New generation of biological upflow filtration for the treatment of industrial and municipal wastewater

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1. Introduction

The application of aerated biological upflow filtration in waste water treatment goes back to the beginning of the 1980s. Since that time, filtration technology has already been used successfully as the principal unit in the treatment of potable water in order to eliminate suspended solids.

The long term positive experience regarding the application of filtration in the treatment of potable water was transferred to waste water treatment. The aim was to achieve mechanical filtration and elimination of dissolved organic and inorganic pollutants, such as BOD and nitrogen in the same reactor.

In this respect, different technologies regarding the biological filtration of waste water were developed, such as upflow and downflow filters including or excluding aeration, as well as different filtering media (Tchobanoglous, 2005). Practical experience with numerous filtration plants in waste water treatment has shown that aerated biological upflow filtration (co-current flow) is currently considered to be the best and most reliable biofiltration technology (Sekoulov, 1996).

As regards the treatment of waste water, the first biofiltration plants were established in the 1980s. Presently, more than 500 plants are in operation in order to treat municipal and industrial waste water (Rogalla, 2003). The most important advantages of biological filtration are high volumetric loads, low outflow concentrations and low space requirements.

Although biofiltration technology boasts several advantages compared with conventional technologies (activated sludge, for example), biofiltration technology could, for economic reasons, not be realised in small and medium-sized plants before now. The reason for this is the fact that biofiltration technology was initially developed for municipal waste water treatment plants of big cities with hydraulic loads above approx. 1,000 m³/h.

Examination of the investment costs of conventional biofilters shows, that the purchase of backwashing equipment consumes most of the money.

Based on long term experience regarding biofiltration, a new generation of aerated biological upflow filters was developed using a new and simplified economic backwashing system. The aim was to decrease investment costs in order to be able, from the economic point of view, to use biofiltration technology in small and medium sized plants as well.

2. Description of the biological upflow filtration process

The principal function scheme of aerated biological upflow filtration is portrayed in Figure 1. The reactor is filled with a granular filtering medium. The material also serves to support media intended for bacterial growth. Raw water is supplied to the reactor from the bottom to the top (upflow). To maintain aerobic conditions and allow aerobic bacterial growth on the material, the reactor is aerated from the bottom (co-current stream). Waste water cleaning is effected through biological activity and mechanical filtration. The clean water leaves the reactor at the top.

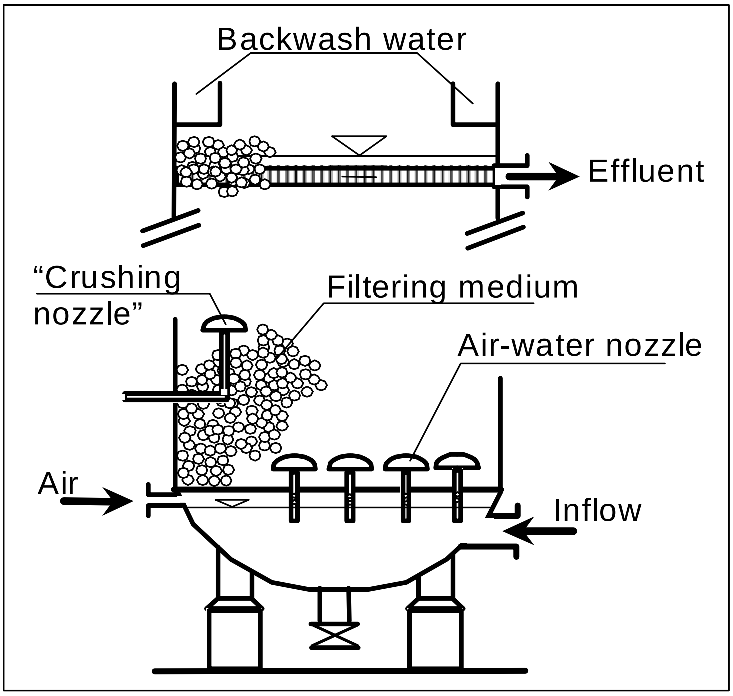

Figure 1: Scheme of biological upflow filtration

The physical properties of the filtering medium are of great importance to the proper functioning of biofiltration. In order to make the bacteria cling to the filtration medium, the roughness of the latter is important. This also exerts influence on the biomass concentration in the reactor. Practical experience concerning the operation of biofiltration plants shows that granular burnt clay is the most suitable. Depending on the type of wastewater and on the targets to be achieved, grain sizes between 2 and 6 mm are used. The height of the material in the filter usually lies between 3 and 5 m. The filtering material lasts several decades. The usual annual material loss is found to be approx. 2 to 3 % pa.

As a result of the retention of suspended solids in the filter, a limiting headloss occurs across the filter bed after a certain operation period. At that point, the filtration phase is completed and the filter needs to be backwashed in order to remove the suspended solids. The headloss at the moment of backwashing amounts to approx. 40 to 80 mbar/m, depending on the filtering material used. Backwashing is implemented as a combined air/ water flushing. After several minutes of air washing only, the filter will be washed using air and water. The final step consists of pure water washing. Backwashing requires approx. 30 to 40 minutes and is usually effected once a day. The amount of water required for backwashing lies within 3 to 5 % of the treated water.

3. Backwashing technology of conventional biofiltration

With regards to conventional biofilters, it is common practice to place the filtering medium on an underdrain air-water nozzle system. The latter is required for an even air-water separation in the filter cross-section.

For an effective backwashing, the following water and air rates are used (Addicks, 1987):

a) Loosening up v_{air} = 60-120 $Nm^3/(m^2\ h)$
b) Rinsing air-water v_{air} = 100 $Nm^3/(m^2\ h)$, v_{water} = 60 $m^3/(m^2\ h)$
c) Rinsing water v_{water} = 40-60 $m^3/(m^2\ h)$

Hydraulic and air load in the filter during operation usually lies in the range of 5 to 10 $Nm^3/(m^2\ h)$. This means that, as backwashing is concerned, loads are required which lie approx. 10 times higher in order to achieve efficient backwashing of the filters. A filter with a cross section of 25 m^2, for example, requires a hydraulic load of 1,500 m^2/h and air loads of 2,500 Nm^3/h for backwashing. The mechanical equipment, connected pipeworks and accoutrements which are required for this purpose constitute the main reason for high investment costs.

In order to avoid the purchase of expensive equipment for backwashing, several technologies were developed to reduce the costs:

- Special crushing nozzles were installed on top of the underdrain system and served to loosen the filter medium without increasing the headloss below the underdrain system (Sekoulov, 1996)
- Filter grains with highly effective sizes were used in order to avoid backwashing (Sekoulov, 1997).
- Filter material with a specific density below 1 [g/cm³] was applied (Sieker, 1996). The floating material is retained in the filter using sieves. Backwashing is carried out from the top to the bottom of the filter.

Any previous approaches aimed at a practical solution for economic backwashing failed.

4. A new system of filter backwashing

The conventional technology concerning the backwashing of biofilters was developed on the basis of experience gained from the use of drinking water filters.

The latter usually consist of dual media and multi-stratified filter beds. To achieve effective cleaning of the filter bed and to keep the filtration layers in their position, fluidisation of the medium is usually required. To backwash a mono-medium filter bed, used for wastewater treatment, simultaneous backwashing of the entire surface is not required. Dislocation of the filter material does not affect the functioning of the filter. This led to the idea of backwashing filters by sections.

The new backwashing technology is based on the principle of combined air / water backwashing by sections. Therefore, a new filter bottom construction was invented (Figure 2).

The new bottom construction requires no underdrain system. Even distribution of water and air is achieved through special radial lances which are located on the bottom of the filter. The lances are constructed in such a way that access from outside of the filter to each lance is enabled. The lances may be fed separately with air and / or water.

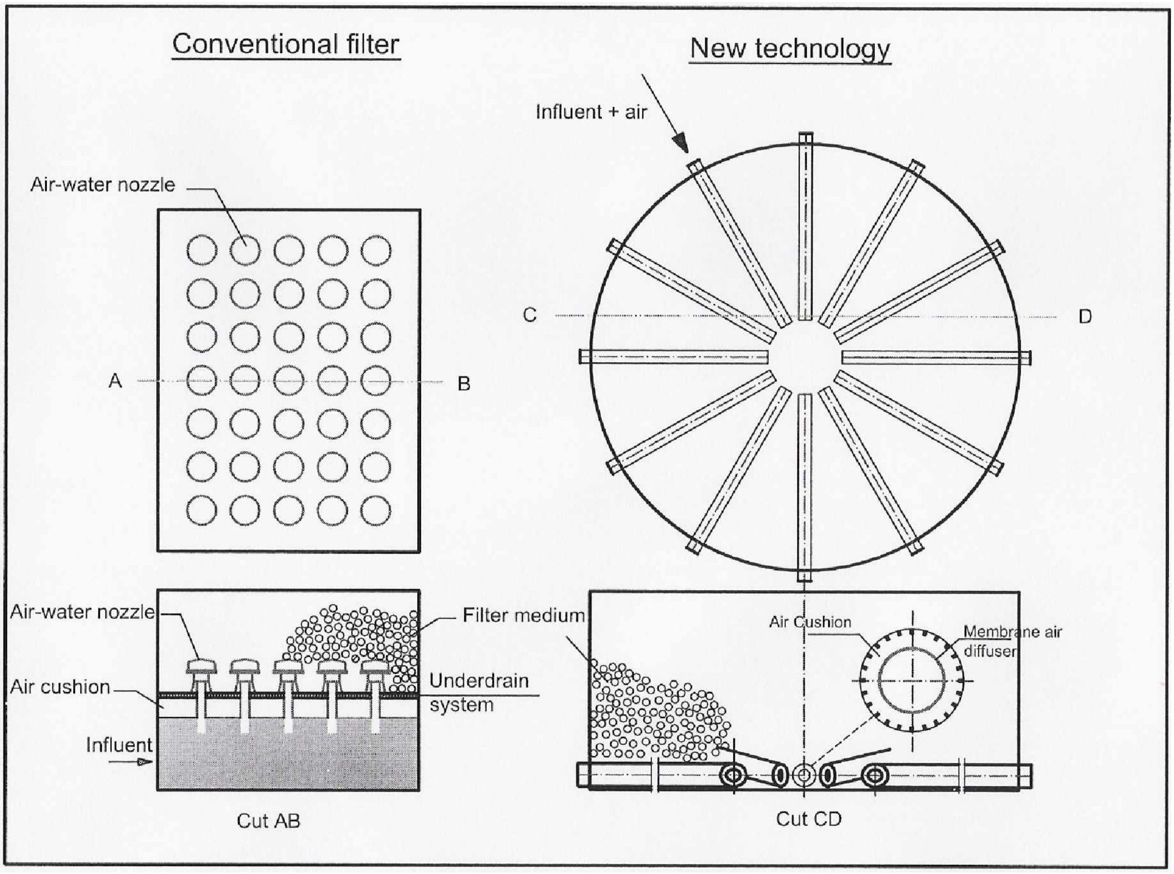

Figure 2: diagram of the conventional and of the new filter bottom construction

The bottom construction consists of radially slotted tubes. These tubes contain fine bubble membrane aerators. This type of construction allows equal distribution of air and water over the entire horizontal cross section. Simultaneously, the aerators can easily be removed for inspection or replacement purposes.

During the backwashing period, three quarters of the horizontal cross section are automatically closed and all the water and air is directed at one quarter of the cross section. In this manner, the required air and water velocities for efficient backwashing are met and no separate pumps or compressors are needed for backwashing. Furthermore, small dimensions for the pipeworks may be chosen.

Whilst the filter is backwashed, all four quarters of the cross section are washed in turn.

Backwashing of the filter is usually implemented using raw water. In such a manner, the raw water pump continuously supplies water to the reactor. There is no need for a raw water backwashing tank and the system works continuously with only one filter.

5. The efficiency of sectional backwashing

In order to provide evidence of the efficiency of sectional backwashing, several experiments were carried out on commercial scale systems. A biofilter with a diameter of 2.30 m and a height of 7.20 m was used. The filtering material in the filter showed a height of 6.00 m. Granular burnt clay was chosen as the material, with grain sizes of 2.5 to 5.0 mm. Prior to these tests, activated sludge with a concentration of 50 mg SS/l was continuously supplied to the filter, until a volume load of 6 kg SS/m³ was reached.

Subsequent to charging the filter with suspended solids, the latter was backwashed using different air and water velocities. For each test, a mass balance was calculated on the basis of the amount of suspended solids found in the backwashing water. The results of these tests are shown in Table 1.

Table 1: removal rate of suspended solids as a function of backwashing velocities (the velocities are calculated on the basis of the entire cross section)

Type of backwashing	**Air velocity [Nm³/(m² h)]**	**Water velocity [m³/(m² h)]**	**Removal rate %**
Full cross section	40	20	96.4
Full cross section	15	10	53.6
¼ cross section	20	10	95.8
¼ cross section	15	10	95.7

The tests carried out with regard to backwashing show that backwashing by sections boasts the same efficiency as conventional backwashing of the entire cross section. Simultaneously, it could be demonstrated that low air and water velocities are not suitable for the efficient backwashing of a filter.

6. Full scale application

The first biofiltration plant where sectional backwashing was applied, was constructed in 2000 in the municipality of Tönning in Northern Germany. Subsequent to successful operation of this demonstration plant over more than 2 years, several new systems were constructed in Portugal, Italy, Hungary and France (see Table 2).
Figure 3 shows the COD inlet and outlet concentration during the start up phase of a full scale plant. Biofiltration has been filled with new filtering material at the beginning of the start-up phase. It could be observed that biological activity of the plant sets in soon after the start-up. After 1 week of operation, 70% of the COD could already be eliminated. After 4 weeks of operation, the target value of < 100 mg/l COD could constantly be achieved. During the entire operating phase, the plant was backwashed once a day. Backwashing did not affect the COD outlet concentration. Subsequent to backwashing, the plant regains its full COD elimination capacity, as a result of the remaining stable biofilm on the support material. The results also show that biofiltration achieves stable outlet concentrations even when COD varies significantly in the inlet.

Table 2: full scale application of biofiltration including sectional backwashing

Name	Type	Hydraulic load [m³/d]	COD inlet [mg/l]	COD outlet [mg/l]	Start-up in
Tönning	Municipal	2.700	600	< 60	2000
Lis Sado	Oil Industry	50	500	< 150	2002
Phoenix	Plastic Industry	500	1.500	< 200	2004
ItalPet	Plastic Industry	200	1.500	< 100	2004
Guzet-Neige	Municipal	700	600	< 60	2005

6. Investment costs

During the last 20 years, numerous biofiltration plants were constructed in Europe for the industrial and municipal wastewater treatment. To assess the investment costs, approx. 20 conventional biofiltration plants in Germany were examined. Based on the total investment costs of the biofiltration turn key plant, including civil engineering, mechanical and electrical equipment (excluding sludge treatment), the specific investment costs were calculated in relation to the filtration surface. Likewise, the specific investment costs of biofiltration plants with sectional backwashing were calculated (see Figure 4).

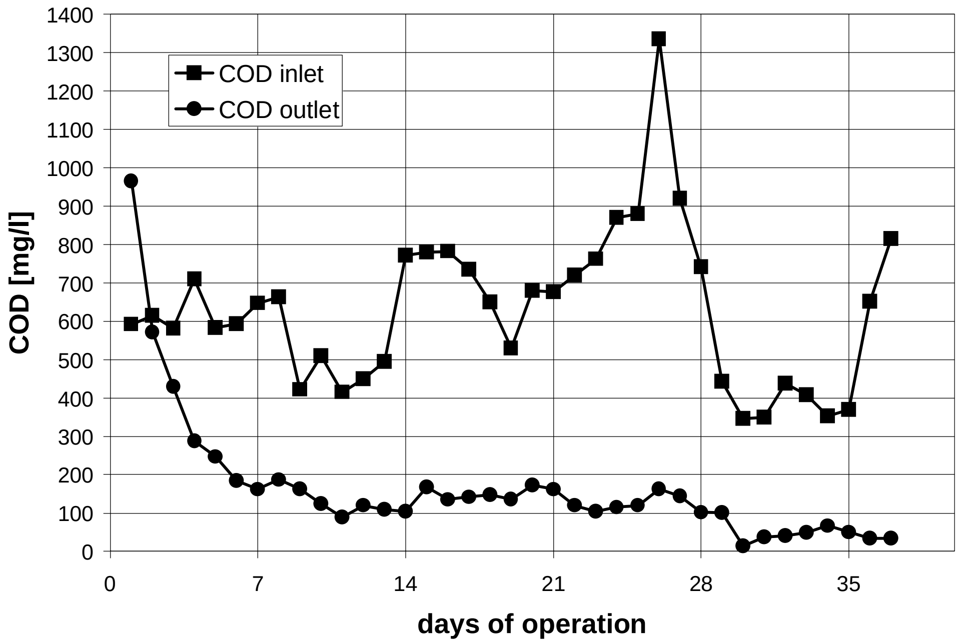

Figure 3: COD inlet and outlet concentrations during the start-up phase of a full scale plant

The results demonstrate that the implemented conventional biofiltration plants show a surface area of between 100 and 3,000 m². The associated hydraulic load of these plants lies between approx. 400 and 10,000 m³/h.

As far as small plants with conventional filtration are concerned, the investment costs amount to up to approx. 40,000 €/m², whereas the costs decrease at larger surfaces. For surfaces over 1,000 m², the specific costs remain stable at approx. 10,000 €/m². The main reason for the fact that investment costs increase as plant size decreases lies in the standing expenses for the backwashing equipment. Defined equipment including pumps, compressors and tubes are required, independent of the size of the filter.

Taking into account economic aspects, the examination of the investment costs also shows that conventional biofiltration is not suitable for small and medium-sized plants, even if this technology boasts several advantages.

Consideration of the investment costs of the new type of biofiltration including sectional backwashing shows that even for small plants, specific investment costs in the 10,000 to 20,000 €/m² range may be realised. Therefore, this biofiltration technology is suitable for small to medium-sized plants as well.

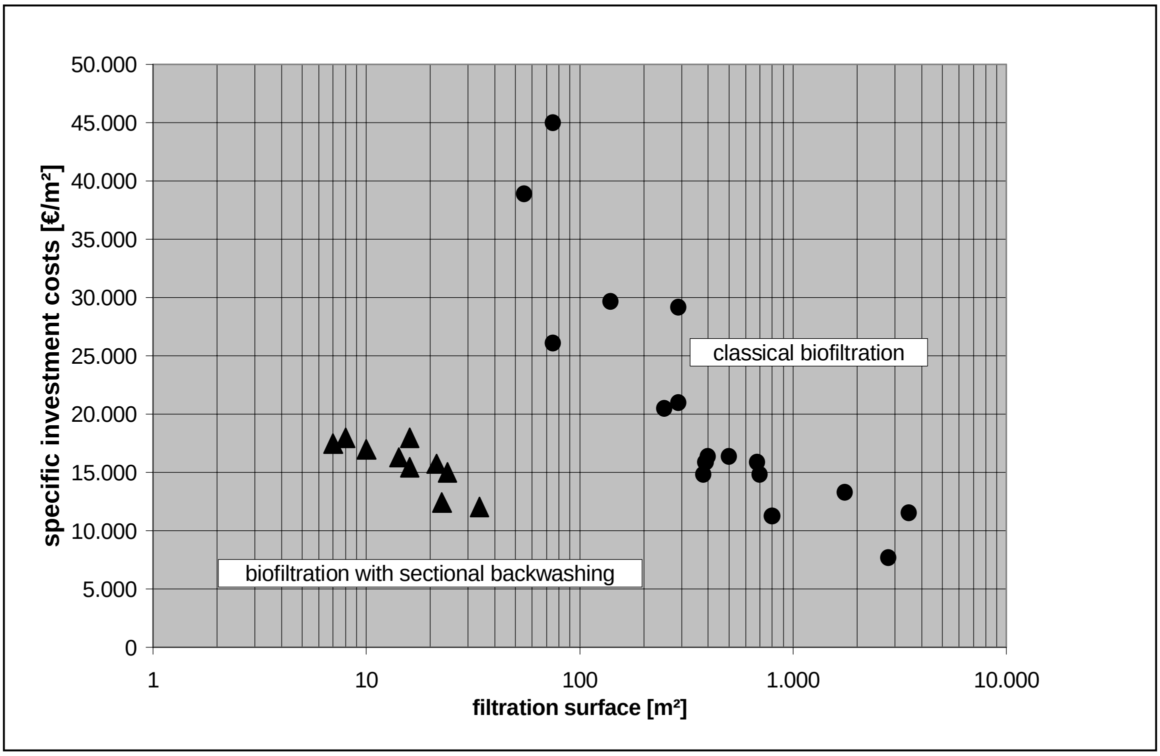

Figure 4: Specific investment costs of biofiltration as a function of the filtration surface

7. Summary

Biological aerated upflow filtration turns out to be a very efficient technology for the intense treatment of industrial and municipal wastewater. The first plants were constructed in the 1980s, in particular for big cities with hydraulic loads over approx. 1,000 m³/h. Currently, more than 500 biofiltration plants are in operation.

The most important disadvantages of biofiltration technology are high investment costs as a result of the equipment required for backwashing.

To reduce the investment costs of biofilters, a new backwashing technology was developed. The new filters have no underdrain system. Water and air is separated using radial lances. During backwashing, 3 quarters of the cross section are closed and the air and water velocities required are achieved in only one quarter at a time. Experiments on a commercial scale demonstrate the efficiency of sectional backwashing.

The investment costs of biofilters including sectional backwashing lie in the 10,000 and 20,000 € /m² range, compared with up to 45,000 €/m² required for conventional backwashing.

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