1403411749

Cranfield UNIVERSITY

CRANFIELD UNIVERSITY
LIBRARY

Biological Aerated Filters

BAF 3

Cranfield University
Wednesday 3rd March 1999

Organised by:
The School of Water Sciences, Cranfield University

Sponsored by OTV Birwelco

Editors – Professor Tom Stephenson and Dr Bruce Jefferson

Published by:
The School of Water Sciences
Cranfield University
Cranfield
Bedfordshire
MK43 0AL, UK

ISBN– 1 86194 015 7

© 1999. The contents are world copyrighted by the School of Water Sciences, Cranfield University, in the first instance. Permission must be sought from the School of Water Sciences before the whole or any part of this document is transcribed.

CRANFIELD UNIVERSITY
LIBRARY

CLASS MARK

628 · 35
BID

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.

CRANFIELD UNIVERSITY LIBRARY

Cranfield UNIVERSITY

BIOMODULE - A COMBINED STRUCTURED AND GRANULAR MEDIA BAF

T.R. Williams, Mowlem Engineering Projects, Port Causeway, Bromborough, Wirral, Merseyside, L62 4TP
T. Stephenson, School of Water Sciences, Cranfield University, Cranfield, Bedford, MK43 0AL

1. Introduction

Biological aerated filters operate as fixed film systems in which micro-organisms grow on a submerged fixed structured or granular inert support media within an aerated reactor (Stephenson *et al.*, 1993). Periodic backwashing of the filter is required as the media bed gradually clogs due to the growth of biomass and retention of solids. The advantage of the BAF process is the small footprint it occupies relative to comparable processes such as activated sludge and trickling filters. The small footprint is due to the fact that the fixed film of biomass on the support material (media) leads to a high concentration of active bacteria per unit volume of the media and thereby to relatively small reactors. Another advantage is the retention of suspended solids that eliminate the need for final sedimentation tanks (Hagedorn *et al.*, 1994). For the same degree of treatment, biofilters require approximately three times less aeration volume than activated sludge units, and twenty times less than trickling filters (Smith *et al.*, 1992). In summary BAF systems are used for providing a treatment method for reducing the amount of organic carbonaceous material (BOD/COD), suspended solids and ammonia in wastewater.

For the ammonia oxidising bacteria (nitrifiers) to prevail the substrate loading rate must be carefully controlled, such that the loading rate does not get too high i.e. 2.5 kg BOD_5/ m^3.d. However, this may only yield a modest reduction in ammonia. In order to achieve a high (80 - 90%) ammonia removal efficiency then the loading rate would need to be <1.7 kg BOD_5/m^3.d (Mendoza-Espinosa and Stephenson, 1999). These figures are only a guide as many other factors affect nitrification such as toxicity due to industrial discharges, pH, which should be in the region of 7.5 to 8.6, and the alkalinity which should be high enough to permit the degree of removal required.

This paper describes the Biomodule; development of existing BAF systems, in order to enhance combined carbonaceous BOD and ammonia removal using the concept of combining fixed structured media with granular media in a single vessel. With granular media, both the BOD_5 and solids loading rates are an important consideration when considering the run time of the reactor. If not controlled this can lead to a premature blockage of the media. The granular media can be more susceptible to toxic shock loading as the mixing will tend to be plug flow. The fixed structured media provides a more open passage for the substrate that permits a higher loading rate and low head loss, but does not provide good filtering characteristics. The fixed structured media operates as a fully mixed system that disperses shock loading throughout the reactor.

The concept was to utilise the fixed structured media as the first stage of treatment in a downflow reactor. This first stage of treatment would be located above a bed of expanded clay granular media that would form the second stage of treatment. The granular media would capture any solids or shed biomass from the 1st stage and would receive a reduced BOD_5 and suspended solids loading in order to facilitate nitrification. Air would be introduced at the bottom of the reactor and would flow countercurrent to the liquid flow on the basis that any oxygen not utilised by the bacteria in the 2nd stage would be 'free' air for the bacteria in the 1st stage.

2. Materials and Methods

2.1 Details of Biomodule

A 100 population equivalent (pe) pilot plant was designed based on industry standard per capita BOD loadings.

The Biomodule pilot plant comprised a single downflow cylindrical reactor (Fig. 1), 1.0m in diameter and containing two types of media. The first was a fixed structured media supplied by Munters (type FB10.12-120.60) with a specific surface area of 240 m^2/m^3 manufactured from 0.3 mm thick rigid PVC corrugated sheets to occupy 0.94 m^3. The second was an expanded clay media supplied by Alpha Insulations from Aridos Ligeros, Spain (Arlita), with a specific surface area of 3.98 m^2/cm^3, size range 3.5 to 6.2 mm, density 1350 kg/m^3 and a voidage without biomass of 30%. The volume of this second section was 0.78 m^3. Both medias were segregated from each other by a 300mm void space which allowed the granular media to expand when backwashing. Compressed atmospheric air was introduced through a header and perforated lateral arrangement at the bottom of the reactor and treated effluent and backwash water were discharged through a separate header and lateral system directly below the air header.

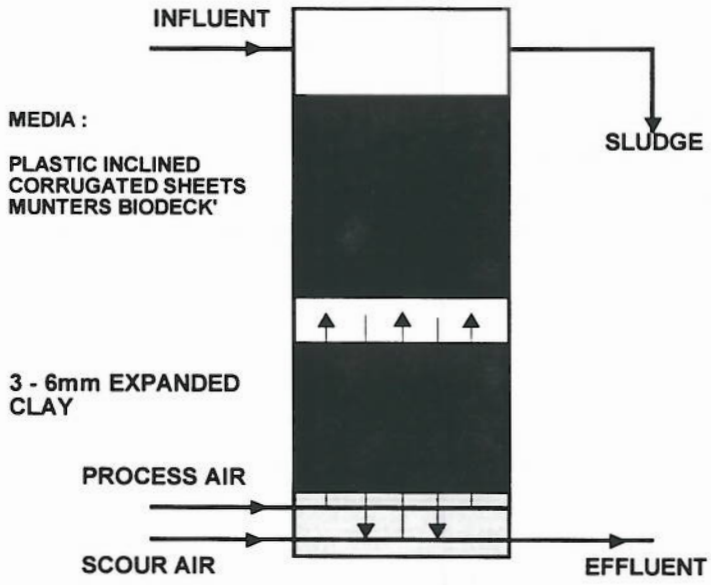


Figure 1: Schematic of Biomodule

The reactor was housed in a 10 m long x 2.4 m wide x 2.4 m high steel transport container with the Biomodule extending through the roof of the container giving an overall height of 3.7 m. Inside the container two rooms were constructed to divide the process plant (wet side) from the motor control centre and controls (dry side). The wet side contained the reactor, air blower, backwash pump, treated effluent/backwash tank, analyser cells, pipework and valves. The dry side contained the motor control centre (starters), instrument panel (I/O), analyser instrument displays and operator interface (SCADA).

Process and scour air are provided to the reactor from a variable speed air blower. The air blower provided oxygen to the micro-organisms during process operation and removes excess biomass from the media during the scouring phase of the backwashing sequence.

2.2 Control Systems

The plant was designed to operate in three control modes: operator control; auto mode 1; and auto mode 2. However, during the trials only operator control and auto mode 1 operations were performed. Using operator control the plant is controlled by the operator from the SCADA interface panel. During this mode of operation the operator has 'manual' control over all the drives, valves, and backwash timers. All analytical signals are received, displayed and trended by the system but no corrective action is taken by the controllers.

With auto mode an automatic mode of operation is used where the control system has complete control over all automatic valves, drives and backwash sequences and the outlet dissolved oxygen is maintained within a pre-set range. Whilst in auto mode 1 the valve sequencing allows the plant to operate in a carbonaceous / nitrification treatment mode. During automatic control the operator can vary process set points and alarm levels through the SCADA interface panel. In auto mode 2 the same features as auto mode 1 are provided except that the valve sequencing allows the plant to operate in a denitrification / nitrification mode.

The control system ran on a DeltaV platform which used Microsoft Windows NT as the base operating system and incorporated the OPC standard (Object Linking and Embedding Process Control) for information exchange, native 32 bit code, object oriented programming based on the IEC1131 part 3 standard and Microsoft Explorer and Microsoft Excel desktop applications. The system handled 35 digital inputs, 25 digital outputs, 12 analogue inputs and 2 analogue outputs.

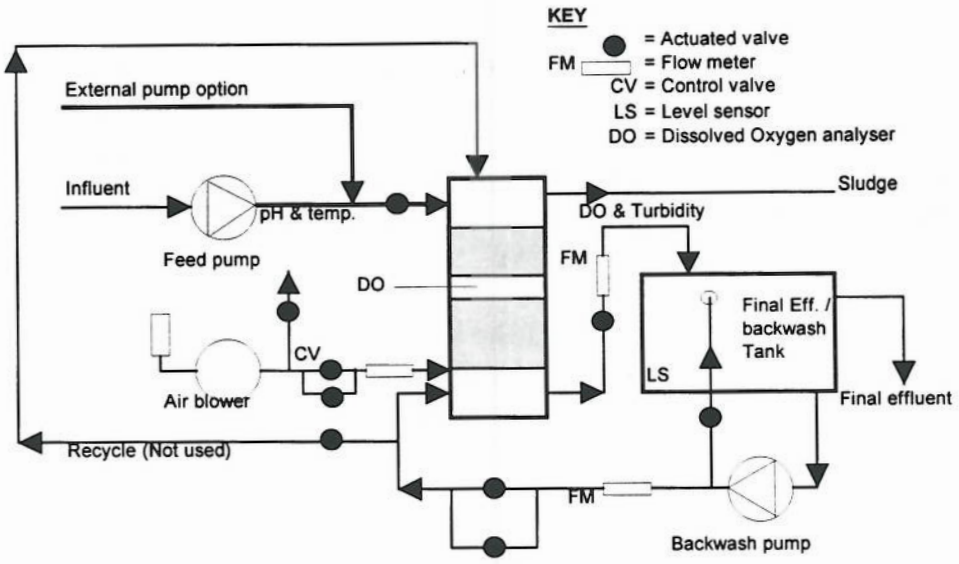


Figure 2: Biomodule Flow Schematic

Trends were available from the SCADA system for inlet temperature, inlet pH, reactor granular media differential pressure, interstage dissolved oxygen, outlet dissolved oxygen (DO), outlet turbidity, final effluent/backwash tank level, backwash flow, air flow and reactor outlet flow.

2.3 Experimental Protocol

Many sewage treatment works accept industrial effluents either directly into the sewerage system or imported by road tanker as sludges/slurries for thickening and dewatering. The monitoring and control by the water company of these industrial wastes is difficult and can present a threat to the proper functioning of the treatment works. In particular, nitrification can be affected in biological processes and the Biomodule has been designed to ameliorate such inhibition. After discussion with Welsh Water the site selected was Queensferry Sewage Treatment Works (STW) in North Wales. The influent wastewater contained some industrial effluents and there was evidence of nitrification inhibition.

When the plant was despatched to site on 21 April 1998 the system functioned in manual control. The next 5 weeks were spent commissioning the control system and analysers to enable the plant to run in operator control and auto mode 1. During this period on 28 April settled sewage was introduced into the reactor for the first time from the outlet of primary settlement tank 1 (PST1, Fig.3). The plant was initially set at a feed rate of 1.44 m^3/h in order to review the reactor's hydraulic capability whilst establishing biomass. On 5 May 1998 the first set of analytical results for suspended solids (SS) and COD for week ending 1 May 1998 were received which revealed a higher concentration of SS/COD than had been anticipated. On 11 May the corresponding BOD results arrived. Considering these early results the plant flow rate was reduced on 5 May to 1 m^3/h and subsequently to 0.8 m^3/h on 10 May.

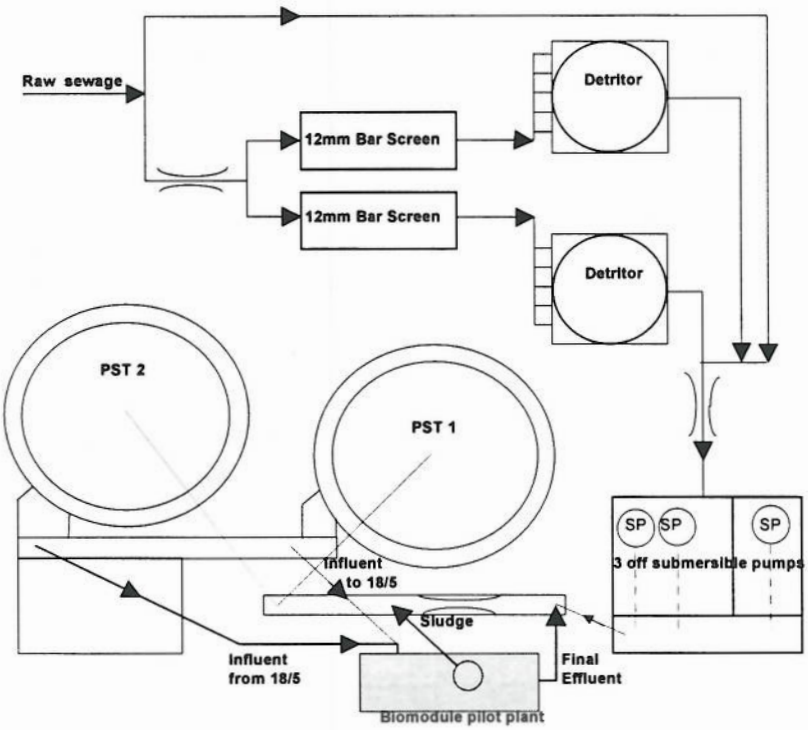


Figure 3: Queensferry STW Site Location Plan

Between the 11 May and 6 June inclusive the plant was generally run in operator control from the SCADA with an occasional trial in auto mode to review the stability of the dissolved oxygen control probes. It was realised during these trials that the probe should be repositioned to the top of the flow cell to achieve the accuracy required. On the 7 June the plant was set in auto mode 1. The feed flow rate was set at 0.8 m^3/h and the outlet DO setting was 2.0 mg/l + - 0.5 mg/l. Backwashing frequency was set at 1:12 h

A detailed sampling programme was carried out over a period of 55 d and four sample locations were selected:
Sample point 1 - Settled sewage / Influent - time averaged composite sample
Sample point 2 - Biomodule interstage - spot
Sample point 3 - Treated effluent - time averaged composite sample
Sample point 4 - Sludge - spot
The composite samples were collected in an automatic sampler which was set to grab 4 samples per hour for a composite hour and 24 composite hour samples per day to form the daily composite sample. The spot samples were taken at random times each day. Sludge samples were taken at approximately 2 min into a wash cycle. All of the samples were analysed by Hyder Environmental Laboratories and Sciences at Runcorn, Cheshire, under NAMAS laboratory accreditation No.0897 using standard methods (APHA, 1997).

3. Results

The results from the performance trial at Queensferry STW were divided into three distinct periods of operation:

Period 1 (11 May to 29 May) – This period covers a period of interrupted operation for the wet commissioning of the Biomodule instrumentation and control system.

Period 2 (30 May – 6 June) – During this period the plant was operated in manual control. The air flow was fixed and backwashing was carried out once per day.

Period 3 (7 June – 20 June) – For this period the plant was in automatic control. The air flow was automatically regulated to achieve a desired dissolved oxygen set point and backwashing was initiated by timer logic.

During the trial periods 1 to 3 the BOD_5 loading rates ranged from 0.55 to 3.78 kg/m^3.d (Fig.4). To produce an effluent that satisfied the Urban Waste Water Treatment Directive (UWWTD) of 20 mg/l BOD_5 then the overall media volumetric loading rate should be less than 2.5 kg BOD_5/ m^3.d which equated to a fixed structured media applied volumetric loading rate of 4.6 kg BOD_5/ m^3.d.

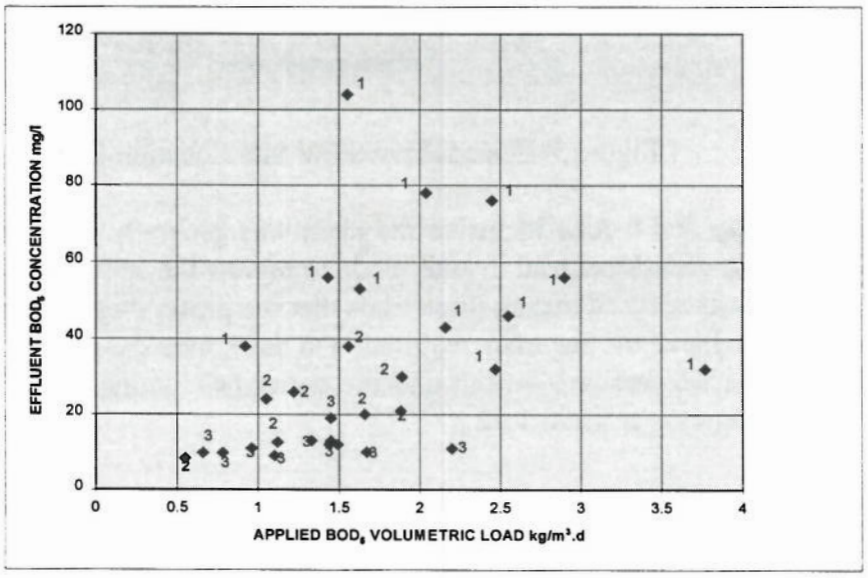


Figure 4: Effluent BOD_5 compared to applied BOD_5 volumetric load for period 1,2 & 3

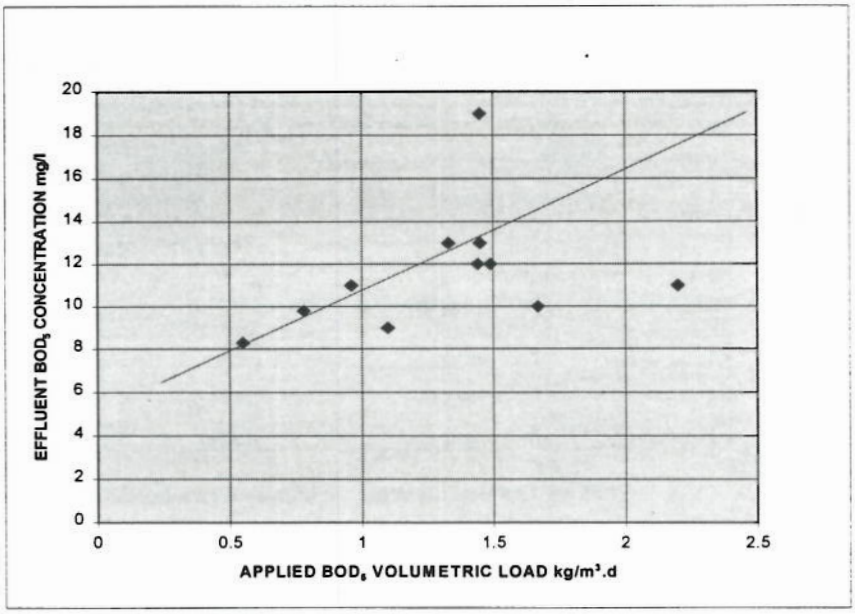


Figure 5: Effluent BOD_5 compared to applied BOD_5 volumetric load for period 3

During the trial periods 1 to 3 the solids loading rates ranged from 0.63 to 1.80 kg/m^3.d (Fig.6). To produce an effluent that satisfied the UWWTD of 30 mg/l SS then the overall volumetric media loading rate should be less than 1.3 kg SS/ m^3.d (Fig.7) which equated to a fixed structured media applied loading rate of 2.4 kg SS/ m^3.d.

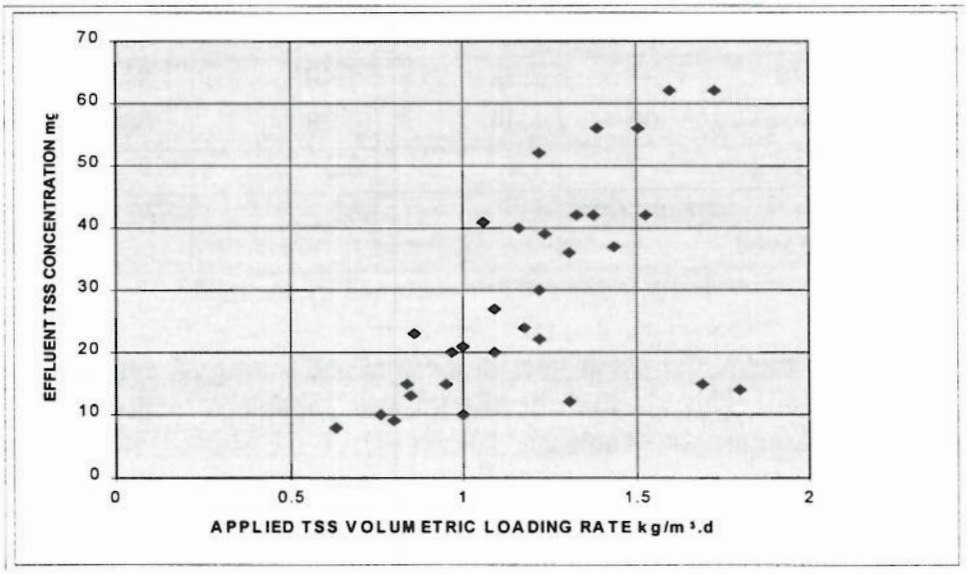


Figure 6: Effluent SS compared to applied SS volumetric load for period 1,2 and 3

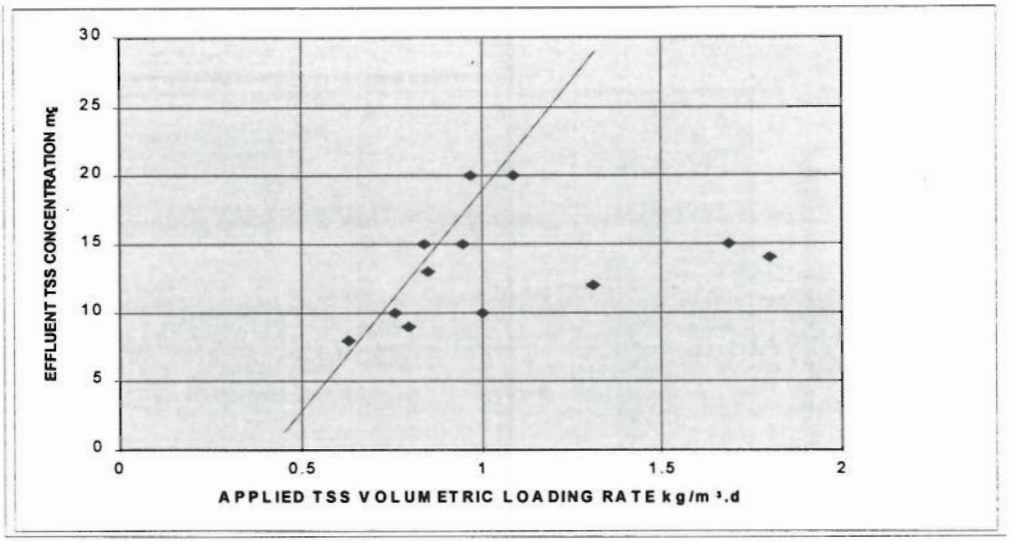


Figure 7: Effluent SS compared to applied SS volumetric load for period 3

Between 7 June and 20 June the Biomodule was operated in auto mode 1 and achieved effluent BOD and SS concentrations of <15 mg/l (Table 1). Throughout this period the mean air flow was 334 m^3/d and the COD:BOD ratio was 3:1.

Table 1: Process performance during auto mode 1

Parameter	BOD_5	COD	SS	NH_3-N
Inlet concentration mg/l	118	383	97	27.4
Outlet concentration mg/l	10.3	88	13.4	26
Inlet load kg/d	2.32	7.40	1.83	0.52
Volumetric load kg/m^3.d*	1.34	4.28	1.06	0.30
Removal rate kg m^3.d*	1.2	3.3	0.91	0.015
Mean air consumption m3/d/kg removed	170	62	225	13641

*Based on the volume in the reactor occupied by the media.

Some ammonia removal did occur later in the trial and during an extended period following on from the main trial. This showed the reactor was capable of achieving a maximum of 64% ammonia removal on the site (Table 2).

Table 2: Ammonia analysis results for period 18/6 to 10/7

Spot NH_3-N	Analysis Results for Period 18/6 to 10/7		
Date	Inlet NH_3-N mg/l	Outlet NH_3-N mg/l	Air flow m^3/d
18/6	23.6	26.3	408
19/6	15.4	12.6	408
20/6	26.8	13.3	432
21/6	26.1	14.1	432
24/6	35.1	14.1	473
29/6		12.0	226
1/7		19.0	480
2/7		15.7	528
3/7		10.8	552
4/7		10.6	504
10/7	40	14.5	408
Mean	27.8	14.8	

The pH for alkalinity values during period 3 were, respectively, close to optimum and sufficient for full nitrification. However, toxicity analysis on the settled sewage using the Amtox (Waterfront Technologies Ltd, UK) revealed some toxicity and therefore inhibition to nitrification.

Table 3: pH, alkalinity and outlet nitrite and nitrate concentrates

Date	pH	Inlet alkalinity mg/l	Outlet NO_2-N mg/l	Outlet NO_3-N mg/l
7/6	7.13	255	-	-
8/6	6.83	218	0.61	0.09
9/6	7.20	247	0.71	12.4
10/6	-	247	0.3	1.39
11/6	-	259	0.45	0.48
12/6	-	238	0.9	1.21
13/6	7.18	-	-	-
14/6	-	269	-	-
15/6	7.24	-	-	-
16/6	-	308	2.82	0.38
17/6	-	270	2.9	1.39
18/6	-	225	3.22	1.74
19/6	-	225	6.73	1.23
20/6	-	275	7.63	3.57
21/6	-	280	6.53	2.53

The low concentrations of nitrate in the outlet also confirmed that nitrification was not occurring. Elevated nitrite concentrations towards the end of the test period (Table 3) indicated that a nitrifying population was developing.

The air flow rates during this period were between 16 m^3/h to 23 m^3/h and averaged 21 m^3/h between 1/7 and 10/7. When the reactor upflow air velocity was above 23 m/h (18 m^3/h) some biomass was displaced in to the final effluent.

Backwashing of the reactor was carried out manually through the SCADA operator interface until the 7th June when the system went onto automatic control. The wash frequencies were initially set at 1:24 h, displacing approximately 1.5 bed volumes per wash, and changed to 1:12 h when in automatic control, displacing approximately 1.2 bed volumes per wash. The outlet turbidity increased immediately after the wash rising to a peak then falling back to its original value approximately 3 h after the wash. This equated to one empty reactor volume which suggested that the wash period was too short, although the SS daily composite samples did not suggest an accumulation of solids in the bed. Over a 24 h period the top water level (TWL) increased by approximately 200 mm. From the outlet flow trends the optimum run time before the flow started to reduce was 16 h.

An air and water combination was used for all backwashes and Table 4 shows the backwash sludge daily volumes and solids loadings. The spot samples were taken 2 min into the backwash sequence. During periods 1 and 2 the backwashing was initiated manually which allowed a greater displacement of the backwash tank volume than in automatic control.

Table 4: Backwash sludge volumes and loadings

Period	Date	Operating Mode	Sludge SS mg/l	Wash Frequency per day	Flowrate/ wash m^3/h	Daily Wash Volume m^3/d	Daily Sludge Load kg/d
1	27/5	manual	472	1	36	2.5	1.18
1	29/5	manual	1096	1	36	2.5	2.74
2	1/6	manual	1272	1	36	2.5	3.18
2	3/6	manual	708	1	36	2.5	1.77
2	5/6	manual	550	1	36	2.5	1.38
3	10/6	automatic	184	2	*	4	0.74
3	18/6	automatic	94	2	*	4	0.38
3	20/6	automatic	510	2	*	4	2.04

* Automatic washing sequence = 60s slow wash followed by 180s fast wash resulting in a total wash water volume per wash of 2 m^3

Table 5 shows the sludge production in terms of kg SS/kg BOD_5 removed. The effect of two washes per day gave better biomass/ reactor solids control which resulted in a lower sludge yield / kg BOD_5 removed.

Table 5: Backwash sludge production kg SS / kg BOD_5 removed

Period	Date	kg BOD_5 removed /d	Kg SS/kg BOD_5 removed
1	27/5	2.22	0.53
1	29/5	2.05	1.34
2	1/6	1.36	2.34
2	3/6	0.96	1.84
2	5/6	1.70	0.81
3	10/6	2.25	0.33
3	18/6	2.25	0.17
3	20/6	2.34	0.87

Sewage was introduced into the Biomodule at a flow of 1.44 m^3/h on 28 April 1998. Foaming was evident for the following 5 d then receded to a low level (air bubbles were visible on the surface). The flow rate was reduced to 1 m^3/h on 5/5 and subsequently to 0.8 m3/h on 10/5. Foaming was again evident on 3/6 which was followed by a 4 d period when the reactor was overflowing at the backwash weir after only 6 to 16 h into the run. When the plant was placed in automatic control on 7/6 and the backwash frequency was changed to 1:12 h the plant showed no deterioration in flow over the 12 h run period.

Tables 6, 7 and 8 show the removal efficiency for COD, BOD and SS across each media phase for each of the analysis periods. From Tables 6 and 7 the amount of COD and BOD removed across each stage is given for a limited analysis. The interstage (between medias) sample showed a high proportion of suspended solids and biomass which would have influenced the COD and BOD values.

Table 6: COD removal efficiency across each media stage

		Stage 1		Stage 2		Overall	
Period	Date	% removal	kg removed	% removal	kg removed	% rèmoval	kg removed
1	27/5	47	3.91	17	0.74	56	4.65
1	28/5	21	1.71	59	3.73	68	5.44
1	29/5	35	2.85	68	3.57	79	6.42
2	1/6	19	1.71	72	5.26	77	6.97
3	12/6	33	1.78	44	1.61	62	3.39
3	17/6	45	4.05	69	3.45	83	7.5
3	20/6	44	2.61	50	1.65	72	4.26

Table 7: BOD_5 removal efficiency across each media phase

		Stage 1		Stage 2		Overall	
Period	Date	% BOD removal	Kg BOD removed	% BOD removal	kg BOD removed	% BOD removal	kg BOD removed
3	12/6	13	0.21	85	1.25	87	1.46
3	15/6	no data	no data	84	1.23	no data	no data
3	17/6	35	1.34	92	2.28	95	3.62
3	20/6	25	0.65	88	1.69	91	2.34

Table 8 shows that other than on 28 May the SS within the interstage zone were higher than the influent solids. To reduce the amount of solids accumulating in the reactor the backwash frequency was changed on 7 July from 1 in 24 h to 1 in 12 h. It can be seen that this had the desirable effect of controlling the solids levels thus showing a higher BOD/COD removal across stage 1.

Table 8: SS removal efficiency across each media phase

		Stage 1		Stage 2		Overall	
Period	Date	% SS removal	kg SS removed	% SS removal	Kg SS removed	% SS removal	Kg SS removed
1	28/5	5	0.12	62	1.4	64	1.52
2	2/6	(629)	-	96	-	69	1.57
3	7/6	Backwash frequency changed from 1:24h to 1:12h					
3	9/6	(176)	-	95	-	85	1.11
3	11/6	(103)	-	95	-	89	1.54
3	18/6	(67)	-	91	-	85	1.36
3	20/6	(2)	-	80	-	79	1.46

( ) Percentage increase

Table 9 shows the COD removal rates across each phase of treatment. For period 3 it can be seen that the mean COD removal rate is very similar for both medias i.e. c 3.0 kg COD /m^3 reactor volume.

Table 9: COD removal rates across each media stage

		Stage 1	Stage 2	Combined
Period	Date	kg COD /d/m^3	Kg COD d/m^3	kg COD /d/m^3
1	27/5	4.16	0.95	2.56
1	28/5	1.82	4.78	3.30
1	29/5	3.03	4.58	3.81
2	1/6	1.82	6.74	4.28
3	12/6	1.89	2.06	1.98
3	17/6	4.3	4.42	4.36
3	20/6	2.78	2.12	2.45

4. Conclusions

• To achieve a 20 mg/l BOD_5 : 30 mg/l SS effluent standard the media overall (fixed structured plus granular submerged) volumetric loading rates (VLR) should be < 2.5 kg $BOD_5/m^3.d$ and < 1.3 kg SS $/m^3.d$. The fixed structured media volumetric loading rate should be < 4.6 kg $BOD_5/m^3.d$ and < 2.4 kg SS $/m^3.d$.

• At a mean BOD_5 VLR of 1.34 $kg/m^3.d$ a 10.3 mg/l BOD_5 mean effluent standard was achieved. At a mean SS VLR of 1.06 $kg/m^3.d$ a 13.4 mg/l SS mean effluent standard was achieved.

• At a mean COD overall media volumetric loading rate of 4.14 $kg/m^3.d$ a mean COD effluent concentration of 88 mg/l was achieved

• Full nitrification did occur in the later days of the trial and during an extended period following on from the main trial.

• For the trial periods 1,2 and 3 the mean sludge production was 1.0 kg SS/kg BOD_5 removed. For trial period 3 (automatic mode) the mean was 0.45 kg SS/kg BOD_5

• The reliability of the equipment during the trial was very good with no mechanical breakdowns. The Delta V control system was found to be very user friendly and simple to reprogram.

5. Acknowledgements

The authors wish to thank Fisher Rosemount for provision of the control systems.

6. References

APHA (1992) Standard methods for the examination of water and wastewater. 18th ed, American Public Health Association, Washington DC, USA.

Hagedorn-Olsen C, Moller H.I, Tottrup H. and Harremoes P. (1994) Oxygen reduces denitrification in biofilm rectors. *Water Sci. Technol.*, **29**, (10-11) 83-91.

Mendoza-Espinosa, L, and Stephenson, T (1999) A review of biological aerated filters for wastewater treatment. *Environ. Eng. Sci.*, in press.

Smith A. and Hardy J.P. (1992) High rate sewage treatment using biological aerated filters. *J.Chartered Inst. Water Environ. Management*, **6**, 179-183.

Stephenson T., Mann A. and Upton J. (1993) The small footprint wastewater treatment process. *Chemistry & Industry*, April, 533-536.