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Biological Aerated Filters

BAF 3

Cranfield University
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3rd International Meeting on Biological Aerated Filters – BAF 3

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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.

DEVELOPMENT OF A NOVEL LIGHTWEIGHT MEDIA FOR BIOLOGICAL AERATED FILTERS (BAFS)

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Abstract

Clay has been foamed and extruded using novel technology, to produce a lightweight media called StarLight C. Altering the production process parameters allows control of the media diameter, density, strength, and surface roughness. In its application as a Biological Aerated Filter (BAF) media, a low density may be advantageous since this will reduce the minimum fluidisation velocity (V_{mf}) of the media. Consequently a lower liquid velocity will be required during filter backwashing, which could reduce the operating costs and increase the productivity of the reactor.

This paper reports the performance of StarLight C and standard expanded clay (media A) as media in pilot scale BAFs treating settled sewage with hydraulic residence times between 58 and 96 minutes. The BAFs were backwashed every 24 hours at a liquid flow rate corresponding to 40% of the V_{mf} of the media. The BAF using StarLight C required approximately half the volume of backwash water needed by the BAF filled with media A.

To optimise the performance of BAFs further the filter run time should be maximised. This requires the media size and voidage to be maximised without compromising filtration efficiency.

1. Introduction

The main advantage BAFs have over other secondary wastewater treatment processes is their small footprint. The land requirements for a BAF are approximately one-fifth of that needed for a trickling filter and one-tenth of that needed for an activated sludge plant (Stensel & Reiber, 1983). This is achieved through two mechanisms. Firstly, the media in the reactor acts as a substratum supporting the growth of a microbial biofilm. The media has a large surface area allowing a high concentration of microbes, typically four to five times that in conventional sewage treatment processes, to be maintained within the reactor (Smith & Hardy, 1992). This facilitates a reduction in the required hydraulic retention time, and a greater load can be treated per unit volume per day. Secondly, the media acts as a depth filter negating the need for a separate solids removal stage. Evidently the media used in a BAF has a large influence over the properties of the process.

One of the main disadvantages of the BAF process is the need to backwash the filter regularly with treated effluent to prevent it blocking. This increases both the maintenance and the capital costs and reduces the reactor productivity. Extending the filter run time and reducing the backwash liquid velocity can reduce these costs. Backwash liquid velocity is usually related to the minimum fluidisation velocity (V_{mf}) for the media. The most efficient backwash conditions

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occur when the bed is collapse-pulsing (Amirtharajah, 1993). The grains then exhibit velocities as high as those measured in a fully fluidised bed. The condition can be reached by applying an air scour together with a sub-fluidisation water wash at a velocity between 40-60% of the V_{mf}. The V_{mf} of media is related to the grain size and density, and the bed voidage (Coulson & Richardson, 1978). Media density can be altered to reduce the V_{mf} without effecting the hydraulic characteristics of the filter.

The aim of this study was to compare the operational performance of two pilot scale BAFs in terms of suspended solids, and oxygen demand removal. One BAF contained standard expanded clay BAF media (media A) and the other a novel lightweight foamed clay (StarLight C).

2. Materials and Methods

Two identical pilot BAFs were run in parallel over a nine month period. Table 1 summarises the operating conditions used. The reactors were 0.2 m diameter PVC cylinders. They were 3.15 m tall and contained 0.3 m of gravel beneath 2 m of media. Each reactor was supplied with air via three aerators at the base. A downflow configuration was used with settled sewage entering at the top of the BAFs. One reactor contained StarLight C, and the other standard expanded clay (media A) used in BAFs.

Table 1: Operating parameters of the BAFs

Parameter / Feed flow (l/min)	0.3 (Day 0-55)	0.4 (Day 56-146)	0.5 (Day 147-222)
Mean total COD load* (kg/m³/d)	4.5	6.3	8.5
Mean susp. solids load* (kg/m³/d)	1.9	2.1	3.5
Hydraulic residence time (minutes)	96	72	58
Air flow (l/min)	3	4	5
Liquid velocity (m/h)	1.4	1.9	2.4

* Based on original bed volume

The specific gravity of these two media along with those used previously in downflow BAFs are compared in Table 2. Many of the materials used in BAFs are porous and absorb water. Thus, their sunken density is greater than their dry density. This applies to all the expanded materials, including StarLight C, which actually sinks in water.

Table 2: Specific gravity of BAF media (Moore *et al.*, submitted)

Material	Density (kg/m³)
StarLight C	800-900
Media A	1400
Expanded fire clay grog	1720
Expanded clay	1350-1600
Expanded shale	1680-1900
Pulverised fuel ash	1950
Pozzolana	1500
Sand	2600
Expanded schist	1400-2000

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The reactors were manually backwashed with treated effluent every 24 hours. The procedure took thirty minutes and consisted of three stages. The first stage was five minutes without influent and with an airflow reduced to just 1 l/min. Next, an air spurge of 20 l/min was applied for five minutes. The third stage consisted of ten minutes combined air scour at 20 l/min, and liquid flow at 40 % of the experimental V_{mf} of the media. This was 10 l/min for StarLight C and 18 l/min for media A. Finally, stages two and then one were repeated before returning to normal operation.

Influent and effluent samples were taken three times a week and analysed using standard methods (APHA, 1992) for suspended solids, soluble and total chemical oxygen demand (sCOD & tCOD), temperature, pH (Russell, UK) and dissolved oxygen (Jenway, UK). Soluble and total biological oxygen demand (sBOD & tBOD) was also measured weekly to establish the BOD:COD ratio for the influent and the effluents. Additionally, the backwash fluid was collected once a week, mixed, and samples taken for suspended solids analysis. Pressure transducers (VEGA, Germany) were attached to the BAFs to monitor the head build up over filter cycles. The backwash velocity of the media A column was reduced to 11 l/min for three days to justify setting the backwash velocity from the media experimental V_{mf}.

3.   Results

The sCOD removal for both reactors was around 75% over all the applied flow rates (Figure 1). This corresponds to effluent sCOD levels below 40 mg/l, tCOD levels below 60 mg/l, sBOD levels below 5 mg/l and tBOD levels below 10 mg/l. There was a reasonably stable relationship between COD and BOD. Approximately 40% of the total COD in the influent, and 15% in the effluent, consisted of BOD.
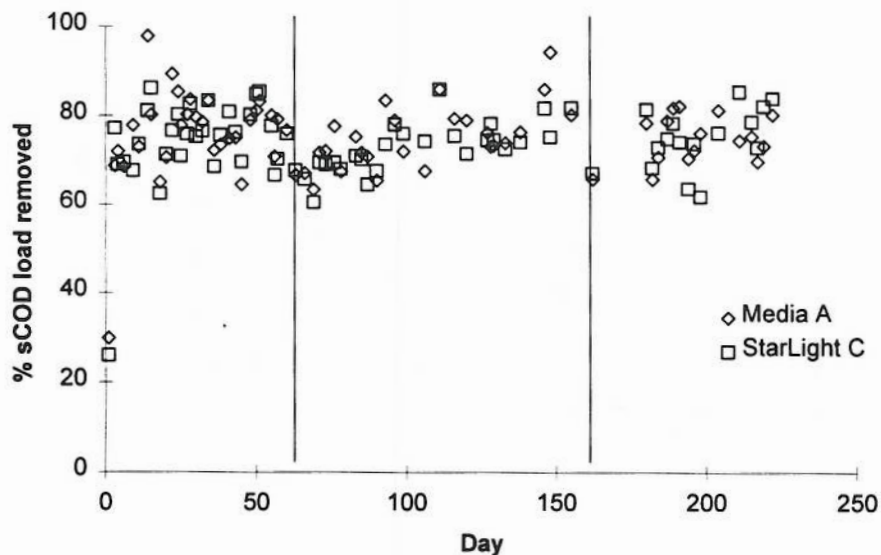

Figure 1: % sCOD removal over 222 days (lines show increases in flow)

The suspended solids removal averaged 87% in both reactors at all the flow rates used (Figure 2). This corresponds to effluent levels consistently below 20 mg/l.

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When the liquid velocity used to backwash media A was reduced to 11 l/min, the headloss build-up during the filter run increased dramatically as illustrated in Figure 3. This indicated that the filter media was not being sufficiently cleaned at the reduced velocity.
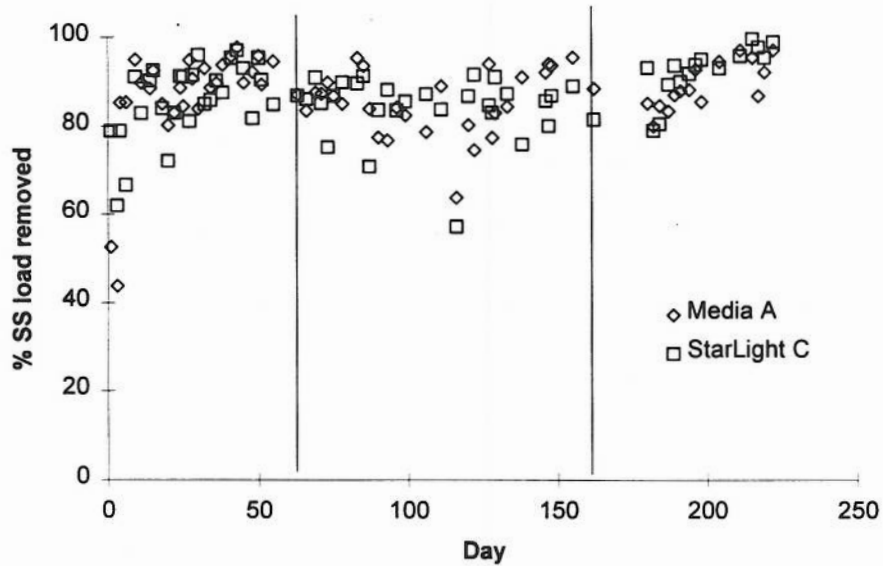

Figure 2: % Suspended solids removal over 222 days (lines show increases in flow)
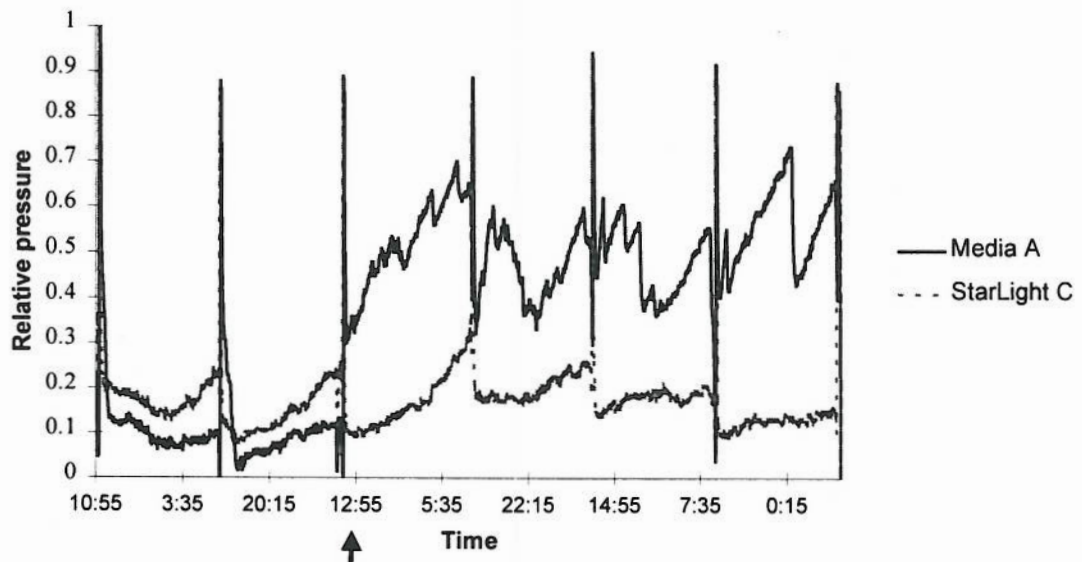

Figure 3: Relative pressure above filter beds. The arrow indicates when the backwash velocity of the media A reactor was reduced

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Confirmation of the reduced backwash efficiency of media A was obtained by examining the solids removed during backwashing. Since both reactors have the same influent and produce similar effluents, they should entrap the same amount of solids. These solids would be removed during backwashing if the procedure were effective. Table 3 shows a large, significant decrease in the solids removed from the media A reactor when the liquid backwash velocity was decreased.

Table 3: Mean suspended solids of backwash effluent

Flow	Mean solids removal at backwash (kg ± st.dev.)	
	Media A reactor	StarLight C reactor
0.4	0.06 ± 0.03	0.04 ± 0.01
0.5	0.07 ± 0.02	0.06 ± 0.01
0.5*	0.04 ±0.01	0.06 ± 0.01

* lowered backwash velocity

4.   Discussion

The sCOD and suspended solids removal results compare extremely well with those of Mann *et al.* (in press) who used very similar reactors at the same facility, but utilised sunken plastic media. They report only 49% suspended solid removal and 73% sCOD removal at flow rates of 0.3 l/min. When Mann *et al.* (in press) increased the flow rates to the BAFs the removal efficiencies decreased further. Only 40% of the suspended solids and 62% of the sCOD were removed at 0.4 l/min. Meanwhile, just 35% of the suspended solids and 30% of the sCOD were removed at 0.5 l/min.

Previously the best performances of true BAFs under normal conditions showed no major effluent deterioration, in terms of COD and suspended solids concentrations, up to loads of 10 kg $COD/m^3/d$ (Approx. 4 kg $BOD/m^3/d$) (Stephenson, 1997). At 0.5 l/min the reactor containing media A received 10 kg $tCOD/m^3/d$ and the StarLight C reactor received 15 kg $tCOD/m^3/d$. Their performance under these conditions indicates both media types have extremely good biological properties.

The BAF containing media A needed to be backwashed at a higher liquid velocity and consequently used more backwash water than the StarLight C reactor. Since the backwashing water is treated effluent from the reactors, the StarLight C reactor treats an extra 80 l of sewage per day. As well as increasing the reactor productivity, reducing the backwash water velocity can reduce the operating and capital costs of the plant by lowering the required specification of the backwash pumping system. The volume of backwash water required by BAFs can also be decreased by backwashing when the pressure in the reactors reaches pre-set levels, rather than at set times. BAFs containing smooth media require backwashing less frequently but often show inferior performance (Mann *et al.*, in press).

Further optimisation of BAF media is possible, because using the technology developed to produce StarLight C, the media diameter, strength and surface roughness can be controlled. Before altering the size and voidage of the media an analysis of the consequences is required.

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BAFs act as granular media, depth filters. The dominant particle removal mechanisms are sedimentation and interception, because the particles in settled sewage are likely to have diameters greater than 1 μm (Goldgrabe *et al.*, 1993). Filtration theory predicts improved filtration when the size and voidage of the media is decreased. Voidage is lower for media composed of small particles, and decreases as the particle size range, smoothness or sphericity increases.

The disadvantage in reducing either the media size or voidage is a corresponding increase in the rate of head pressure build-up above the filter (Coulson & Richardson, 1978). This shortens the filter run time, which increases the process power, and clean water utilisation. Therefore, an ideal media would be composed of particles with a uniform size just small enough to reach the required effluent standard. Voidage should be maximised by utilising non-spherical, rough particles, so that head loss build-up is minimised.

In addition to increasing the voidage, non-spherical, rough particles are also thought to increase filtration efficiency. This may be due to the local changes in flow direction improving the collection of particles from the flowing suspension (Ives, 1990). Rough surfaces also improve filtration indirectly by promoting biofilm growth on the media surface. Thus, theoretically non-spherical rough particles can achieve the same amount of particle removal as smaller spherical particles and lower the operational costs.

The EC treatment standard required for sensitive areas is currently effluent suspended solids concentrations of 35 mg/l and BOD levels of 25 mg/l. The pilot reactors in this study produced effluent of a much better standard than this. Therefore, the next stage of the media optimisation will involve increasing the media size to reduce the pressure build up above the filters and so increase the filter run time. The precise design of media using novel technology should allow optimisation of BAF media for different applications.

5. Conclusions

- Both materials performed very well as BAF media showing superior performance to materials previously tried.

- When media A was backwashed at below 40% of its V_{mf} there was incomplete solids removal which led to increases in head pressure build up above the filter.

- The lightweight StarLight C media has a low V_{mf} and consequently used roughly half the volume of cleaned effluent during backwashing than media A. It showed 19,14, and 11% increased productivity at flow rates 0.3, 0.4, and 0.5 l/min respectively.

- Further studies on BAF media should help optimise the process and reduce both its operating and capital costs. Optimal media characteristics will depend on the reactor application. Therefore, media which can be manufactured with controlled properties such as size and density provide definite advantages.

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6. Acknowledgements

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