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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.



BAF'S GET MEDIA ATTENTION

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Abstract.

The Biological Aerated Filter is an accepted wastewater treatment option that has the advantage of treatment and solids separation in a single, compact reactor. Choosing the correct support media for the attached biomass is critical in the design and operation of the process to achieve the required effluent quality. This paper considers the physical properties of granular media, such as density, shape, size and surface structure in relation to biomass attachment and treatment efficiency. A pilot evaluation of downflow granular media BAF columns filled with media of different particle sizes, operated over a range of hydraulic and volumetric loading rates, is reported. Nitrification on the smallest 2-4 mm media was found to be inhibited at loading rates above 0.5 kg NH₄-N and 2.5 kg BOD / m³media/d due to the greater heterotrophic growth and enhanced wash requirement.

Key Words: Biological Aerated Filter, media, properties, size, nitrification

1. Introduction

Increases in population and water demand, and the potential for wastewater reuse, has led to the imposition of stricter wastewater discharge standards. Existing wastewater treatment plants will require uprating or upgrading and, in some cases, first time treatment provided to ensure public health is not compromised and environmental quality is improved.

The Biological Aerated Filter (BAF) is an accepted wastewater treatment option, especially where available land area is limited. Generically, the process comprises a submerged attached growth reactor in which the wastewater to be treated flows up or down through a bed of granular or structured media supporting the fixed biomass. The media may be sunken, fixed or floating. Process air is introduced at or near the base of reactor, rising up through the bed.

Treatment of soluble matter and solids removal are achieved in a single reactor. Excess biomass is removed by periodic backwashing of the media.

The four main BAF types can be described in relation to their flow regime and media type:

- Upflow sunken granular media co-current process air
- Upflow floating granular media co-current process
- Downflow structured media counter-current process air
- Downflow sunken granular media counter-current process air.

Other systems have been developed at pilot scale, including a granular sunken media BAF with horizontal flow configuration, based on matrix filtration principles, a mixed granular media/structured media downflow BAF and the re-circulating ,floating media REBAF.

A schematic of a downflow sunken media BAF is shown in Figure1.

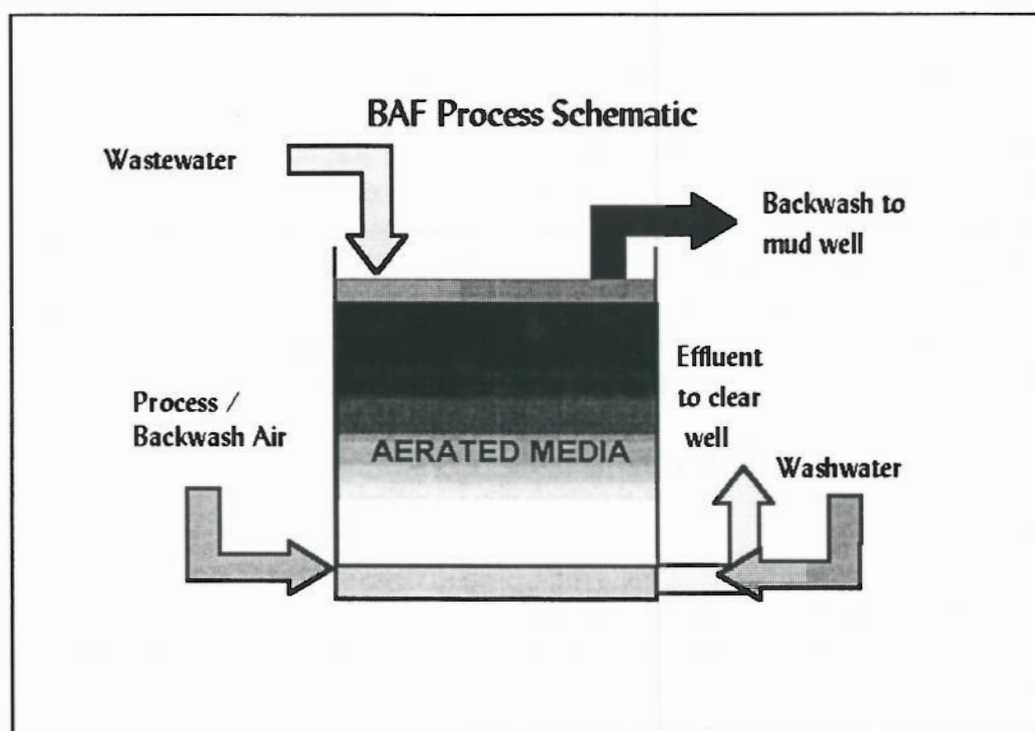


Figure 1. Downflow sunken granular media BAF

The process has the advantages of a small land area requirement, it is easily covered or built underground , it is not affected by sludge bulking and it has a high degree of automation.

The BAF process has been used in a number of forms since the early 1930's. The system as we know it today was developed in the early 1970's with Condren (1990) reporting over one hundred plants operating in Europe, North America and Japan.

The operation of many full scale plants has been reported. Smith and Edwards (1985), Churchley et.al. (1985) described operational experiences with BAF plants in the UK for uprating existing treatment plants.

Since the early evaluation carried out by Stensel *et.al.*(1988) the process has had relatively few applications in North America, however more recent pilot work carried out by Newbigging *et.al.*(1995) in Windsor, Ontario, and Carrio *et.al.*(1995) at New York's NewTown Creek plant are heralding a revived interest.

2. Design Criteria

Smith and Edwards (1985), confirming work by Stensel and Reiber (1983), identified four key criteria for BAF design. These are:

- hydraulic and volumetric loading rates
- backwash rate, frequency, and backwash liquor management
- process air flow rate, distribution and control
- media characteristics

The effects of flow and load variation on a sunken 2.5 - 4mm granular media BAF are shown for steady state flows in Table 1.

Table 1. Steady state load variation results.

HLR	m/h	1	1.5	2	3
HRT	min	60	40	30	20
BOD VLR	kg/m ³ /d	1.2	1.7	2.6	3.9
NH ₄ -N VLR	kg/m ³ /d	0.2	0.3	0.4	0.6
TKN VLR	kg/m ³ /d	0.4	0.6	0.9	1.35
Ss _{out}	mg/l	5	7	17	32
BOD _{out}	mg/l	7	12	13	17
NH ₄ -N _{out}	mg/l	1.1	1.7	7.9	13.1
TKN _{out}	mg/l	3.7	3.8	18	25
SS Rem.	%	95	93	83	69
BOD Rem.	%	93	88	91	75
NH ₄ -N Rem.	%	93	89	52	2
TKN Rem.	%	89	88	45	22

Despite the number of plants in operation and the clear advantages of the process, a number of issues have been highlighted with respect to the performance and operability of the process. For the downflow granular media BAF the single most important issue is headloss development and the subsequent backwash requirement.

Headloss development is dependent on :

- volumetric and hydraulic loading rates
- biomass growth rate and type
- backwash efficiency
- media and packed bed characteristics.

Understanding the influence of media type, size, shape, and surface characteristics is critical in the design and operation of the BAF process.

3. Media Characteristics

The purpose of the media in a BAF is to provide a stable support surface for bacteria and micro-organisms to allow optimum transport of reactants and products in to and out of the biofilm and to provide optimum conditions for headloss development and backwashing.

In general BAF media should:

- give the required effluent quality
- be capable of biomass attachment
- be inert, hard and durable
- be easily cleaned of excess biomass
- be available at appropriate (low) cost

More specific criteria for assessing media suitability for BAF applications relate to the media grains themselves and the characteristics of the packed bed, such as voidage, which they form. For the media particles these include:

- Specific Gravity
- surface characteristics
- hardness/ friability
- particle shape
- particle size

A number of different types of media have been used in BAF applications including Granular activated carbon (GAC), Anthracite, quartz sand, sintered pulverised fuel ash, expanded clay, blast furnace slag and marble chippings.

The physical properties of media tested at pilot scale by Thames Water R&D and , where appropriate, used in full scale plants are shown in Table 2.

4. Specific Gravity.

The SG of the media, along with the particle size and shape, governs the fluidisation velocity and hence the backwash water and air rates required to remove excess biomass from the filter bed. The higher the SG of the media, the higher the wash water rate required to achieve the required "pulse-collapse" conditions.

BAF's are generally designed with a combined air and water wash. If the SG of the media is relatively low care must be taken to ensure media is not lost over the backwash launder during the

combined wash phase. From Table 3, Blast Furnace Slag has the highest SG, and hence will require a higher wash rate than expanded shale of a similar particle size. This will have an effect on the capital cost of the process. Higher wash rates mean larger pumps and pipe work.

Table 2. Physical properties of sunken granular BAF media.

<i>Media</i>	<i>SG</i>	<i>Size</i>	<i>oidage</i>	<i>Shape</i>	<i>Attrition</i>	<i>Site/ Trial</i>
<i>Lytag</i>	1.94	2.8 – 5.6	47	A / S	5.5	Parr Heathcoat Milford Haven
<i>Ex.Shale 1</i>	1.46	3.4 – 6.7	45	A		Canadian
<i>Ex.Shale 2</i>	1.61	2.3 – 4.7	43	A	2.3	Silchester Saffron Walden
<i>Ex.Shale 3</i>	1.46	2.3 – 4.7	42	A	2.8	Heathcoat
<i>Norsk Leica</i>	1.6	2.8 – 5.6	46	A / S		Millenium Dome Silchester
<i>BF Slag</i>	2.8	6	53	A	low	Pilot
<i>Scoria</i>	2.3	2 – 4	45	A	low	Pilot
<i>Pumice</i>	1.1	2.5 – 4	45	A	high	Pilot
<i>Arlita</i>	1.55	3.5 – 6.2	53	S	1.4	Vacarisses
<i>Starlight</i>	1.34	2.6 – 3.4	38	A	45.2	Test

5. Surface Characteristics

Porosity and Specific Surface Area

In general BAF media will have a rough, porous surface structure. Figure 2 shows a scanning electron micrograph (SEM) of the surface of a grain of expanded shale showing a highly porous grain surface with both large and small pores.

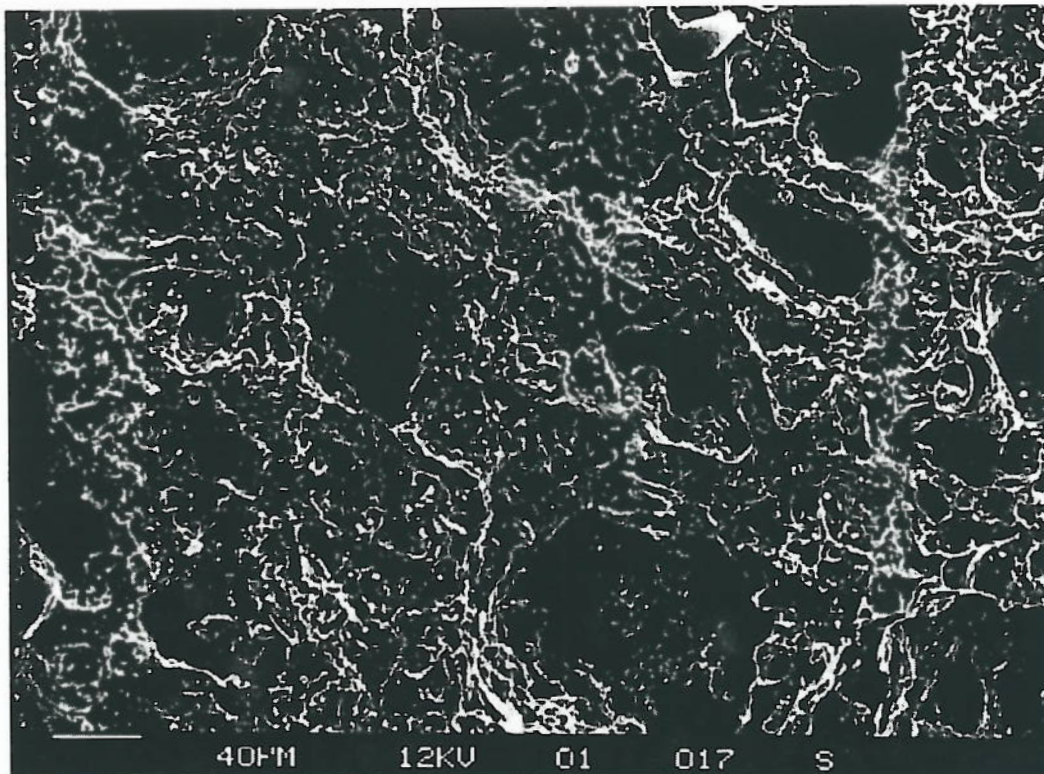


Figure 2. Expanded Clay surface SEM

Work has been carried out at Thames Water's Manor Farm R&D Facility to investigate the effect of surface porosity and particle shape on process performance.

Identical 4m² SAFe Process filters were filled, one with spherical Lytag media and the other with crushed, angular Lytag. Both media had exactly the same particle size distribution. The plant was run at a range of hydraulic and volumetric loading rates to assess any difference in treatment efficiency.

The ammonia removal results, shown in Figure 3, demonstrate that the crushed Lytag gives better nitrification rates than the comparable spherical Lytag media. Results for BOD removal showed no significant difference.

By crushing the pelletised Lytag the porosity of the media particles is increased giving an increase in specific surface area. The effect of other factors, such as particle shape and bed voidage can not be discounted as they could also affect the rate of nitrification.

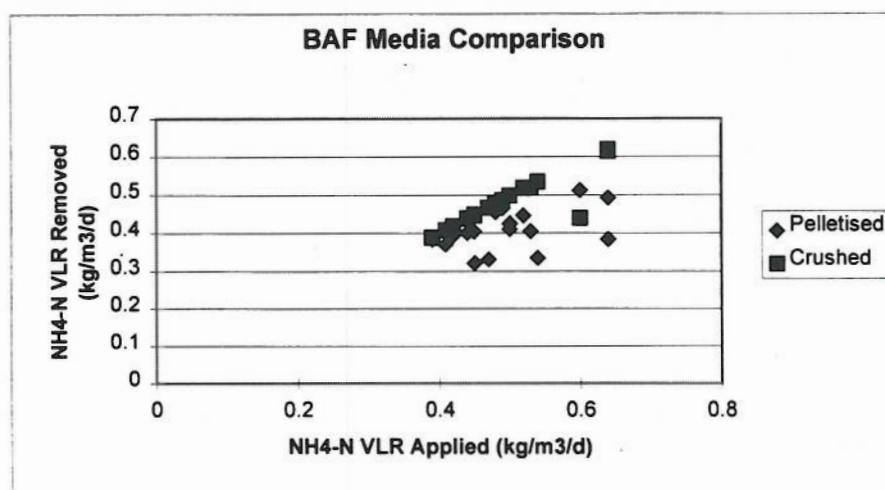


Figure 3. Comparison of crushed angular and spherical Lytag media

6. Surface interactions

Granular BAF media is generally inert, with no physical or chemical interactions other than biomass adhesion. The BEWA acid solubility test is used as a measure of chemical reactivity. Lytag, expanded shale and Arlita were tested and shown to have acid solubilities in the range of 0.4 - 1.4%, well below the maximum allowable figure of 5% (Kent, 1998).

In some cases, the surface properties of the media can be used to enhance the treatment process. For example:

- Marble chips - increased pH at the media surface to enhance nitrification
- Zeolyte - ion exchange at the media surface captures ammonium ions for improved nitrification.
- Granular activated Carbon (GAC) - absorption of the substrate onto the active carbon sites gives a longer residence time and enhanced treatment.

In pilot trials carried out at Thames Water's Banbury wastewater treatment plant an aerated GAC BAF fed with secondary effluent achieved 10% greater reductions in recalcitrant COD than a conventional GAC absorber. The removal of COD was 50% greater than that predicted from the theoretical GAC capacity.

7. Hardness and Attrition

BAF filter media will be subjected to attrition during loading of the media into the filter shell and during the air scour and combined air and water phase of the backwash. The attrition test employs an accelerated backwash procedure (Ives, 1990) involving 100 hours of washing, representing 3 years of washing at 6 minutes per wash. The quantitative figures for attrition in Figure 3 (Kent et.al., 1996) range from 1.4 - 5.5% for the Lytag, expanded shale and Arlyta. These figures are relatively

high in relation to the BEWA criteria for conventional filter media, however the figure should be taken as a relative indicator of friability for what is a different application. Even in relative terms the "starlight" media, subjected to the extended backwash test and the pumice media, subjected to pilot trials, showed a high degree of attrition.

8. Particle Shape.

The sphericity of the media affects the packing arrangement of the filter bed and the required wash water flow rate. Experiments on pilot columns has shown angular Lytag media to have a fluidisation velocity 15% higher than spherical media of the same size range and a bed voidage of 5% lower. This is due to the irregular media shape packing down in the filter bed, thus occupying more of the voids between the media particles.

Operation the larger scale filters at Manor Farm with crushed and pelletised Lytag demonstrated filter run times of 13 and 17 hours respectively, at an hydraulic loading rate (HLR) of 1.75 m/h. This indicates that the reduced bed voidage with the angular media provides a finer filter, removing more suspended solids and BOD in the top of the bed. This would improve nitrification lower down the bed.

The pilot columns performed in a similar way with a higher solids removal at the top of the filter bed and a 5% improvement in nitrification on the angular Lytag at a 1.3 m/h HLR.

9. Particle Size

Media particle size and the particle size distribution governs the specific surface area available to support the attached biomass and is the major determining factor in bed voidage and headloss development. Hence it is critical to the treatment performance and operability of the filter.

An evaluation into the effects of changes in particle size on effluent quality from a granular media downflow BAF has been carried out at Thames Water's Manor Farm Research Facility (Kent, 1998). The pilot plant comprised four number 0.5 m diameter columns with underdrains and process air supply. Each BAF column was filled to a depth of 1.8 m with Lytag media of different sizes. The nominal particle size distributions where:

- 2 - 4 mm
- 2.8 - 5.6 mm
- 4 - 8 mm
- 5.6 - 11.2 mm

Each filter was subjected to the same operating conditions with a period of operation at four incrementally increasing hydraulic loading(HLR) and volumetric loading rates (VLR). These periods corresponded to HLR's of 0.5, 1, 1.5 and 2 m/h. Process air rates were set such that the air supply was not limiting process performance.

Effluent quality with respect to BOD, $\text{NH}_4\text{-N}$ and SS removal, and the rate of headloss development was monitored during each period.

The results for BOD removal against BOD VLR, $\text{NH}_4\text{-N}$ removal against $\text{NH}_4\text{-N}$ VLR, and $\text{NH}_4\text{-N}$ removal against BOD VLR are shown in Figures 4, 5, and 6 respectively.

The results for BOD removal show a reduction in BOD removal related to media size at each loading rate, with the two smaller size media continuing to achieve above 90% removal at BOD VLR's up to 5 kg BOD/ m^3 media/d. The two larger media sizes showed a drop off in BOD removal at higher HLR's and BOD VLR's. This was also associated with a lower SS removal efficiency, indicating, as might be expected, that the higher voidage associated with the larger media grain size was allowing solids related BOD to pass through the bed at higher hydraulic loads.

Even at the higher BOD loads the larger media filters were not reaching their terminal headloss before backwashing was carried out.

The results for $\text{NH}_4\text{-N}$ removal show the smallest 2 -4 mm media to have the greatest removal efficiency at the lowest loading rate. However, the treatment efficiency is reduced significantly as the load is increased above 0.5 kg $\text{NH}_4\text{-N}$ / m^3 media/day, and the 2.8 - 5.6 mm media becomes more efficient.

The greater reduction in nitrification efficiency occurred as a result of the increased headloss development observed with the smaller media.

All columns were manually backwashed at roughly 12 hour intervals. At HLR's above 1m/h the 2 -4 mm media was found to reach terminal headloss in less than the 12 hour operating period. Blocking of the bed in this way leads to short circuiting and poor process air distribution thereby decreasing treatment efficiency.

Both the larger media sizes show significant reductions in nitrification as the load is increased.

Comparison of $\text{NH}_4\text{-N}$ removal with BOD VLR show that nitrification is reduced for all media sizes at a BOD VLR of 2.5 Kg/ m^3 /d. As BOD is driven deeper into the bed by increasing HLR and VLR the faster growing heterotrophic organisms will out compete and inhibit the growth of the slower growing autotrophic nitrifiers, resulting in a reduction in $\text{NH}_4\text{-N}$ removal.

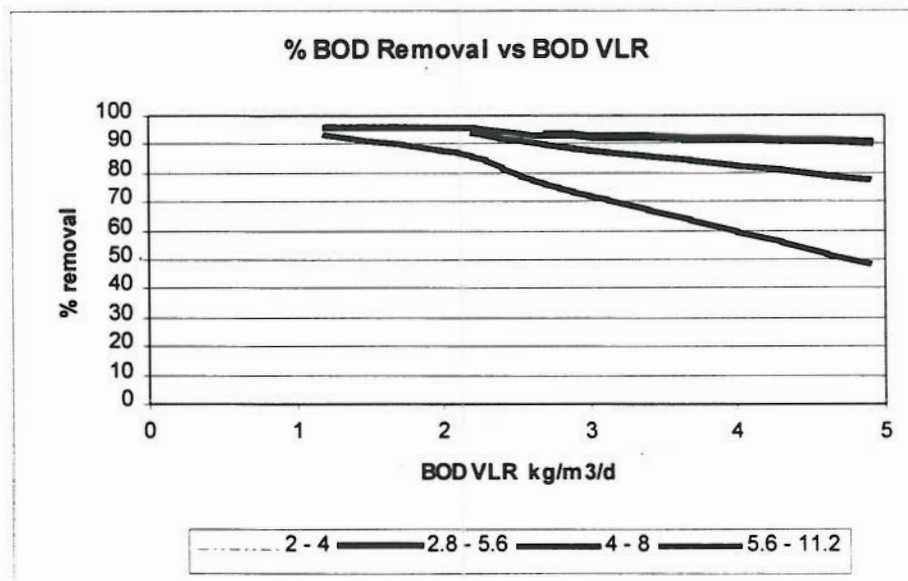


Figure 4.

10. Conclusions

Understanding the effects of the physical and chemical characteristics of the chosen biomass support media is essential in the design and operation of BAF's.

Particle density is an important parameter in setting backwash water and air rates. Lower density media can save costs in the provision of pumps and pipework because of the lower wash rates required, however, lower density values are often associated with higher attrition rates. This can cause extra cost through media replacement and blocked underdrain systems.

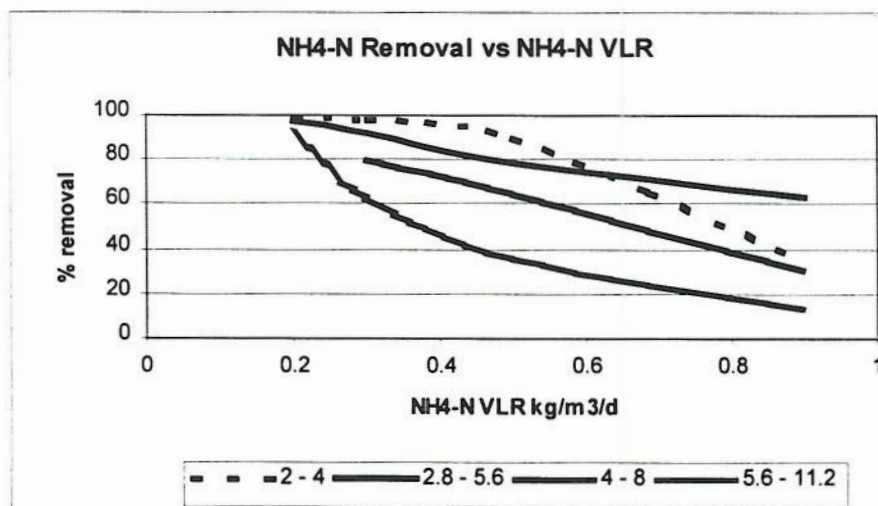


Figure 5.

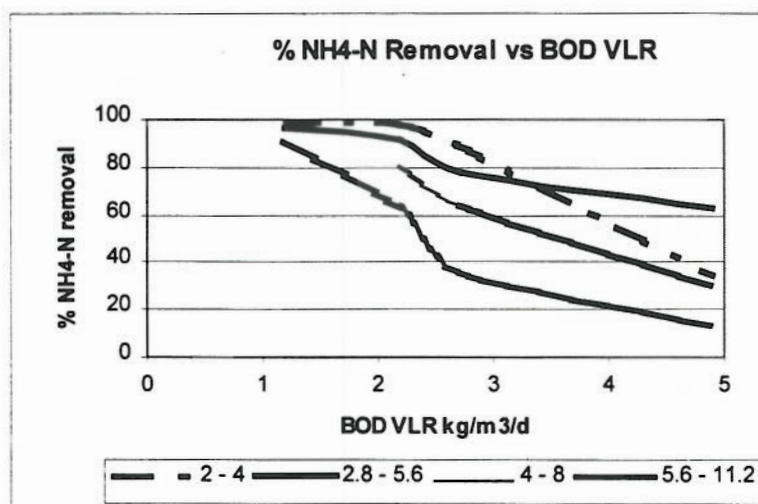


Figure 6.

Optimising media particle size is critical in designing a BAF plant to achieve a specified effluent quality. BOD removal is less affected by particle size than nitrification.

At $\text{NH}_4\text{-N}$ VLR's of less than $0.5 \text{ kg/m}^3/\text{d}$ the small, 2-4 mm media size achieved the best nitrification rate with the penalty of a higher headloss development rate and an increased wash frequency. At higher rates the lower filter voidage led to increased solids capture and heterotrophic biomass growth in the top of the filter leading to shortened filter runs.

At higher rates the larger 2.8 - 3.6 mm media achieved the best $\text{NH}_4\text{-N}$ removal efficiency. Correct filter backwashing is essential in maintaining treatment efficiency.

11. Acknowledgements

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