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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.



RECENT APPLICATION AND DEVELOPMENTS OF THE BIOBEAD SYSTEM

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Abstract

This paper describes the background of recent engineering changes to the Biobead™ system. In particular known design pitfalls are described. The development of technically improved aeration and flow distribution methods are outlined. The extension of the system to combined C & N removal is outlined together with some recent experimental data which shows higher than expected de-nitrification performance. The benefits of a pre-filtration before the aerated part of the media bed is apparent particularly when removal of industrially derived COD is required to reach UWWT directives standards. This method also allows tertiary treatment of high influent solids whilst maintaining Ammonia removal.

1. Introduction

Whilst BAFF (Biological Aerated Flooded Filters) systems have been available in Europe since the early 70's ⁽¹⁾, commercial units have been available only since 1980, being supplied notably by OTV ⁽²⁾ and Degremont ⁽³⁾. The uptake of the technology in the UK was slow. A start was made at the Water Research Centre in 1986 where both technical and commercial evaluations were made ⁽⁴⁾. This was picked up quickly by Yorkshire and Thames Water companies. From about 1989 onwards a new impetus developed to meet new effluent standards such as River Quality Objectives, European Bathing Beach Standards and Urban Waste Water Treatment Directive. Often these requirements had to be met on existing sites with limited space or on new sites where minimal environmental impact in terms of visual amenity or odour emissions were required. These needs will often direct the designer towards compact, high rate plants rather than conventional Activated Sludge plants.

At that time the problems associated with BAFF technology were considered to be:-

- a) Reliable and effective removal of Biomass and other solids from the media.
- b) Recovery of performance after media cleaning.
- c) Control of Biomass inventory and age.
- d) Pressure drop build up.
- e) High air usage and thus high operating cost.
- f) Odour control.
- g) Media life and retention.
- h) High capital costs.

Many variants of the BAFF system are now available but the common feature is a media made from mineral, metal or plastic upon which an active biomass is retained which effects biological of the particular waste water in the presence of dissolved oxygen supplied usually by a direct aeration system. The media can be a granular material either lighter or heavier than water. Alternatively a structured, fixed position media can be used often in conjunction with a solids removal stage, which the finer granular filtering media does not require.

2. The Biobead™ System

The Biobead™ system resulted from a development programme in partnership with Anglian Water. This has been described elsewhere ⁽⁵⁾ and engineering development has rested solely with Brightwater Engineering Ltd since 1993.

Biobead is an upflow, buoyant media BAFF as shown in figure 1. Flow enters the base of a cell and is distributed by a deflector plate. The flow then passes upwards into the media bed. The media is granular (3-4 mm diameter) made of a mixture of polyethylene's with a textured surface which is also compounded to have a neutral electrical charge to assist biomass attachment. The media below the aeration grid forms a filtration zone which removes suspended solids in the influent. This zone can also be deepened to form a de-nitrification zone when influent contains nitrate or a recycle from a nitrified effluent. Dissolved oxygen is provided from air injected into the bed by the aeration grid. This air also provides energy to lift and mix the influent within the bed. Media is retained by a perforated stainless steel mesh attached to a load bearing structure. A level of liquid is held above the mesh to facilitate transfer of water to and from adjacent cells during the cleaning process.

The media will periodically require to be cleaned due to build up of solids and the consequent back-pressure and impairment of oxygen transfer. For most common variants of design, the cleaning cycle commences with cessation of flow to that cell. Air is then fed to the lower air scour distribution grid which causes the bed to fluidise and circulate fully within the cell. This is a feature unique to Biobead and results in vigorous cleaning of the media. When this process has been completed, clean liquid from other cells is used to displace the sludge from the base of the cell using the liquid distribution system in reverse. Normal feed to the cell is then returned except that effluent is recycled via the sludge handling system to remove dispersed solids within the media bed.

Daily mean loading rates are typically 2.5kgBOD/m³day for carbonaceous treatment or up to 0.6kgNH₄-N/m³ day for Nitrification dependant on effluent quality required and the treatability of the influent. These figures allow for the normal UK diurnal variation of about 1.7 peak to daily mean. Where 24 hour composite samples are used for compliance higher loading can generally be applied to reach particular standards. For wider daily variations care must taken to ensure that peak loads are not excessive. With respect to hydraulic loads up to 6m³/m³ hour is possible depending on the allowable pressure loss and the organic loading rate applied.

The modular nature of the cells allows safe scale-up to be made to any number and size of cell. At this time our designs centre on aeration and media retention grid sizes of 5.5 meters square.

The Biobead system has found application to the following duties:-

- a) Carbonaceous BOD/COD removal.
- b) Nitrification as tertiary treatment.
- c) Combined suspended solids removal and nitrification.
- d) Combined BOD removal and nitrification.
- e) Combined BOD removal, nitrification and de-nitrification.

BFF systems can be configured to achieve any form of biological treatment. The pre-filtration zone of the Biobead system offers the opportunity and advantage of:-

- a) Achievement of effluent standards normally associated with tertiary sand filters.
- b) De-nitrification.
- c) Rectification or elimination of secondary treatment final settlement.
- d) Rectification of poor primary treatment.

3. Design Pitfalls

There are 4 main categories of problem which Brightwater and other BAFF suppliers have experienced over the last few years. Namely:-

3.1 Under-sizing

This will occur where inadequate loading and hydraulic data are provided at the design stage. Related to this is the problem of designing for peak loads created by diurnal, pumping size, storm first flush effects and industrial discharges. The modular basis for BAFF design usually makes this type of problem easily to correct once diagnosed.

3.2 Primary Treatment

BAFF systems have a finite solids storage capacity above which oxygen transfer is reduced and pressure drop will increase rapidly. Effective primary treatment or media bed cleaning procedure is thus essential. Some problems have been found when BAFF return liquors have been returned for co-settlement in a lamella plate primary treatment due to growth of biomass on the plates. Wide spacing of the plates or an effective plate cleaning system will rectify this problem.

Under saline intrusion condition primary treatment will be impaired due to density changes. In fact temperature change is a good method for monitoring saline intrusion. Sludge thickening will also be impaired. Cell lysis where rapid changes in salinity occur will also increase soluble BOD load passed forwards for treatment. Chemical addition is an effective countermeasure in these conditions.

3.3 Salinity

Intermittent saline intrusion above 3000mgCl/litre will disrupt any biological process unless acclimatisation occurs. Lower loading rates ($<2\text{kgBOD/m}^3\text{day}$) will reduce this problem but it is likely that suspended solids will increase in the final effluent to an extent that a tertiary filter is required. For UWWT standards this may not be necessary since 24 hour composite samples are used.

3.4 Septicity

This represents a major problem to all BAFF systems due to their low retention times. Septic shock is a toxic effect which will substantially reduce performance by pre-empting oxygen supply and by permanent changes to the biomass composition. Notably the growth of extra-cellular polysaccharides and filamentous organisms can cause blockage and binding of the media as well as killing active bacteria and higher life forms. The intensive cleaning method of the Biobead system is a clear advantage in overcoming such problems. However such problems are best dealt with outside the BAFF system preferably at source by design/operating changes or chemical dosing. The role of returned sludge liquors to primary treatment in creating septicity should not be over-looked.

If problems as outlined above are known but not capable of solution by cost effective means then sensitivity of BAFF systems should rule them out at the process selection stage.

4. Aeration System and Pre-Filtration Zone

The original Biobead systems employed rubber membrane diffusers attached to the cell floor. Over a period of time, performance data showed that limited capture of solids occurred with this arrangement, the ultimate life of rubber membranes remained uncertain and the evenness of the air distribution was sensitive to state of cleanliness of the media bed. Thus a revised design was developed wherein air was injected part way up the media bed by a lattice of small bore stainless steel pipes with 1mm large holes. This arrangement was optimised to allow easy installation and removal by a modular design where typically 3 sections (e.g. 5.5m by 1.8m) would be installed within a cell 5.5 by 5.5m. A similar arrangement was developed for the now separate scour system fixed directly to the base of the cell used to clean the media. Thus air distribution is even throughout the cell operation cycle.

This arrangement also allowed a non aerated bed of media to be positioned under the aeration grid which can be used for filtration of solids or anoxic biological treatment in the presence of a dissolved source of oxygen.

5. Inlet Flow Distribution

In order to scale up the cell size to a range of size suitable for greater than 200,000 pe, computational fluid dynamic (CFD) was used to assess simple scale up rules. It became apparent that the current designs were at their same limit, particularly at low flow and e in reverse flow mode. To extend the size range from 5.5 x 5.5 metres to 16.5 x 11 metres an inlet arrangement such as in figure 2 was mooted. Figure 3 shows the flow distribution results when this inlet channel design is combined with a simple central feed and distribution plate arrangement. This gives a high concentration of flow at the centre of the base of the cell which is unsatisfactory. This was modified by introducing a staggered horizontal slot arrangement as shown in Figure 4. Simulation showed the correct sizing of the slots required to give both a good flow distribution to each slot equal to within a few percent and a desirable flow pattern below the media bed as in Figure 5.

There is a clear commercial benefit of moving to such designs and the use of CFD gives a clear direction to final design arrangements.

6. Combined C & N Removal in a Single Reactor

Nutrient removal is a growing requirement from the water industry. The combination of Carbonaceous and Nitrification with the Biobead system is best achieved by using 2 stages in order to gain control of sludge age at higher ($>1.5 \text{ kgBOD/m}^3\text{day}$) loading. Again commercial pressure suggests that higher loading in a single cell is desirable.

To this end a programme of investigation into combined C&N removal was completed using a pilot plant as shown in Figure 9. This is similar to previously reported small scale work but with deeper beds and a recycle of final effluent to the anoxic zone of the cell where De-nitrification takes place. Very high effluent quality was obtained as shown in figures 6, 7 and 8. Overall BOD loads were in the range of 1.0 to $2.5 \text{ kgBOD/m}^3\text{day}$ but it is clear that reduced BOD loads in the aerobic zone of the media bed were instrumental in achieving the combined full nitrification and high BOD removal. For a substantial part of the test, the recycle was 1:1 with the feed so that the maximum Nitrogen removal expected is 50 %. In figure 8 it is shown that the reduction is 60 to 80%. This could be due to 2 reasons. There may be back mixing of Nitrate from the aerobic region to the anoxic zone or alternatively Nitrate may be taking part in oxidising Ammonia or residual BOD after its' formation in the aerobic region presumably by diffusing into areas of low D.O. The effect is more pronounced when BOD is high. Whatever the explanation the effect is clearly real and beneficial. This remains to be studied on a larger scale to make sure this is not an artefact of scale such as a wall effect. The same effect has been found in large Biodisc installations. The oxidation of Ammonia by Nitrate has been described elsewhere by Stephenson ⁽⁶⁾.

7. Full scale applications of Biobead

A selection of full scale applications and results follow below.

7.1 *Madeley STW (North West Water)*

Here Biobead was applied in the form of prefabricated rectangular steel tanks. The design intent was to complete nitrification and rectify poor humus tank performance to achieve a 20/45/2 BOD/SS/ NH_3N standard. The performance test results are shown in figures 10 and 11. A recent study by North West Water ⁽⁷⁾ has checked performance of a small scale pilot column (0.3 metres diameter) along side that of full scale. Differences in cleaning and back wash characteristics were found together with higher level of channelling as shown by tracer tests. Overall treatment performance was similar but better than the pilot, achieving for example an average of 0.48 mg $\text{NH}_4\text{-N/litre}$ full scale and 0.58mg/l on the pilot. Thus pilot scale results can safely be applied to full scale design.

7.2 *Criccieth STW (Welsh Water)*

This unit was designed to achieve a 20/30 mg/l BOD/SS standard on a 95%-ile basis following gravity settlement primary treatment. Loading rates varied between 1 and $3.5 \text{ kgBOD/m}^3\text{day}$. Overall test results over an extended period are shown in Figure 12. This unit also included an integral launder filter to reduce recycle volumes and give more security to the following UV disinfection stage.

7.3 *Lyme Regis STW (South West Water)*

This system is similar to the Criccieth system applied at a green field site at a coastal location to achieve UWWT standards and to meet the European Bathing Beach Standards. Typical performance results are shown in Figure 13 and 14.

8. Conclusions

- a) The Biobead has been developed into a commercially successful and technically effective product with more than 25 applications in operation and a further 3 units under construction within the UK.
- b) Whilst BAFF technology has gained wide acceptance within the UK it must be carefully applied if design pitfalls are to be avoided.
- c) Salinity and septicity of influent should be avoided or eliminated if BAFF systems are to be used. Lower loading rates are advisable in these circumstances.
- d) Extension of scale of operation can be achieved by evolutionary development guided application of CFD and finite element stress analysis of key system component
- e) The system will find cost effective application in nutrient for both discharge and recycling duties

9. References

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Figure 1 The Biobead™ System

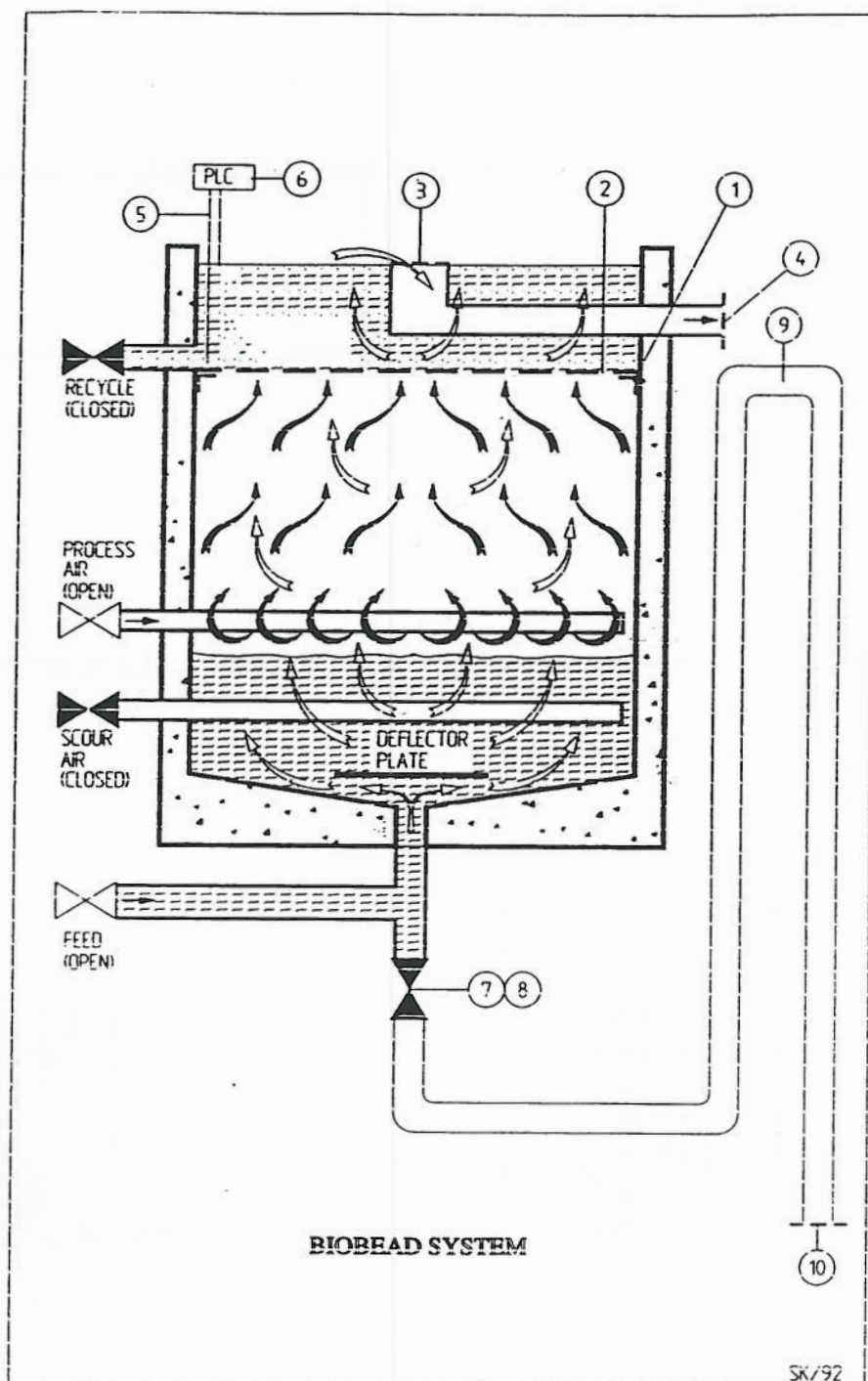


Figure 2 Schematic of Inlet Channel System

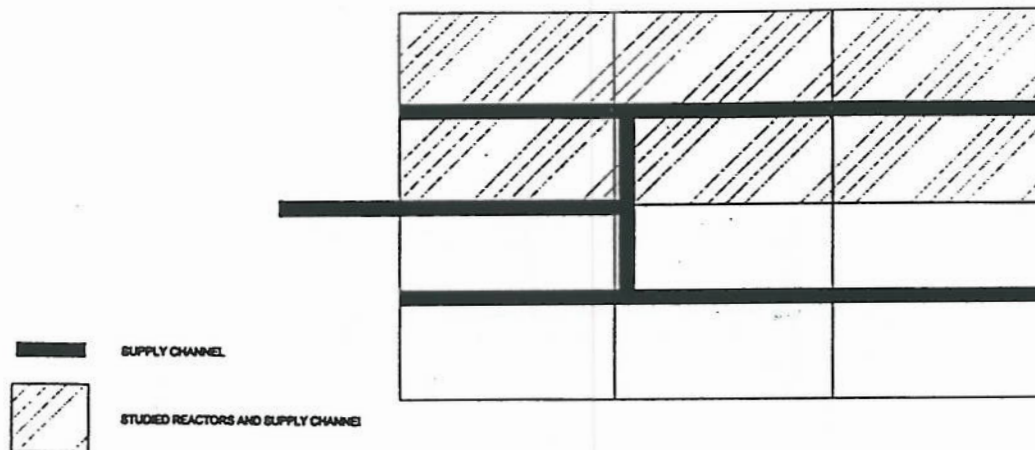


Figure 3 Water Flow Pattern in Reactor with Central Feed and Deflection Plate

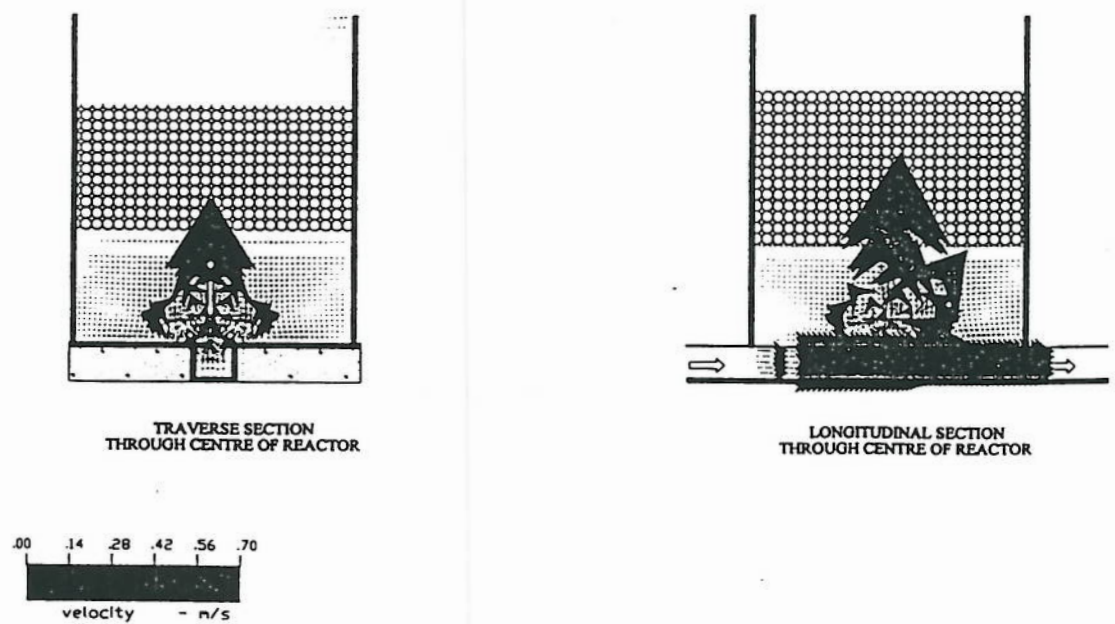
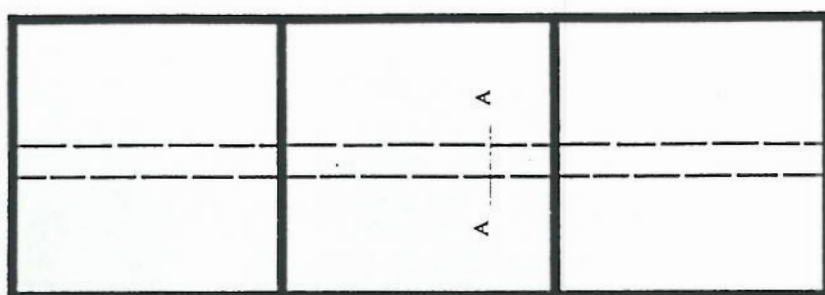
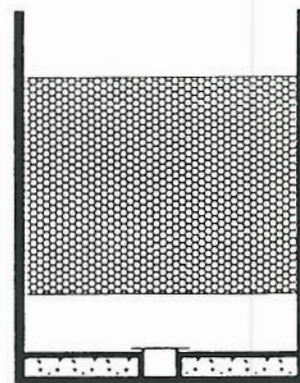


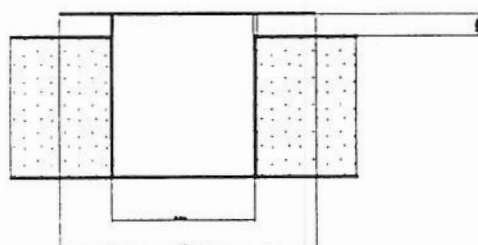
Figure 4 Detail of Horizontal Inlet



VERTICAL SECTION THROUGH CENTRE OF THE REACTOR



LOCAL ENLARGED DETAIL AT SECTION AA



SIX CELL ARRANGEMENT

1	2	3

Figure 5 Flow Pattern at 0.05m above Floor

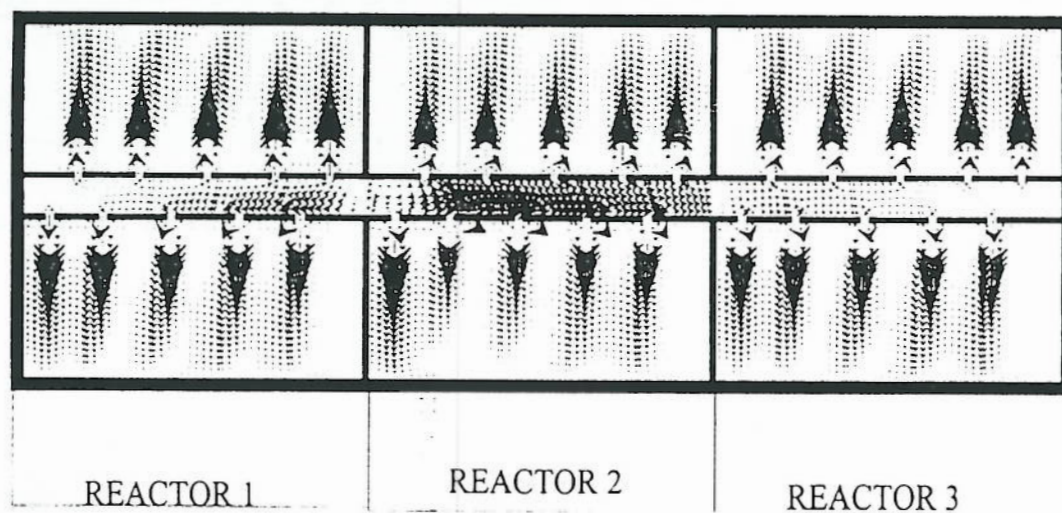


Figure 6

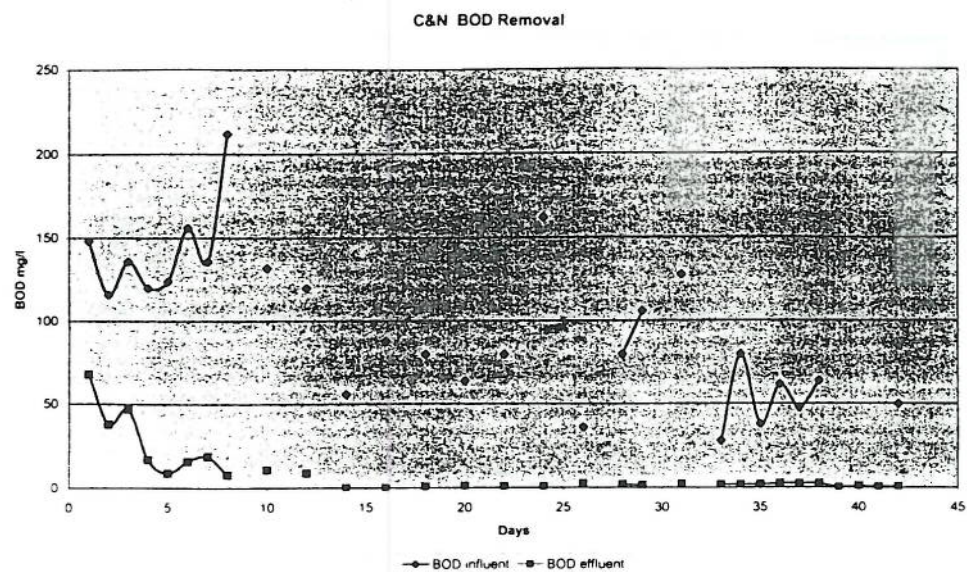


Figure 7

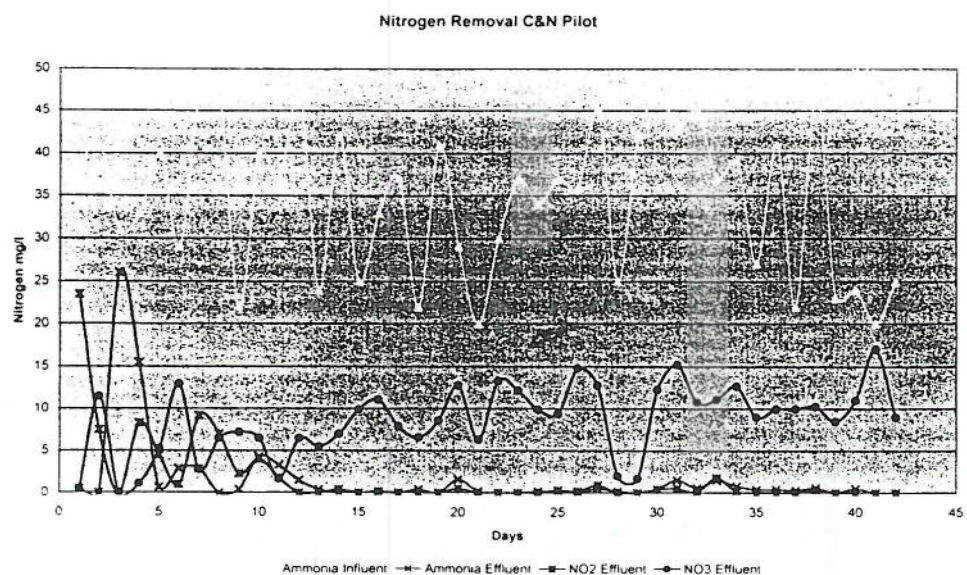


Figure 8

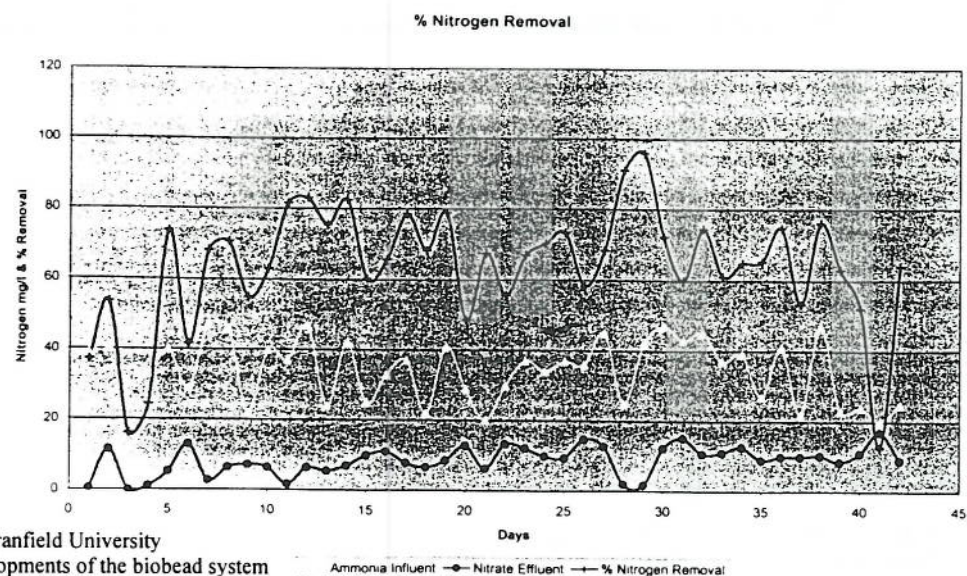


Figure 9

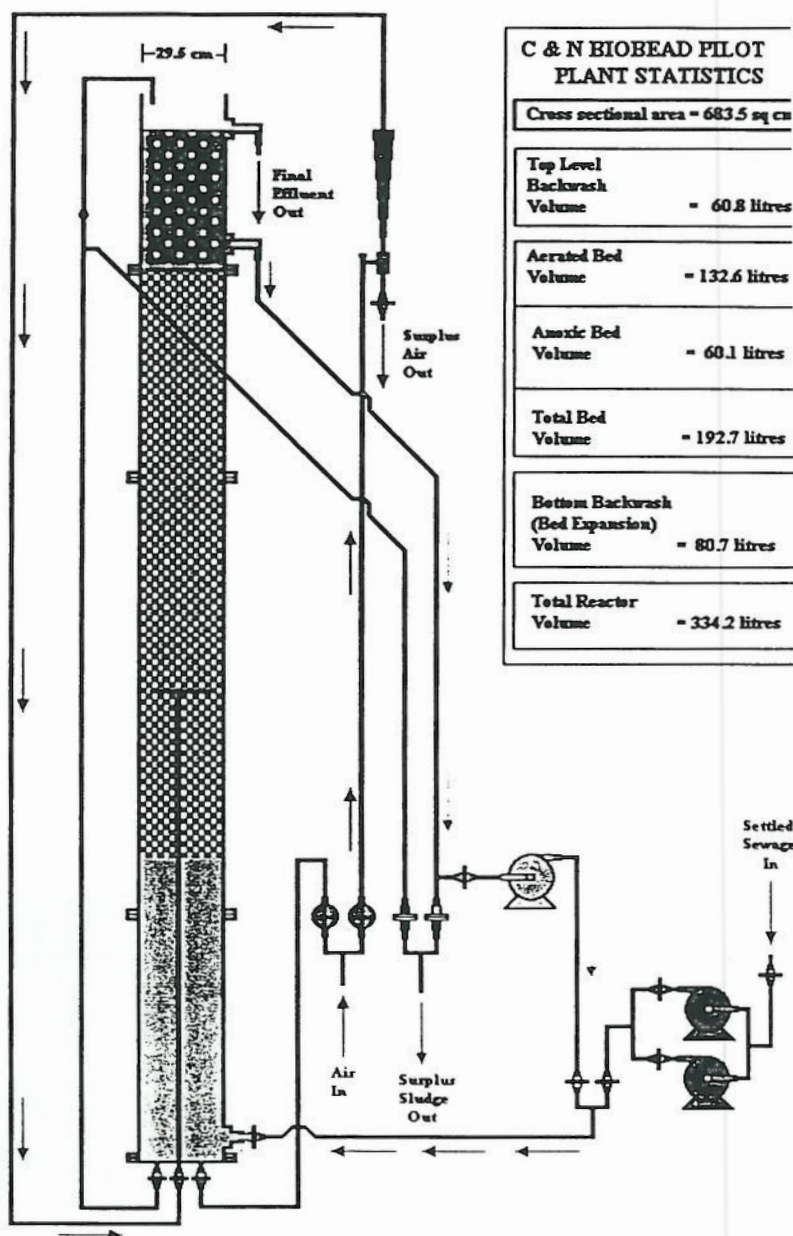
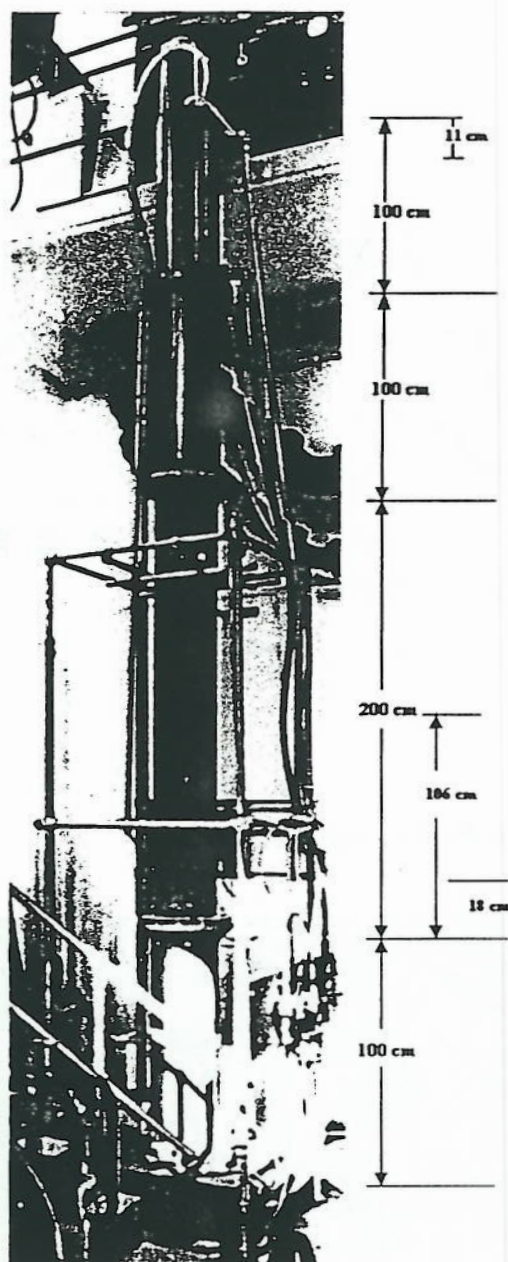


Figure 10

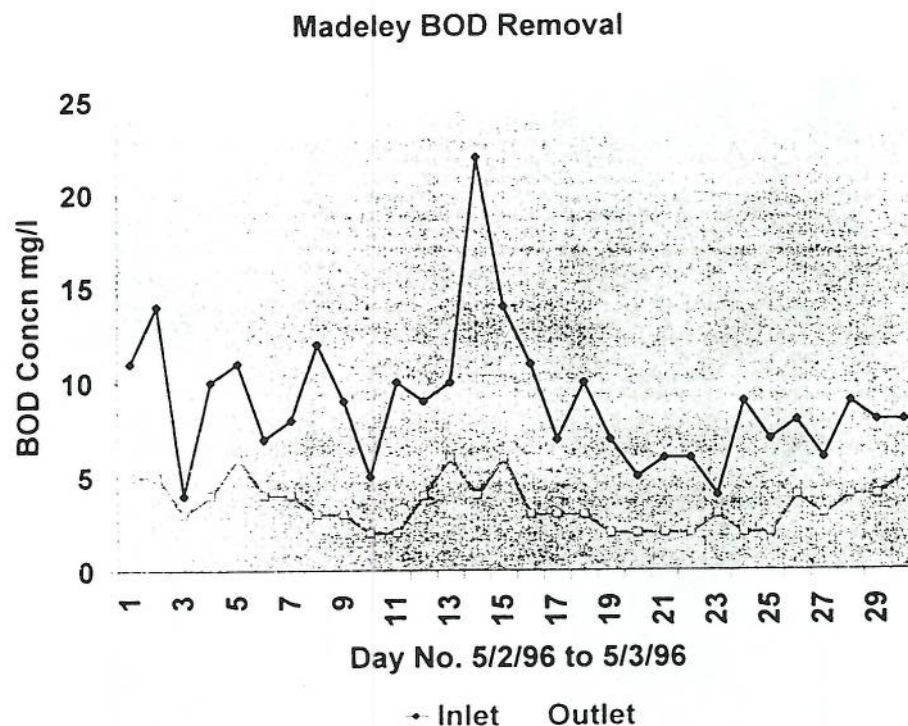


Figure 11

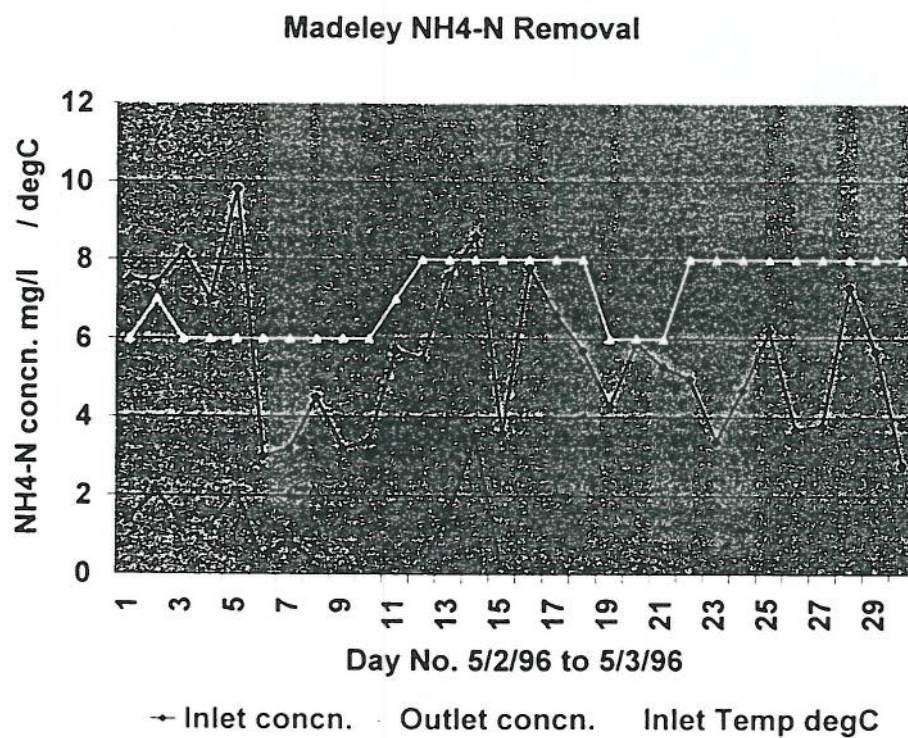


Figure12

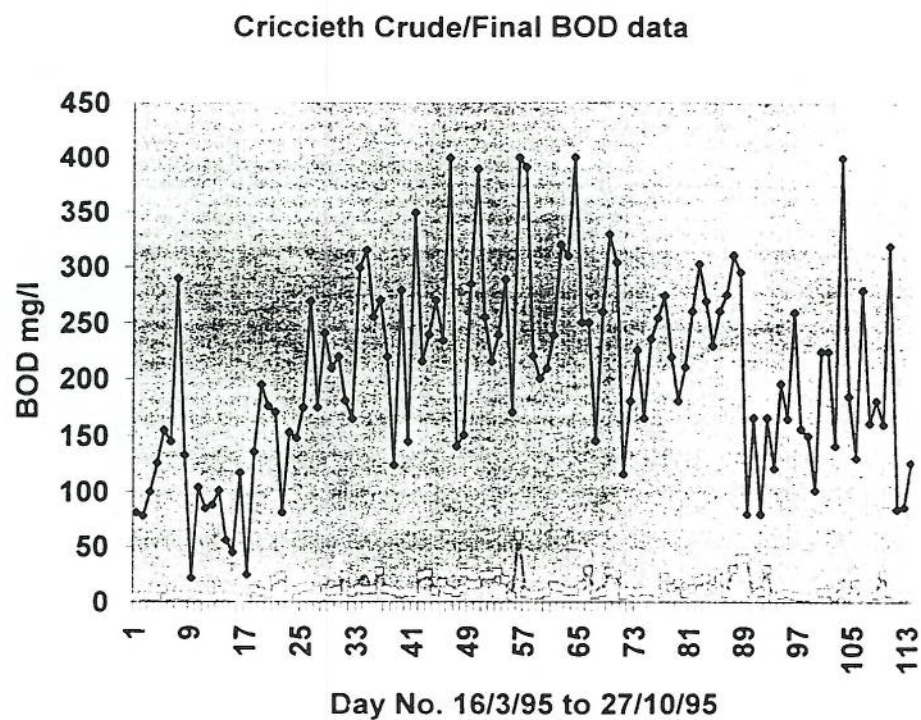


Figure 13

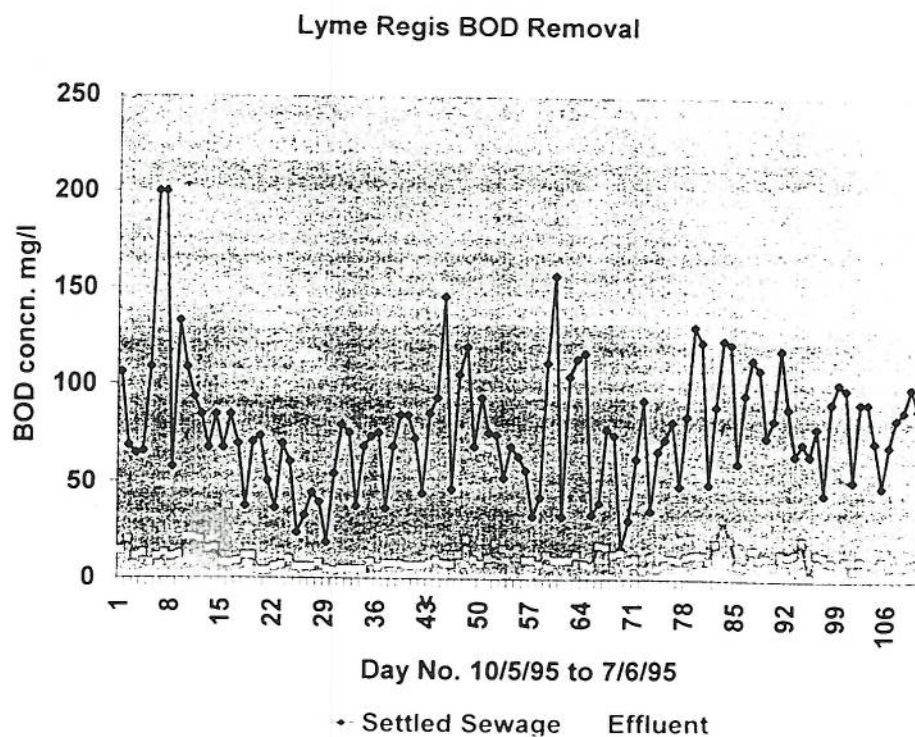


Figure14

