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Biological Aerated Filters

BAF 3

Cranfield University
Wednesday 3rd March 1999

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3rd International Meeting on Biological Aerated Filters – BAF 3

Wednesday 3rd March 1999 - Cranfield University

Following the success of the first 2 BAF meetings held at Cranfield University, the School of Water Sciences is holding a third one day international meeting on Biological Aerated Filters.

Since BAF 2 work has progressed on the development and optimisation of BAFs in wastewater treatment. The process is now operated in the UK. Further refinements to the process have also increased the potential of BAF technology to a wider range of applications.

The aim of this 3rd meeting is to review the latest research work related to BAFs, examine operating experiences and consider future market potential for the BAF process.

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HIGH RATE BIOFILTRATION

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Abstract

High rate biofiltration is a process which has gained popularity in recent years as effluent discharge consents become ever more stringent and the available land to construct new facilities becomes more scarce.

This paper discusses the developments in the Biofor® process, which has allowed the previous design limiting parameters to be increased. Significant improvements in technology combined with a better understanding of the biofiltration mechanism have allowed a new generation of Biofor® plants to be constructed. This is due to a significant program of development work focussing on increasing the water velocity through the filter, to allow an increased applied loading rate without impairing filter performance.

Keywords

Biological Aerated Filter ; carbon removal ; nitrification ; denitrification ; upflow filter ; land availability ; applied load ; water velocity ;

1. Introduction

Many wastewater treatment plants are now required to meet increasingly stringent effluent standards, particularly around nitrogen pollution. In the case of large municipalities, treatment facilities are being installed ever closer to urban areas, and in some cases are part of the city-landscape. This new trend, justified on economic grounds, affects the choice of the technology to be used.

Upflow co-current biological aerated filters (BAF) are well suited for expanding or upgrading existing plants particularly when land availability is at a premium. This process develops a much higher concentration of active biomass than the traditional suspended growth activated sludge system. Smaller reactor volumes and the absence of secondary clarifiers results in a system that uses about one third of the foot print surface of an activated sludge system (Mac Coy 1997). Other advantages favouring the BAF process are lower odour levels, modular construction and fully automated operation.

The BAF technology is a relatively new technology with the first plants being completed in Europe in the early eighties (Pujol and al 1997).

On a world-wide basis, BAF systems have been selected for many large cities (Colombes near Paris; Oslo Norway; Köln Germany; Liverpool UK; Roanoke US). To date, approximately one hundred Biofor® BAF plants (Figure 1) have been built throughout the World.

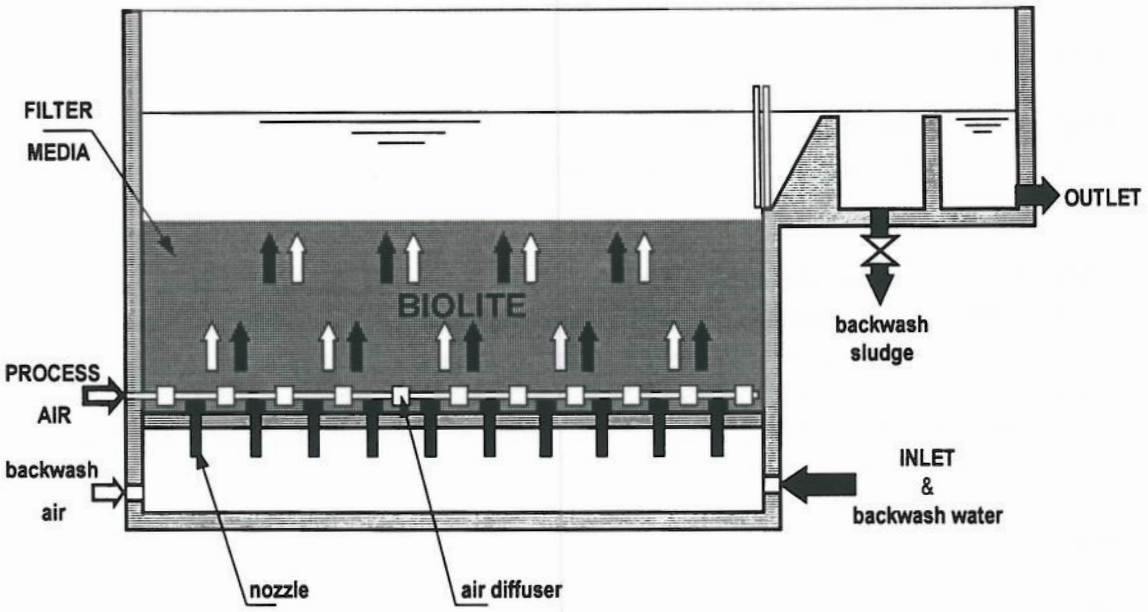


Figure 1: Biofor® process

The process is based on four principles:

1. A single layer of Biolite®, the carrier material which is a compound of clay particles having an S.G greater than 1.0 ;

2. An upflow distribution of both air and water ;

3. A specific process aeration (Oxazur®) and air regulation system for carbon removal and nitrification; a dosing system of easily assimilated substrate (methanol) for denitrification;

4. Custom designed filter backwash sequences, which have been developed to allow the filter to operate at its optimum.. The normal frequency between backwashes is 24 hours.

The upflow reactor was selected in preference to the down-flow system for the following reasons:

- It enables higher loading rates in TSS and carbon
- It gives better water distribution, which in turn utilises the entire depth of the media for filtration purposes (no surface clogging).
- There is no need for a periodic bumping of the media to remove entrapped N_2, which is swept along with treated water.

An important parameter for such a process is the applied loading rate (Boller and al 1994). For carbonaceous, nitrification or denitrification applications, this parameter can be expressed by the daily pollution load (Carbon, Ammonia or Nitrates) applied to one cubic meter of filter media.

Using a number of different studies carried out in recent years, this paper will examine the influence of the water velocity and the applied loading rates on the removal efficiency of the BAF. In addition, the combined effect of both water velocity and applied loading rates is also examined.

2. Evolution of the BAF Technology

The first generation of upflow biofilters appeared in Europe in the early 80's. Water velocities ranging from 1 to 10 $m^3/m^2.h$ were usually applied to aerobic biofilters and up to 14 $m^3/m^2.h$ on anoxic biofilters.

The applied loads were about 2 to 3 kg $BOD/m^3_R.d$ and 1.5 kg NH_4^+-N/ $m^3_R.d$,with the expected removal efficiencies being respectively around 70 % and 80 to 90 %.

Recently, significant improvements in the technology and a better understanding of biofiltration mechanisms have allowed the design parameters to be increased without detriment to plant performance. Research works have demonstrated that the increase of flow velocity in particular improves the substrate transfer between the bulk liquid phase and the biofilm (Horn 1992; Shigehisa and al, 1994).

The higher the water velocity, the higher the substrate transfer rate to the biofilm. Similarly, the better the flow distribution, the better the biomass distribution throughout the biofilter. Despite reducing the contact time, the increase in water velocity has a positive effect on the global transfer rate and therefore on the maximum capacity of the filter. Moreover, even at high water velocities, the level of suspended solids at the outlet remains stable and within the relevant effluent discharge consent standard.

The main limit of these biofilters is the applied loading rate, which is related to the expected treated effluent quality. It remains the primary design parameter when sizing a biofilter.

Comparable performances are obtained on the Biofor® with water velocities ranging from 10 to 33 $m^3/m^2.h$ combined with higher loading rates. The current limits for these parameters rest around 18 kg $COD/m^3_R.d$ and 2.5 to 3 kg NH_4^+-N/ $m^3_R.d$ as shown below.

2.1 Biofor C

At the North West Water Sandon Dock STW in Liverpool, Biofor® C was selected as the process for the new secondary treatment plant, which is under construction at the time of writing. The Biofor plant will consist of 20 No. biofilters, with a plan area of 141 m^2 each. Pilot plant trials were carried out for 7 months during 1997 (May to December) on this site.

The pilot plant was located downstream of the existing Primary Tanks. Principle dimensions were 2 m^2 surface area and a 4 m media depth. 24 h composite samples were collected in order to analyse the influent, settled sewage and effluent from the Biofor pilot plant.

The effluent quality to be achieved is a 70 % reduction of the BOD load across the entire plant in the flow to full treatment with a 95 %ile compliance. This implies that the Biofor plant will have to remove at least 60 % of the daily BOD load in settled sewage on 95 %ile basis.

During the entire trial period, plant performance was good :

- the average BOD removal rate was 80 % for an average load of 5.4 kg/m^3/d
- 98 % of the results are above 60 % BOD removal
- 93 % of the results are above 70 % BOD removal
- 55 % of the results are above 80 % BOD removal

The plant performance remained high regardless of the incoming load.

Figure 2 represents the applied and eliminated loading rates on the Biofor® when operated at an average flow rate of 6.5 m^3/m².h. This graph demonstrates the ability to continue to eliminate BOD load at a rate directly proportional to the applied load with no reduction in performance despite significant increases in the applied load.

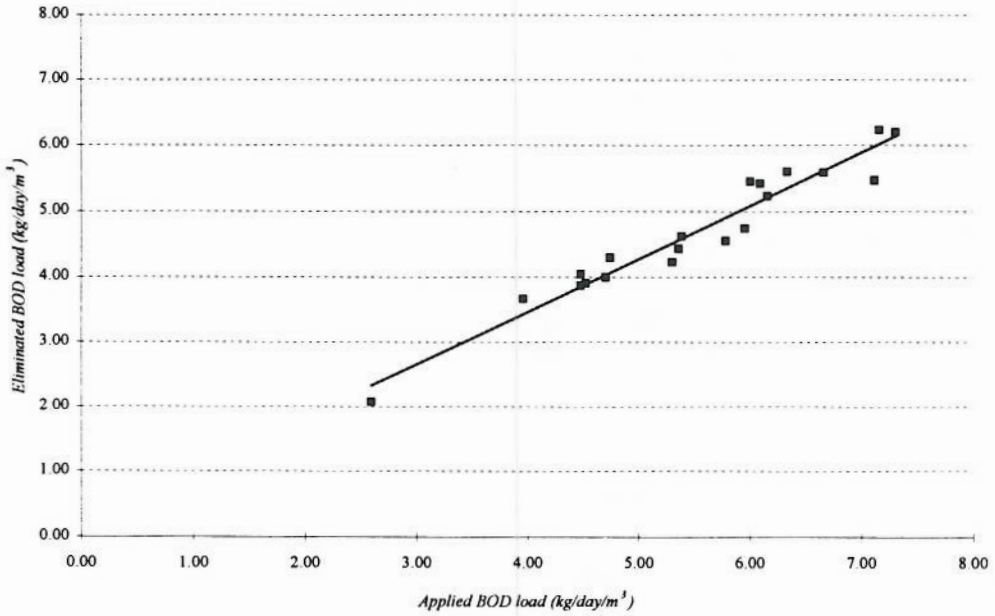


Figure 2: Eliminated BOD load vs. applied BOD load - v = 6.5 m^3/m².h

Figure 3 shows the same parameters and even with the pilot plant being run at 13 m^3/m².h, similar removal efficiencies were obtained.

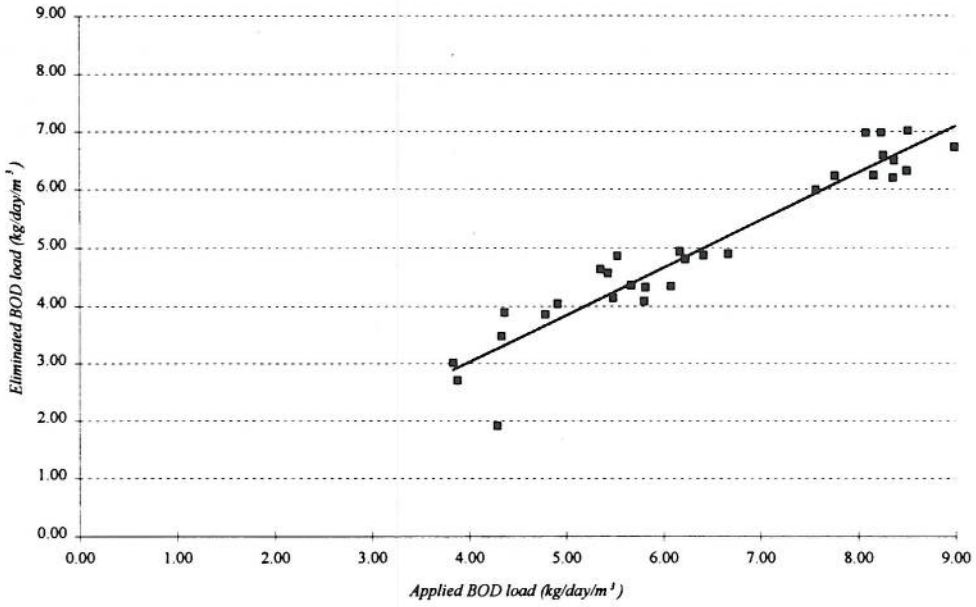


Figure 3: Eliminated BOD load vs. applied BOD load - v = 13 $m^3/m^2.h$

2.2 *Biofor N*

In France, SIAAP, the statutory body in charge of waste water management for the Paris area has to upgrade its major facility, Achères STW. This upgrade comprises a new tertiary treatment facility located downstream of the existing activated sludge plant (completely mixed type with medium F/M ratio).

An industrial biofilter prototype (144 m^2) has been operated since August 1992 in a number of different configurations. The results below cover the effect of high nitrogen and high organic carbon loading rates as well as the influence of water velocity.

Table 1 shows the annual characteristics of the inlet water to the Biofor®, with the average concentrations and temperatures of approximately 600 samples.

Table 1: Inlet BAF concentrations in mg/l

Parameter	SS	COD	BOD_5	TKN	NH_4^+-N	Temperature (°C)
Average	26	75	26	25	24	18
Standard Deviation	17	29	14	5	7	3

The NH_4^+-N concentration is relatively steady (close to 25 mg/l) except during long rainy periods (minimum value of 12 mg/l). The extreme temperatures are 11°C in winter and 25°C in summer. In winter, the sewage has a slightly higher carbon content (10 to 15 % more).

At high temperatures, without any limitation in the nitrification mechanisms, the biofilter is able to eliminate very high loading rates (up to 2.5 kg NH_4^+-N /m^3_R.d) with 90% efficiency (Fig 4 in Pujol and al, 1996). These are the maximum values obtained, up to now, on such a large size Biofor®. Usual applied loading rates are close to 1 kg NH_4^+-N /m^3_R.d. During the same period, the maximum outlet concentrations for BOD and SS were respectively 10 and 16 mg/l.

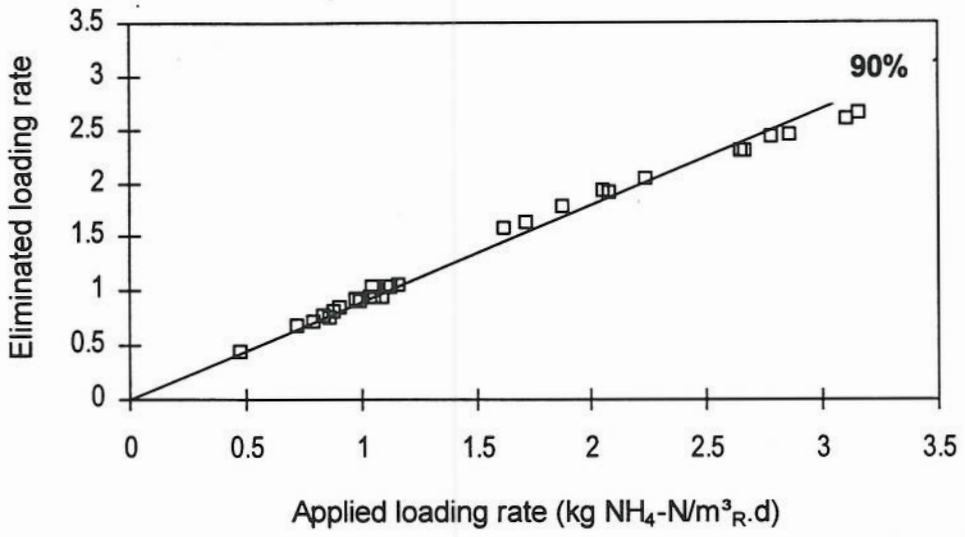


Figure 4: Eliminated versus applied loading rates in the Biofor® prototype

The effect of the water velocity has been examined, showing that the nitrification performance is not dependent on the water velocity. Three different ranges of water velocity were examined, (4-6, 6-8 and 8 to 10 m/h), with the highest applied loading rates well in excess of 1 kg NH_4^+-N /m^3.d. The nitrification efficiency varied from 80 to 100 % during most of the test period, thus demonstrating the high efficiency and reliability of the Biofor® process.

The highest removal rates coincided with the highest water velocities, as long as the nitrification capacity of the biofilter was not exceeded. During the winter period, at low temperatures (11 to 13 °C), there was a decrease in the nitrification rate due to the decreased activity of the nitrifying bacteria (this phenomenon has been well documented in numerous technical publications). The analysis of these results shows that the water velocity is a positive factor rather than a limiting factor for the nitrification as long as the nitrification conditions are not limiting (temperature, aeration, backwashing, etc.).

During the same period, the SS and BOD removal were observed as the Biofor® also acts as a polishing treatment stage. Figures 5 and 6 (Pujol and al, 1998) show a similar relationship between applied and eliminated load for SS and BOD as for NH_4^+-N, for the different ranges of water velocities.

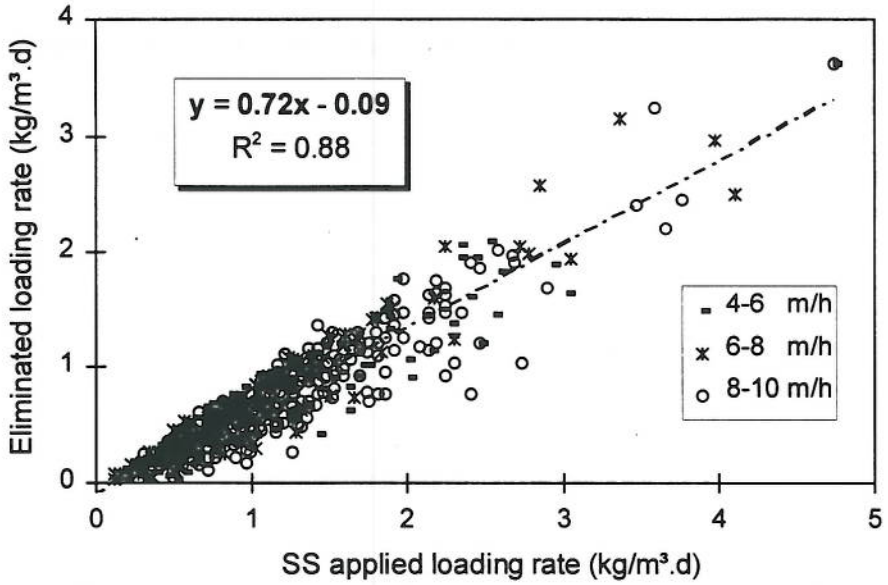


Figure 5: Influence of the water velocity on the SS retention

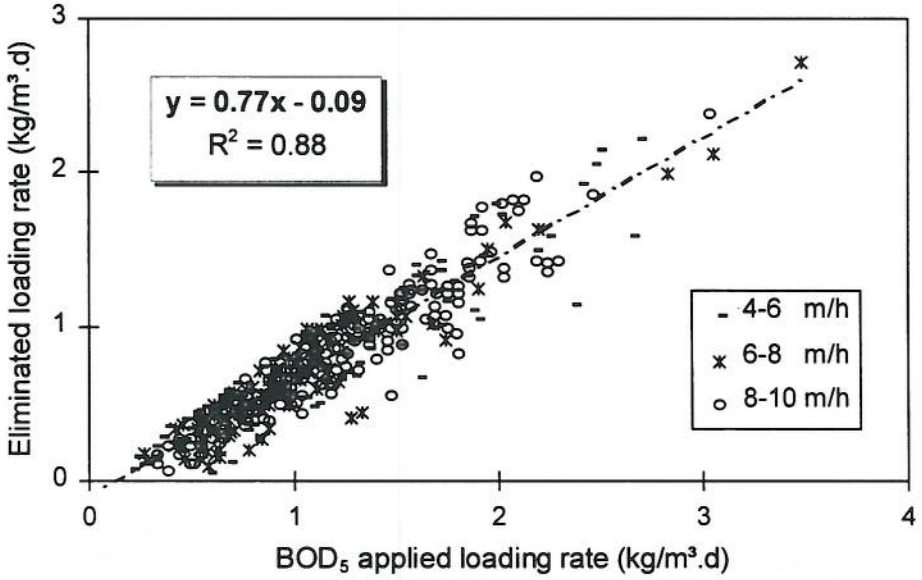


Figure 6: Influence of the water velocity on the BOD removal

During this period, with stable removal efficiencies of 66 % for SS and 75 % for BOD, the biofilter continues to nitrify even at periodic high BOD loading rates up to 2 kg BOD /m^3.d.

Table 2 summarises the removal efficiencies and outlet concentrations obtained (average and 90 %ile) during this test. These results demonstrate the excellent reliability of the process whilst operating at high water velocities.

Table 2: Average removal efficiencies and outlet concentrations

	BOD_5	COD	SS	NH_4-N
Removal efficiency (%)	68	51	65	94
Outlet concentration (mg/l) - Av.	6	38	8	1.5
Outlet concentration (mg/l) - 90 %ile	14	51	16	4

Finally simulations of wet weather conditions were carried out in order to assess the impact on the nitrifying performance of the biofilter.

During these tests, the water velocity was constant at 16 $m^3/m^2.h$, which is particularly high. The mixing of primary settled effluents with the outlet of the secondary clarifiers allowed an increase in the applied Carbon loading rate to a figure close to 6 kg $BOD_5/m^3_R.d$ and 15 kg $COD/m^3_R.d$. At the same time, applied Ammonia loading rates were increased up to a maximum value of 2.4 kg NH_4^+-$N/m^3_R.d$.

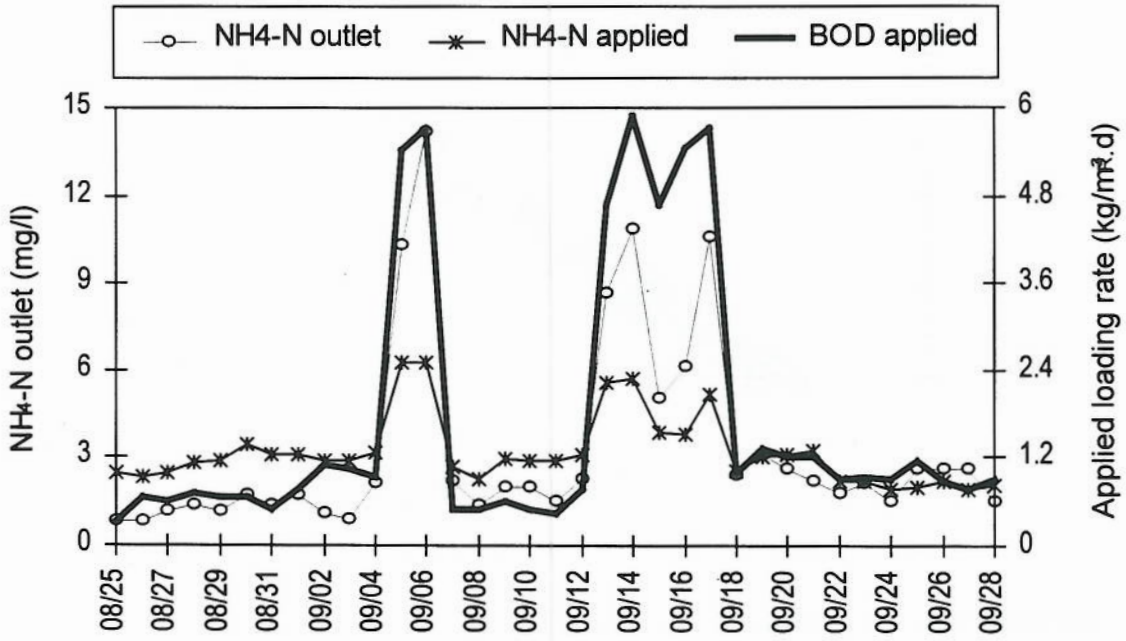


Figure 7: Storm water simulation period

The impact of high carbon loading rates meant ammonia levels in the effluent rose from 5 to 14 NH_4^+-N mg/l (Fig 7 in Pujol and al, 1996). Whilst the ammonia levels rose, removal efficiency across the plant remained high as the prototype still removed 7.5 kg $COD/m^3_R.d$, and 1.1 kg NH_4^+-

N/m^3_R. Due to the high applied loads, the suspended solids removal was limited to some 50% (around 30 mg/l effluent concentration).

In conclusion, the prototype achieved simultaneous carbon and ammonia removal, this is particularly interesting, taking into account the rainy weather conditions. Once the test was complete and flows returned to their previous dry weather levels, the nitrification process returned to its previous performance levels. This confirms the presence of active nitrifiers in the filter

2.3 Biofor DN

Two pilot tests were performed on anoxic DN Biofor® utilised in pre-denitrification and post-denitrification. One of the aims of the tests was to explore high water velocities in non-limiting carbon conditions with high applied loading rates.

2.3.1 Biofor Pre-DN

A one-year study was carried out on two semi-industrial up-flow biofilters (0.27 m² area and 4 m media depth) - a pre-denitrification stage (Pre-DN Biofor®) followed by a nitrifying stage (N Biofor®) with recycle. It was designed to treat the primary settled municipal wastewater of Evry SWT for both carbonaceous and nitrogenous pollution.

Table 3 and figure 8 (Peladan and al, 1997b) present the results obtained during two periods, testing respectively water velocities of 24 and 31 $m^3/m^2.h$. As nitrites were always lower than 1 mg/l, results are expressed in term of NO_x-N = NO_3-N + NO_2-N.

Table 3: Results of the Pre-DN biofilter

water velocity	tempe-rature	inlet NO_x^--N	outlet NO_x^--N	NO_x^--N removal rate	NO_x^--N applied loading rate	NO_x^--N eliminated loading rate	total COD applied loading rate	TSS applied loading rate
$m^3/m^2.h$	°C	mg/l	mg/l	%	$kg/m^3.d$	$kg/m^3.d$	$kg/m^3.d$	$kg/m^3.d$
23	18	10.6	0.9	92	1.5	1.4	61	17
31	14	8.2	1.3	86	1.5	1.3	63	18

Similar results are obtained at both velocities. The extremely high applied loading rates of total COD and TSS show that the applied Carbon did not limit denitrification and that the high levels of TSS at the inlet had no adverse effect on the process.

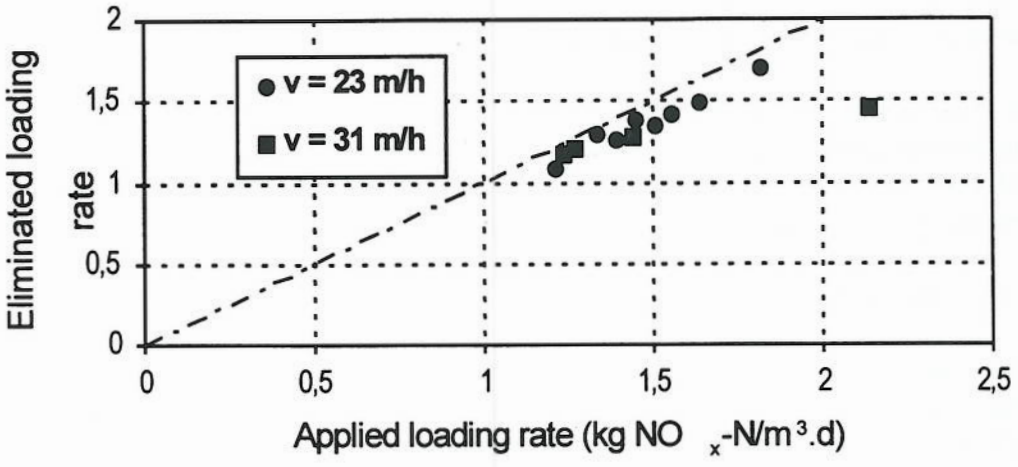


Figure 8: Loading rates on the Pre-DN pilot

However, further investigation shows that the eliminated loading rate of nitrates is dependent upon the recycle rate increasing the nitrates and oxygen content of the water. If the recycle rate is too low, the nitrate applied loading rate becomes a limiting factor. If the rate is too high, organic carbon is the limiting factor as the recycled oxygen consumes it.

At Evry, it was found that the optimum recycle rate is 250 %. The denitrification removal efficiency was 68 % on average, reaching 90 % when readily biodegradable COD is available in sufficient quantity, i.e. for a ratio of soluble COD/NO_3^--N greater than 9 as shown on Figure 9 (Ninassi and al, 1998).

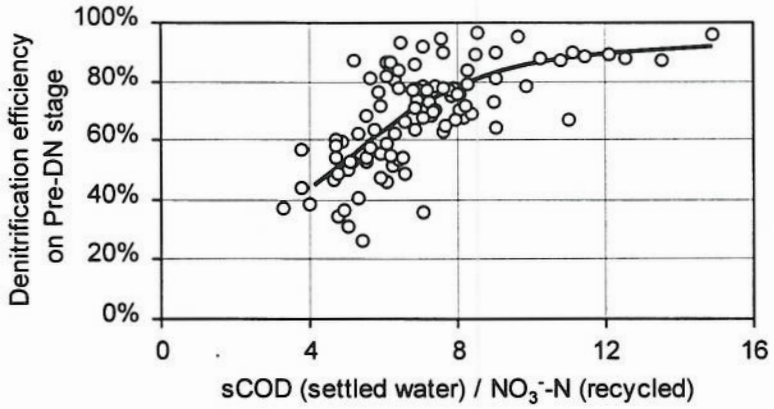


Figure 9: Denitrification rate conditional upon sCOD/NO_3^--N ratio

2.3.2 Biofor Post-DN

Post denitrification is the effective and rapid nitrates removal process , which is required when very high discharge consent standards apply. The addition of an exogenous substrate is required in the

process, with methanol being the most widely used carbon source. Both the technical and economic viability of the process depends on the correct adjustment of the methanol dosing.

Oslo STW in Norway is the first full-scale post denitrification plant operating with the Biofor® process. Unfortunately results from this plant are not available. However, the pilot study carried out at this site showed a total denitrification for loadings up to 4.8 kg NO_3^--N/m^3.d with water velocity in excess of 10 m^3/m^2.h. Fig 10 refers (Pujol and al, 1995).

In summary, the results show the process performs well over a wide range of flow conditions as the NO_3^--N content of the treated effluent was lower than 2 mg/l for 70 % of all samples analysed.

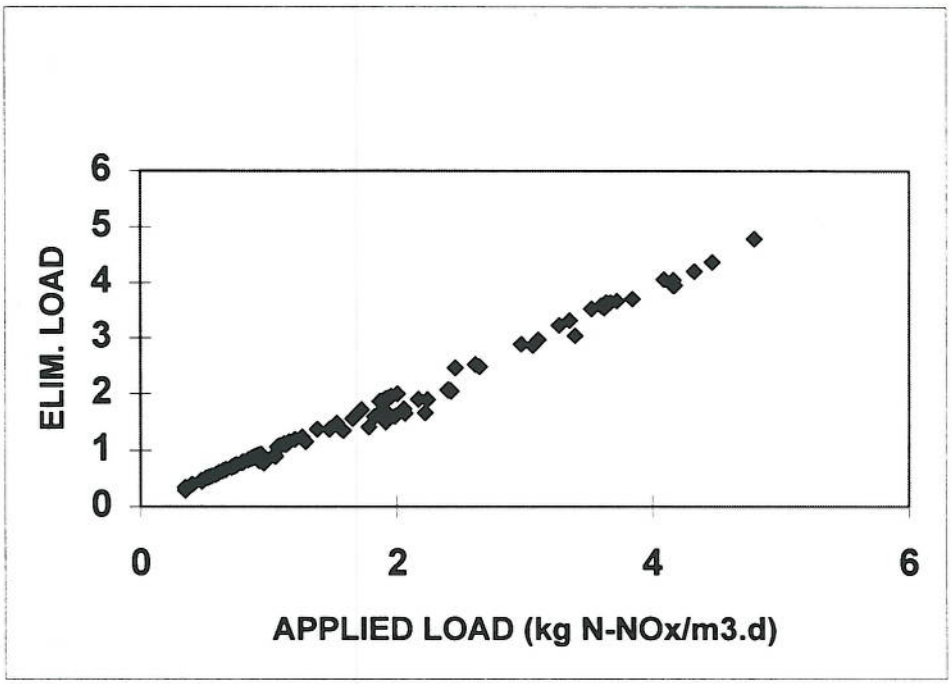


Figure 10: Eliminated versus Applied Loading Rates

The impact of water velocity was studied further at Corbeil STW (France) where a Post DN pilot was tested after a full scale Biofor® N. Figure 11 (Peladan and al, 1997b) presents a similar linear relationship between eliminated and applied loading rates as in figure 10, even though the water velocity was increased to 22 and 33 m^3/m^2.h respectively.

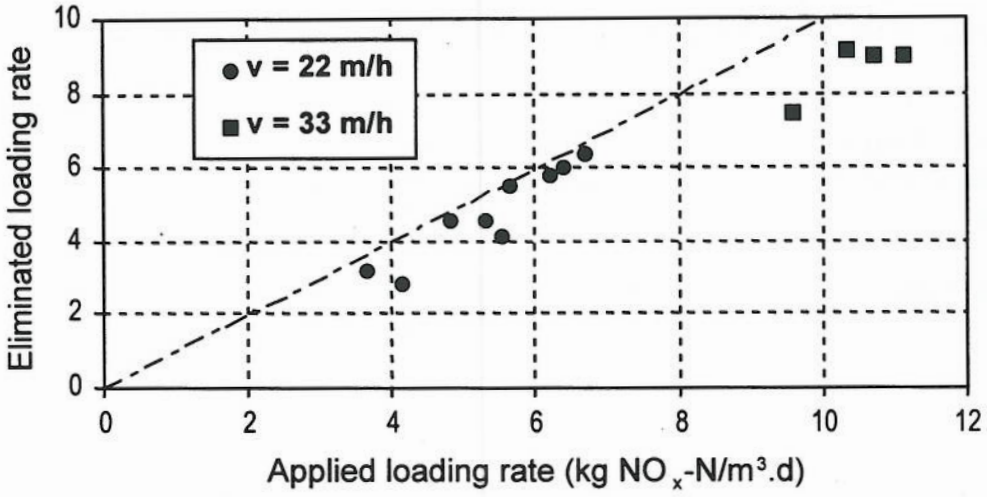


Figure 11: Loading rates on the Post-DN pilot

4. Conclusion

Up-flow, compact and intensive biofiltration processes can be used in a number of different treatment applications. Multiple applications and combinations are possible depending on the influent quality and the required level of treatment for a particular site.

Depending on the conditions, the limiting values of the applied loading rates combined with high water velocities could be used for the design of full-scale plants. The resultant combination of higher water velocity and higher loading rates gives a smaller biofilter footprint for a given plant than what was previously available.

Evolution of both the Biofor® C and Biofor® N technology combined with better control of the backwash and its impact on plant performance have led to better performing plants. In many cases, actual plant performance is noticeably improved over the theoretical design performance criteria.

Another benefit of these new design criteria is the flexibility in the process design to handle sudden changes in the incoming sewage if required (e.g. flows and loads, storm water flows). As the water velocity is no longer a limiting factor, these upflow biofilters are of particular interest where the treatment of dilute sewage or storm water flows is required.

5. Acknowledgements

We take this opportunity to thank both North West Water and their engineer's, Bechtel Water Technology Ltd. for their assistance during the pilot plant trials at Liverpool and also their consent to use some of the data from the report in this paper.

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