SOIL CLOGGING IN VERTICAL FLOW REED BEDS - MECHANISMS, PARAMETERS, CONSEQUENCES AND ..... SOLUTIONS?

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ABSTRACT

The purification efficiency of vertical flow reed beds (VFB) is dependent on a very efficient soil aeration. In most systems this is achieved by intermittent pulse loading at the surface providing an oxygenation by massflow and diffusion. These oxygen transportation mechanisms only function as long as the upper layers of the bed have a high drainage capacity. Purification efficiency drops significantly when constant ponding occurs.

A review of the literature on clogging in sand filters is given. In own evaluations the following observations are made: Clogging occurs only in the upper 0-15 cm of the bed. Clogging is dependent on the height of organic mass loading. The content of volatile solids in the upper layers could not be proven as a significant parameter influencing clogging. The infiltration rate can be restored by giving the beds a recovery period of several weeks. The required length of rest is dependent on weather conditions, winter is the most critical time.

KEYWORDS

Infiltration rate, oxygen demand, soil air, soil clogging, subsurface flow, vertical flow beds, volatile solids, soil air

INTRODUCTION AND DESCRIPTION OF THE PROBLEM

Vertical flow reed beds (VFBs) have become more and more common during the last years. Due to their high purification efficiency and relatively small land requirement, they are attractive in situations where other natrural systems can not be applied. The dimensioning of the VFBs varies widely between 1-2 m²/p.e (COOPER & BREEN, 1994) and 5 m²/p.e. (PERFLER et al., 1996).

The purification efficiency of VFBs is mainly based on very efficient soil aeration. Therefore BOD, COD and ammonia removal is high, but N_{tot} -elimination is limited. In most systems the soil aeration is achieved by intermittent pulse loading at the surface providing an oxygenation by massflow and diffusion. The mass flow mechanism only function as long as the upper layers of the bed have a high drainage capacity and the surface of the bed dries out between two loadings.

Therefore the purification efficiency drops significantly when soil clogging and continuous ponding occurs (KUNST & FLASCHE, 1995; PLATZER, 1995).

When clogging occured in some of the VFBs this was new to the authors, as during the pre-tests no clogging was observed. In literature on VFBs most authors do not report observations concerning clogging with the exception of COOPER & BREEN (1994).

MECHANISMS OF SOIL CLOGGING

Soil clogging is a very well known natural effect in sand filtration, but the results of the studies concerning clogging differ widely. A review of the literature on soil clogging was carried out in order to identify the mechanisms and the most important factors affecting soil clogging.

The hydraulic capacity of soils is dependent on the amount of the hydraulic usable pore volume. The following mechanisms mainly influence this volume or reduce the infiltration rate and are therefore to be considered in an evaluation of soil clogging:

- Deposition of organic and inorganic solids at the surface, developing into a clogging mat and leading to outer blockadge of soil pores (surface filtration); deposition at the grain surface in the pores, leading to inner blockadge (volume filtration) (LÖFFLER, 1969; DE VRIES, 1972).
- Biomass production and excretions in the soil pores due to a constant nutrient supply in the wastewater (AVNIMELECH & NEVO, 1964; BAAKE, 1985). In order to maintain a long term functioning of a VFB production and mineralisation of biomass have to be in an equilibrium state. The volume of biomass is more important concerning clogging than the dry weight.
- Chemical precipitation and deposition in the pores

The reduction of the infiltration rate is described in the literature as a process with different phases (JONES & TAYLOR, 1965;OKUBO & MATSUMOTO, 1983; SIEGRIST & BOYLE, 1987). Mostly two or three phases are distinguished but defined differently.

Factors influencing soil clogging

As the distribution of grain size of the filter material has a determinating influence on pore size and hydraulic capacity, it is obivous that it has a major influence on the soil clogging. The grain size is important as well for soil recovery. DE VRIES (1972) found that the oxygen concentrations in coarse sand returned to the starting values more quickly than in fine sand.

Although a strong influence of the organic load is widely accepted (SIEGRIST & BOYLE, 1987; JONES & TAYLOR, 1965; LAAK, 1986; OKUBO & MATSUMOTO, 1983), the conclusions drawn differ. The reason for this has to be seen in the different conditions in which the experiments are carried out. The experiments of SIEGRIST & BOYLE (1987) and DE VRIES (1972) indicate a strong influence of the oxygen supply on the soil clogging, whereas LAAK (1986) states that clogging is only dependend on the organic load before reaching an equilibrium state. For planted soil filters Löffler (1992) reports loadings up to 40 g/m²/d BOD_5 which he deduces from experiments carried out at planted soil filters for groundwater recharge.

Besides the organic loading, the loading of suspended solids (SS), especially non-biodegradable SS, is one of the main factors which influence soil clogging (LÖFFLER, 1969; SIEGRIST & BOYLE, 1987; OKUBO & MATSUMOTO, 1987; LAAK, 1986).

The influence of temperature on soil clogging is discussed controversely (DE VRIES; 1972; OKUBO & MATSUMOTO , 1983). Higher temperatures result in higher biological activity and higher growth rates. On the one hand this results in a quicker degradation of the organic matter filling the pores, on the other hand the soil pores are filled by a higher content of biomass.

The influence and effects of different loading cycles are also discussed controversly. Several authors state that intermittent loading cycles are better for soil aeration and therefore lead to quicker biodegradation of organic load. Keeping the soil under aerobic conditions is seen as a possibility to control the clogging process (DE VRIES 1972; KUNST & FLASCHE, 1995). KRISTIANSEN (1982) observed quicker soil clogging when he loaded his filters intermittently.

Apropriate lengths of recovery periods are reported by BOUWER et al. (1974). They found a length of 10 days for summer conditions whereas 20 days were needed in the winter.

METHODS

The water content was measured useing the TDR (time domain reflectrometric) method (PLAGGE, 1993). This method allows direct onsite measurements of the water content of soils by using the dielectric determination of moisture. The method is very precise, the precision is about ± 1%.

For measuring O_2 and CO_2 contents in the soil air an own method was developed. The samples are taken out of the soil at depths of 10, 30 and 50 cm using high-grade steel pipes of 5 mm diameter. In order not to influence the soil air balance the volume taken out has to be kept as small as possible. The experiments showed that a volume of 0.5 l is sufficient for the analysis. For the analysis of the O_2-content a conventional oxygen electrode (WTW Oxi 96) for the measurement of oxygen in water is used, which was first tested for the application in air.

The infiltration tests were carried out using the Open-End test developoed by the US Bureau of Reclamation (SIEKER & HARMS, 1987). This method is a very simple mean to measure the onsite infiltration rate without disturbing the soil filter. The test was slightly modified for application for measurements at the surface. Measuring the infiltrated water per time and the hydraulic head the infiltration rate K can be calculated. The method serves quite well as long as the reed is not too dense.The infiltration rates measured onsite differ almost by a factor of 10 from the hydraulic capacities calculated by grain size using the equation developed by BEYER (1964). The reason are remaining unsaturated areas even after longer (several hours) wetting periods.

The soil samples for the volatile solids and deposits are taken using a drill. For most parts 4-5 samples are taken at the surface of a VFB. The samples are kept at 4 °C until analysis. For the analysis the sand is mixed with water and put into an ultrasonic bath for 20 min. The mixture is stirred up and after sedimentation of the sand it is decanted several times until the water remains clear after stirring. Both the sand and the deposits are dried at 105 °C and weighted in order to obtain the dry matter. The relation between the weight of the deposits and the sand is expressed in mg deposits/g sand. This method does not distinguish between deposits and silt. Therefore the initial content of deposits is needed, in order to calculate the rise of deposits. The volatile solids were analyzed according to the DIN 38414 part 3.

RESULTS

The measurements are carried out at pilot plants for 150 p.e. (Ließen) and 330 p.e. (Merzdorf). Desgin and layout of the two plants are described elsewhere (PLATZER, 1996). Table 1 shows the range of soils used. Sand A is a medium sand having a d_{10} of 0.21 mm and a uniformity (U) of 4. The Sand-Bentonite mixture consists of sand A mixed with 4% Bentonite. Sand B and C are finer than Sand A.

Initial hydraulic capacity was sufficient with all sands. The purification efficiency of the soil and the sand mixed with bentonite was significantly better than the purification efficiency of the sand A (Platzer, 1995a), but the infiltration rate in the beds filled with soil decreased quickly and continous ponding was observed. In autumn 1994 clogging occurs as well in some of the sand filled beds (Sand A and Sand-Bentonite) at the plant Merzdorf (PLATZER, 1995b) In order to determine the factors responsible for the clogging various tests were carried out.

Table 1: Characterisation of the soils used at Merzdorf and Ließen

Plant	Type of sand	d10 [mm]	U d_{60}/d_{10}	Porosity [%]	hydraulic capacity after BEYER [m/s]
Merzdorf	Soil	0.007-0.015	17-36	32-36	-
	Sand A	0.21	4.0	32-34	$4.0*10^{-4}$
Ließen	Sand B	0.11	4.5	31-38	$0.8*10^{-4}$
	Sand C	0.095	4.2	32-37	$1.1*10^{-4}$
Both plants	Sand-Bentonite	0.10	6.3	31-33	$0.8*10^{-4}$

Tests of the drainage behaviour in vertical flow beds

As the high purification efficiency of VFBs is dependend on an effective soil aeration, tests were carried out to understand the drainage behaviour between two pulse loadings more fully.

Figure 1 shows the changes in the water content at different depths (10, 30, 50 cm) of a VFB filled with sand C in Ließen. The VFB is a bed with a high hydraulic capacity. At a depths of 10 cm a strong rise in water content can be observed during and immediately after the pulse loading. The water content increases from 14 % to 31 %, which is close to saturation. After 3 hours minimal pore water content is attained again. The greater the depths the slower the rise is and the smaller the difference is between highest and lowest moisture.

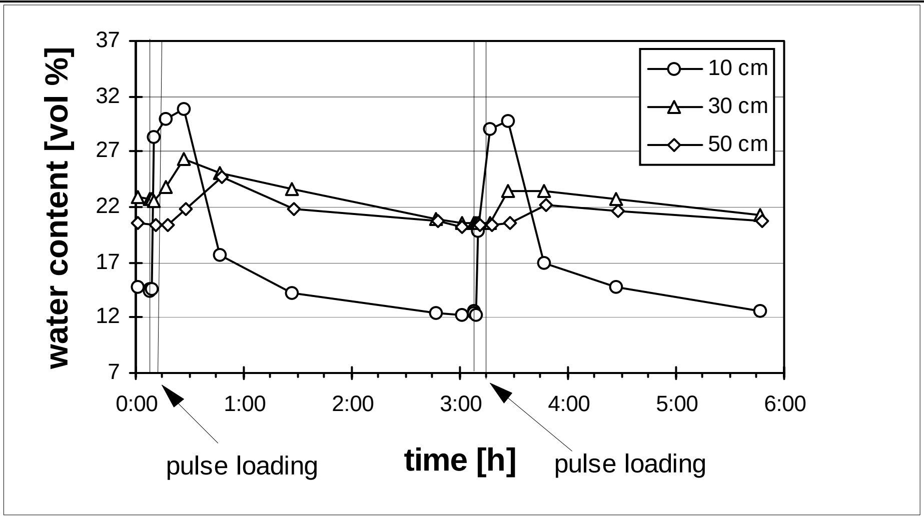

Figure 1: Drainage behaviour of a non-cloggeed VFB filled with sand B (VOLL 1995)

Figure 2 is analogous to Figure 1, but the observed area of VFB filled with sand A in Merzdorf was clogged. Hardly any change in water content can be seen during a loading cycle. The water content at the depths of 10 and 50 cm is close to saturation and the water content at 30 cm depth is close to minimal pore water content. This shows that soil clogging in VFBs occurs only at the surface. The purification efficiency of VFBs is affected strongly by intermittent loading and a sufficient drying time between two pulses. This is due to the need of oxygen transport into the soil by mass and diffusive transport. The purification efficiency for NH_4-N drops significantly when continuous ponding occurs at the surface (KUNST & FLASCHE, 1995).

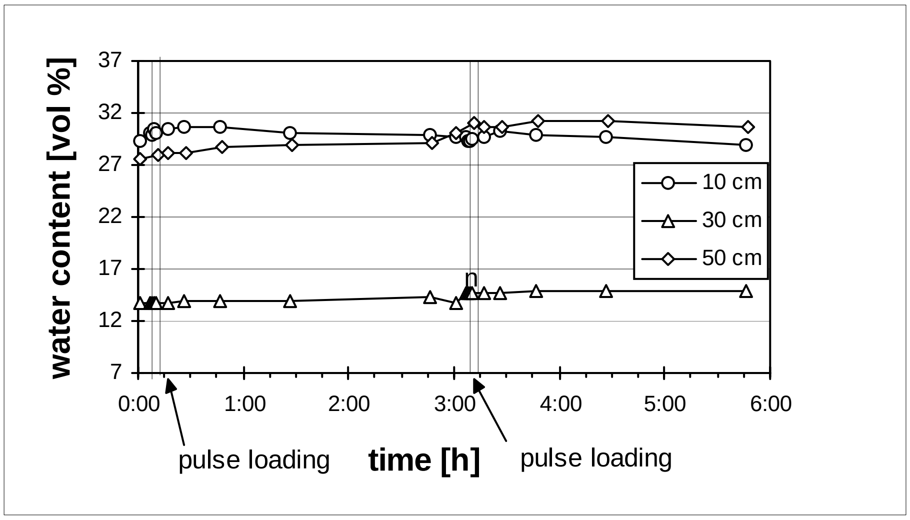

Figure 2: Drainage behaviour of a clogged VFB filled with sand A (VOLL 1995)

Oxygen supply in vertical flow beds

Oxygen transport in the VFB is mainly achieved by masstransport and diffusion. In order to choose the appropriate loading intervals for the VFBs it is important to have a better understanding of the process which contributes most to soil aeration.

The typical percentages in natural soils range from 10 to 20 % O_2 and 2-5 % CO_2 (SCHEFFER & SCHACHTSCHABEL, 1988). Tests in beds which were not operated for 5 month resulted in O_2-percentages of 19-20 % and <1-2 % CO_2 for all depths (Table 3) (VOGEL, 1996). Under loading conditions of 2 loadings per day the O_2 content drops from 4-6% in 10 cm to 2-3% in 50 cm, while the percentage of CO_2 rises from 5-7% (10 cm) to 6-8% (50cm) (Table 3).

At all depths the higher contents for O_2 where found at the plant at Ließen. At the plant at Ließen the wastewater has relativly low concentrations (COD 390 mg/l, N_{ges} 76 mg /l), but the hydraulic load is high. At the plant at Merzdorf the concentrations are high (COD 690 mg/l, N_{ges} 123 mg /l) but the hydraulic load is much lower than in Ließen. This observation leads to the conclusion, that the mass transportation process is very significant for the total oxygen supply.

Under clogging conditions the O_2 content is almost zero in both plants at all depths (Table 3).

The sum of O_2 and CO_2 percentage is much lower than the expected 21 %., typically it ranges between 13 and 17 %. Random samples showed, that the difference is explained by the content of nitrogen, which is >80 %.

Table 3: O_2 and CO_2 percentages at different depths of the VFBs at different loading conditions

Soil air contents of the VFBs at different depths	Merzdorf unloaded [%]	Ließen unloaded [%]	Merzdorf 12 hour-cycle [%]	Ließen 12 hour-cycle [%]	Merzdorf clogged [%]	Ließen clogged [%]
O_2 in 10 cm	17,8	20,6	5,3	7,0	0,7	1,6
O_2 in 30 cm	19,8	20,2	2,4	4,6	0,8	1,1
O_2 in 50 cm	19,6	19,9	1,8	3,0	0,8	1,0
CO_2 in 10 cm	1,5	< 1,0	6,7	5,3	7,8	2,3
CO_2 in 30 cm	1,1	< 1,0	7,9	5,6	6,7	3,4
CO_2 in 50 cm	1,3	< 1,0	8,3	6,1	6,4	3,4

Infiltration rate

Soil clogging is not a problem as long as a sufficient infiltration rate can be obtained again by resting the bed. Infiltration rate tests were carried out under different loading conditions in order to obtain experience about appropriate loading and recovery cycles. Figure 4 shows some of the results achieved in different loading situations. The infiltration rate dropped from about $1\text{-}2 \cdot 10^{-5}$ m/s to about $5\text{-}12 \cdot 10^{-7}$ m/s. A dependence of the total amount of loaded DOC since the last recovery on the infiltration rate can be seen (MAUCH, 1996). It has to be taken into account,

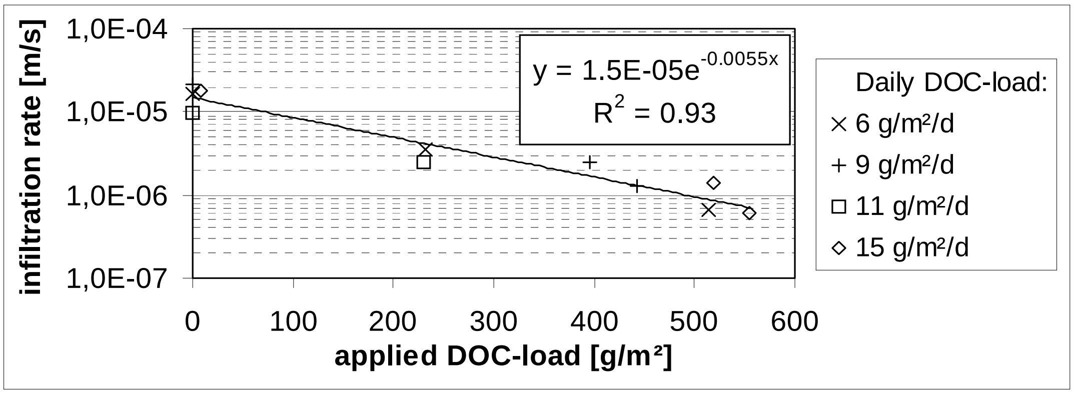

Figure 4: Infiltration rate in relation to applied DOC load since the last recovery period

that these data are gained only from the plant at Merzdorf (highly concentrated wastewater) and are not confirmed by tests with other wastewaters. The most important observation is an almost complete restauration of the infiltration rate of the beds when they are rested. The infiltration rate rises from the low values reported above back to capacities of about 10^{-5} m/s. Hence it is not possible to establish the required length of a recovery period. It depends on the weather and climate conditions. Cold and wet situations prolong the needed recovery period.

Volatile solids and deposits in the soil

Searching for a parameter which would allow the development of the clogging to be predicted the volatile solids and deposits in the soil were measured and compared with the infiltration rate (Figure 5). No relation between those two parameters was found. On the contrary the content of volatile solids was often higher after recreation than during loading periods. It may be concluded that form and distribution of volatile solids in soil pores are more important with regard to the infiltration rate than the total amount of volatile solids.

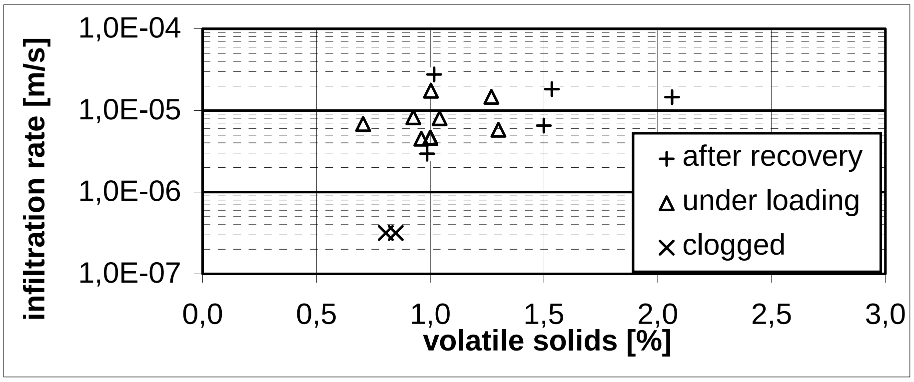

Figure 5: Volatile solids at a depth of 10 cm plotted versus infiltration rates under different operating conditions

CONCLUSIONS FOR DESIGN, CONSTRUCTION, MAINTENANCE AND FURTHER RESEARCH

Soil clogging is a process which takes place in all highly loaded systems. The oxygen demand is a very important factor but the mechanisms of clogging are not completely understood. The total organic load seems to be less important concerning soil clogging than the concentrations.

As systems with relatively low loadings do not show any clogging the maximum load for prevention of clogging should not exceed 25 g COD/m²/d under the climate conditions of Central Europe. The systems can be loaded higher when operated with recovery cycles. The clogging process is reversible but concerning the apropriate length of loading and recovery periods more knowledge has to be gained. In order to enable recovery periods, the total area of VFBs should be divided into at least 2 better 4 sections.

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