand Filter, Key Factors

### RESUMEN

El manual alemán A 262 para humedales artificiales de 1998 fue revisado totalmente y será publicado en 2005.

Este manual trata de humedales con flujo vertical y horizontal, que usan arena como material filtrante. En este manual los coeficientes básicos para diseño y operación son discutidos. Lo principal es proteger los sistemas contra sobrecarga. Frecuentemente los sistemas con flujo vertical requieren un área de 4 m<sup>2</sup> por persona con respecto al clima de Alemania. Para la remoción del nitrógeno se puede calcular una recirculación entre el filtro del flujo vertical y el pretratamiento anaeróbico. El material filtrante se encarga de la remoción del fosfato. Por lo que se debería cambiar el material periódicamente.

### PALABRES CLAVES

Humedal, filtro de arena, filtro biológico, flujo subterráneo, valores básicos

## 1. INTRODUCTION

The German guideline A-262 (ATV, 1998) on constructed wetlands has been completely revised recently and will be published as DWA A-262 in 2005. A separate DWA guideline M-178 dealing with treatment of combined sewage overflow (CSO) in constructed wetlands is in preparation (Uhl and Dittmer, 2004). There is a 15 years history of subsurface flow vegetated sand filters development, employment and regulation in Germany. Because of continuously rising standards for discharge into sensitive watersheds great efforts have been made to improve the efficiency of natural like systems for wastewater treatment by means of planted soil filters.

Within the last decade there has been a move from the use of simple horizontal flow systems to more technical vertical flow ones and various combinations. The preferred filter medium has changed from very fine grain sizes including clay and humus material to a moderate coarse sand. Since the biological treatment is based on biofilm it is important to bring in as much surface area as possible (biofilter). This can be achieved by using a fine substrate. On the other hand there is a continuous chemical exchange with the substrate itself. Carbonate is buffering the nitrification process and phosphorus can be precipitated or adsorbed to calcium, iron or aluminium rich filter media. Suspended solids are filtered at best by fine grain sizes and the high hygienic performance of slow sand filter systems is well known from drinking water processing. The further retention of nitrogen, ammonium and phosphorus as well as of pathogens has been of special interest in several investigations of the last years.

## 2. MATERIAL AND METHODS

A literature review on subsurface flow constructed wetlands was done in order to define the key factors concerning performance and longevity of planted sand filter systems as being used

in Germany (Rustige, 2003). The state of the art already had been investigated in a joint research project called "vegetated soil filters" from 1998 to 2002 (Fehr et al, 2003). The objective had been the intense monitoring of several demonstration sites over a three years period of time as well as the evaluation of treatment wetlands being in operation for at least 3 up to 15 years.

The philosophy of the new guideline is to fulfil the following needs in this order:

1. Determine maximum organic (i.e. oxygen demand) loading rates in order to avoid clogging
2. Meet hydraulic needs
3. Optimise oxygen input
4. Optimise operational factors
5. Go for enhanced performance (nutrients)

The wetlands according to guideline A-262 are characterised by horizontal flow, use of sand as filter medium and restriction to pre-treated wastewater. The key factors for design and operation and their recommended values are (draft version 2004):

Type of filter medium: sand  $0,2 \text{ mm} \leq d_{10} \leq 0,4 \text{ mm}$ ; uniformity  $U < 5$ ;  $k_f ? 10^{-4} - 10^{-3} \text{ m s}^{-1}$

Filter thickness:  $H \geq 0,5 \text{ m}$  (for vertical flow (VF) or horizontal flow (HF))

Drainage layer: VF:  $H \geq 0,2 \text{ m}$

Treatment area: HF:  $a \geq 5 \text{ m}^2$ ; VF  $a \geq 4 \text{ m}^2$  (SWTP < 50 pe, otherwise loading limits)

Loading rates: HF:  $\text{COD} \leq 16 \text{ g m}^{-2} \text{d}^{-1}$ ; HLR  $\leq 40 \text{ mm d}^{-1}$   
VF:  $\text{COD} \leq 20 \text{ g m}^{-2} \text{d}^{-1}$ ; HLR  $\leq 80 \text{ mm d}^{-1}$  (< 12°C);  
HLR  $\leq 120 \text{ mm d}^{-1}$  ( $\geq 12^\circ\text{C}$ )

Intermittent loading: VF: time interval  $\geq 6$  hours; flow  $> 6 \text{ l m}^{-2} \text{ min}^{-1}$ ; each load  $> 20 \text{ mm}$

### 3. RESULTS

#### *COD/BOD*

There is no doubt about the high efficiency on reduction of COD and BOD by means of subsurface flow constructed wetlands. The investigation of VF- and HF-systems in operation for several years (Fehr et al, 2003) showed a good and stable performance. The expected COD performance is about 85 percent. That means a COD effluent concentration below 150 mg/l is to expect if inlet concentration is less than 1000 mg/l. The median COD of all systems was 41 mg/l.

#### *Organic load*

The limit on organic loading of sand filter systems is derived from Winter (2003). He found a significant influence of organic load and suspended solids concentration in wastewater on filter clogging. He had investigated vertical flow systems under operation conditions and defined three different states: unclogged, partially clogged and completely clogged.

Although there may exist more factors leading to clogging of vertical flow sand filters there is a higher risk when TSS in the wastewater exceeds  $100 \text{ mg l}^{-1}$  or TOC concentration is higher than  $140 \text{ mg l}^{-1}$ . There also seems to be a limit of COD load of  $20 \text{ g m}^{-2} \text{ d}^{-1}$  as proposed by several authors. COD limit was chosen as the key parameter for prevention of clogging. The interpretation of the process is a blocking of surface by suspended solids and the blocking of pores by biomass growth depending on substrate concentration. It could be shown by Maciel (2004) that microbial extracellular polymeric substances (EPS) are also responsible for pore clogging. This can be reversed by interrupting operation for some time. For that reason there always should be parallel filter beds which can alternately be switched from operation to rest.

**Tab 1. Factors for clogging of VF sand filter systems derived from 21 cases by Winter (2003)**

	<b>LOADING RATES/ CONCENTRATION</b>	<b>UNCLOGGED (N=10)</b>	<b>PARTIALLY CLOGGED (N=5)</b>	<b>COMPLETELY CLOGGED (N=6)</b>
<b>TSS</b>	<b>G/M<sup>2</sup>/D</b>	<b>&lt; 4</b>	<b>&gt; 1</b>	<b>&gt; 6</b>
	<b>MG/L</b>	<b>&lt; 90</b>	<b>&gt; 65</b>	<b>&gt; 100</b>
<b>COD</b>	<b>G/M<sup>2</sup>/D</b>	<b>&lt; 16</b>	<b>&gt; 3</b>	<b>&gt; 21</b>
	<b>MG/L</b>	<b>&lt; 350</b>	<b>&gt; 250</b>	<b>&gt; 400</b>
<b>TOC</b>	<b>G/M<sup>2</sup>/D</b>	<b>&lt; 3,9</b>	<b>&gt; 2,5</b>	<b>&gt; 4,2</b>
	<b>MG/L</b>	<b>&lt; 80</b>	<b>&gt; 90</b>	<b>&gt; 140</b>
<b>DOC</b>	<b>G/M<sup>2</sup>/D</b>	<b>&lt; 2,2</b>	<b>&gt; 1,2</b>	<b>&gt; 2,2</b>
	<b>MG/L</b>	<b>&lt; 50</b>	<b>&gt; 45</b>	<b>&gt; 50</b>

### *Hydraulic load*

Kayser (2003) investigated the nitrification process in VF sand filters and hydraulic loading rates. When the organic load was within the above shown limits then a maximum hydraulic loading rate (HLR) of up to 120 mm d<sup>-1</sup> was acceptable for sufficient oxygen input. When monitoring and regulating the batch feed by oxidation-reduction-potential a HLR of 180 mm d<sup>-1</sup> was acceptable. Depending on the grain sizes of the filter sand it can take up to six hours for dewatering after each batch feeding. This time is necessary for aeration of the filter bed. So for optimum oxygen input there should be no more than four batches on each filter bed per day. It has to be considered that the flux is very much depending on temperature or viscosity of water respectively.

### *Nitrification*

Nitrification has been investigated at VF-systems. If nitrification is poor it usually means a lack of oxygen input. In consequence there is a decrease of aerobic degradation and an increase of sludge in the filter. This can cause severe clogging which may not be possible to regenerate easily. Kayser found that the ammonium/nitrate concentration which is coherent with oxidation-reduction potential is a crucial parameter for good operation of VF sand filter systems.

No limit of TKN mass loading for nitrification can be shown so far. This of course depends on the content of carbonate within the filter sand and wastewater respectively. With a carbonate poor sand good nitrification rates up to TKN loads of 11 g m<sup>2</sup> d<sup>-1</sup> could be achieved (Kayser, 2003). It could be shown in praxis that a minimum filter layer of 30 cm sand was sufficient for good nitrification at all TKN loading rates. The nitrification efficiency was about 90 percent when temperature was higher than 10 °C.

### *Nitrogen removal*

Nitrogen removal takes place in horizontal and vertical flow systems. Platzer (1998) suggested from his experiments that alternative pathways for denitrification and nitrification play an important role in sand filter wetlands because they are very low loaded systems compared to technical processes. In VF systems - designed for nitrification - nitrogen removal rates of 20-40 percent were found (Fehr et al, 2003). Several attempts on enhancing denitrification rates in VF systems failed. The general problem is the very good performance on TOC-removal when nitrification is sufficient. This means a lack of carbon for the heterotrophic process. When a horizontal flow filter is used a better nitrogen removal rate can

be expected in the first place. 50 percent of monitored HF sand filters showed a mean nitrogen removal rate of more than 48 percent (Fehr et al, 2003).

For a good design on denitrification the classical pre-denitrification process has been proofed to work out very well by several authors. A vertical flow filter was combined with recirculation over simple unstirred reactors like settling tanks or ponds. For a 75 percent reduction of total nitrogen a 3fold recirculation rate can be calculated. Practical experiments showed that a recirculation rate of greater than 2 was not useful since the denitrification rate within the VF systems decreased with higher loading rates at the same time. In any case the VF stage has to be designed for the higher hydraulic loading rates regarding a maximum of nitrification.

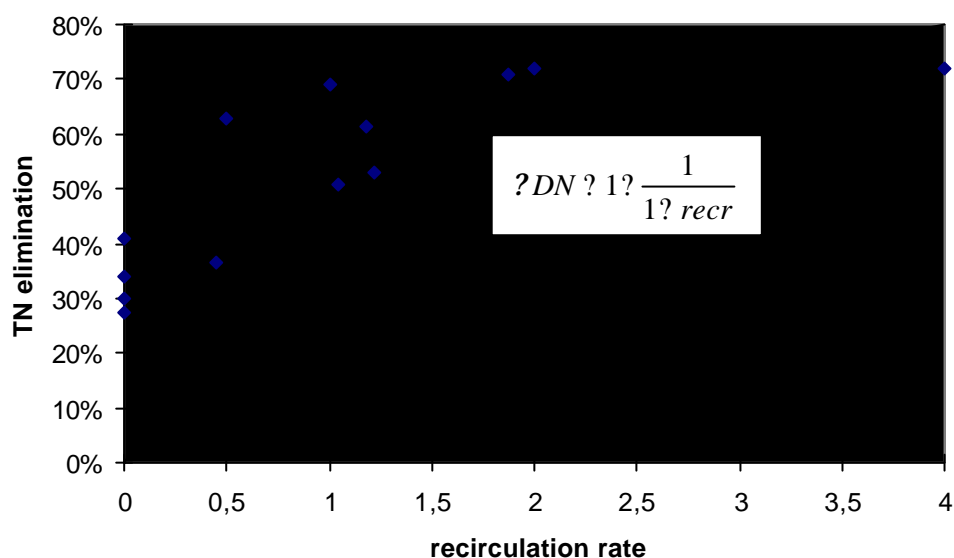


Fig. 1 Denitrification by recirculation and ordinary function of activated plant process

If the VF system is supplemented with a succeeding HF sand filter post denitrification can be achieved. It is useful to add settled wastewater from the first stage bypassing the VF. In that case the lack of carbon within the HF reed bed can be minimised. For special wastewater like landfill leachate a separate carbon source like acetic acid has been added very successfully in our practical experiments. By this means the TN concentration could be reduced from median concentrations of 255 mg l<sup>-1</sup> down to 56 mg l<sup>-1</sup> over a 15 month period of time from Feb 04 until May 05 (n = 26). The performance ranged from 70 percent (in at least 85 percent of all cases) up to 93 percent at maximum.

#### Phosphorus removal

The best removal efficiency of phosphorus in subsurface flow wetlands was observed from HF systems with hydraulic loading rates of 10 mm d<sup>-1</sup> or less (Rustige et al, 2003). There was found a high phosphorus content in humus and sludge within the inlet area of some investigated reed bed systems. The accumulation of phosphorus in wetlands is reversible. The equilibrium concentration of the aqueous phase rises continuously with the amount of total accumulated phosphorus within the filter medium. That means P removal then only takes place with increasing input concentrations. Higher amounts of Fe- and Al-hydroxides as well as Ca and total organic matter show a positive effect on phosphorus retention. The correlation

of phosphorus within filter media with cation exchange capacity and organic matter indicates that the building of unspecific compounds including metals and humus substances is relevant in sand filter systems. Thus in order to improve the P retention of SSF wetlands humification should be supported. This is not possible with intermitted loaded VF-systems but in HF systems. A good phosphorus retention could also be achieved by a separate phosphorus sorption filter (following HF reed bed) containing filter sand with high Fe hydroxide contents from drinking water filtration which was tested at Wiedersberg wetland. The performance of the filter was approximately 67 percent (average) at input concentrations of 0.5 to 3 mg l<sup>-1</sup> within first three years.

### Pathogens

The reduction of pathogen or indicator micro-organisms by sand filter treatment was investigated by Hagendorf (Fehr et al., 2003). They found the best elimination rates in two stage VF/HF systems reaching the order of 3 to 5 log whereas one stage systems only were half as good. The performance was depending on long term hydraulic loading rates. The elimination of pathogens decreased when 120 mm d<sup>-1</sup> had been exceeded for several days. Short hydraulic overloads had no negative impact though. When input concentrations were very high the elimination rate was high as well - not depending on hydraulic loading rates.

At regular operation the effluent of two stage sand filter constructed wetlands met the hygienic parameters of EU guidelines on bathing water and on agricultural irrigation. The comparison of 15 different microbiological parameters such as bacteria and phages within more than 3 700 analyses showed that *E.coli* is a convenient parameter for cost effective and representative evaluation of the microbiological efficiency of subsurface flow wetlands.

The hygienic performance of sand based reed beds may be elucidated by Fig. 2. The removal of representative indicator organisms within two sequencing subsurface flow stages reached values of 3 to 4 powers of ten.

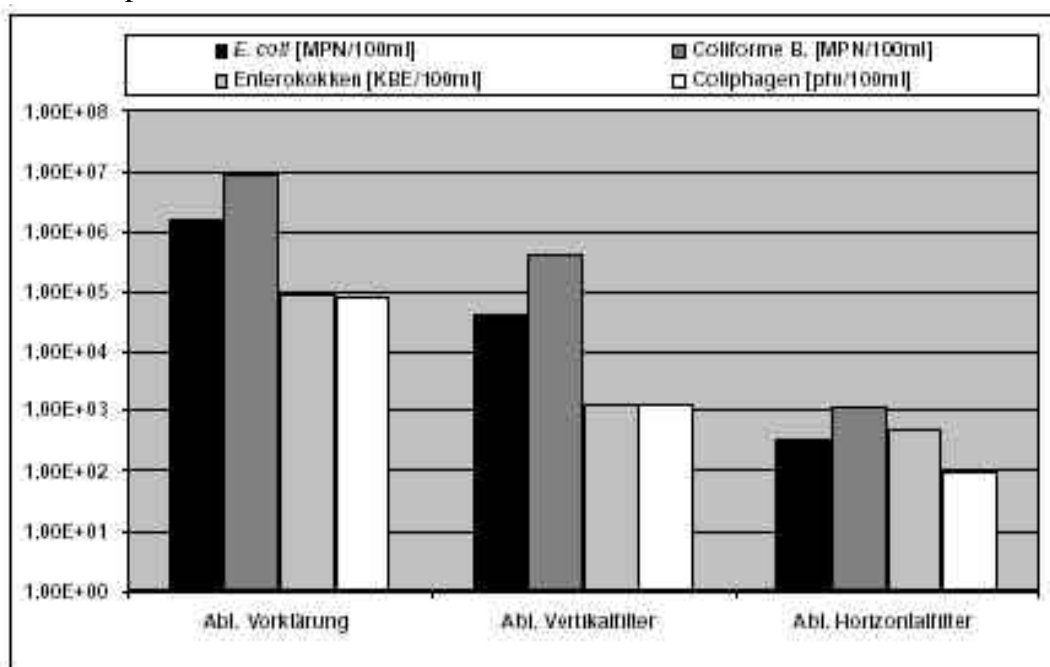


Fig. 2 Mean pathogen concentrations in the effluent of settling tank (Abl. Vorkl.), VF (Abl. Vertikalf.) and HF (Abl. Horizontalf.) of the constructed wetland at Wiedersberg, at more than two years of monitoring. FEHR ET AL. (2003)

#### 4. DISCUSSION

The long time experience with sand based horizontal and vertical flow constructed wetlands in Germany has lead to design criteria which make operation of constructed wetlands with fine filter media safe. The system is optimised for use with pre-treated wastewater. Design parameters for aerobic treatment are specific to surface area and not to volume. This is also the case for vertical flow systems which show most biological activity at the near surface. It has to be taken into account that the filter systems in Germany are designed to overcome long periods with low temperature and low degradation activity. In spring time when water temperature rises above 10 °C there is a high oxygen demand while pores are getting filled up by fast growing biomass. Every year the maximum ammonium concentration can be watched between April through May indicating a lack of oxygen. The investigations of sand filter systems have shown the importance of effective pre-treatment. The optimum system configuration for COD removal seems to be a VF gravel bed for removal of sludge followed by a VF or HF sand filter depending on further reduction aims.

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