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Biological Aerated Filters

BAF 3

Cranfield University
Wednesday 3rd March 1999

Organised by:
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Editors – Professor Tom Stephenson and Dr Bruce Jefferson

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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.



A NEW GENERATION OF AERATED FILTER

J. Martin, OTV Birwelco Ltd, Mucklow House, Mucklow Hill, Halesowen, West Midlands, B62 8DG

A GENERATION OF BIOLOGICAL AERATED NEW FILTER

1. History

The use of the activated sludge process is a very well known technology. It is and has been used very widely in full scale plants from its first development at the Davyhulme works in Manchester. However this process becomes very difficult to upgrade or to extend in order to ensure compliance with either more stringent discharge consent conditions or to achieve the same quality of discharge where increasing flows are the problem.

This problem of upgrading or extension to existing works led OTV almost twenty years ago to develop the bio-filter process. This process consists of essentially biological filters operating either in the down flow or up flow mode, the main benefits of this system being they are compact in their space requirements, together with their ability to combine both filtration and aerobic/anaerobic bio degradation. They are used for the removal of suspended solids, COD, BOD, ammonia (and nitrate) either in the secondary or the tertiary treatment stage, plus with the use of a precipitating chemical, they can also be used for the removal of phosphates.

2. Single Media Downflow – BAFF

The first of the biological aerated filters developed by OTV was the **BIOCARBONE** process, which combines the biological treatment by means of a fixed biomass and the filtration of the treated water in a single structure. This process is suitable for all domestic and many industrial effluent requirements, and it is perfectly adapted to the elimination of carbonaceous pollution and both nitrification and de-nitrification. It is to be recommended where the sites have limited area and where the plants or structures require a cover to prevent local nuisance.

The first installation was completed in 1982 and the process is now used worldwide with more than one hundred operating reference plants.

LONGITUDINAL SECTION

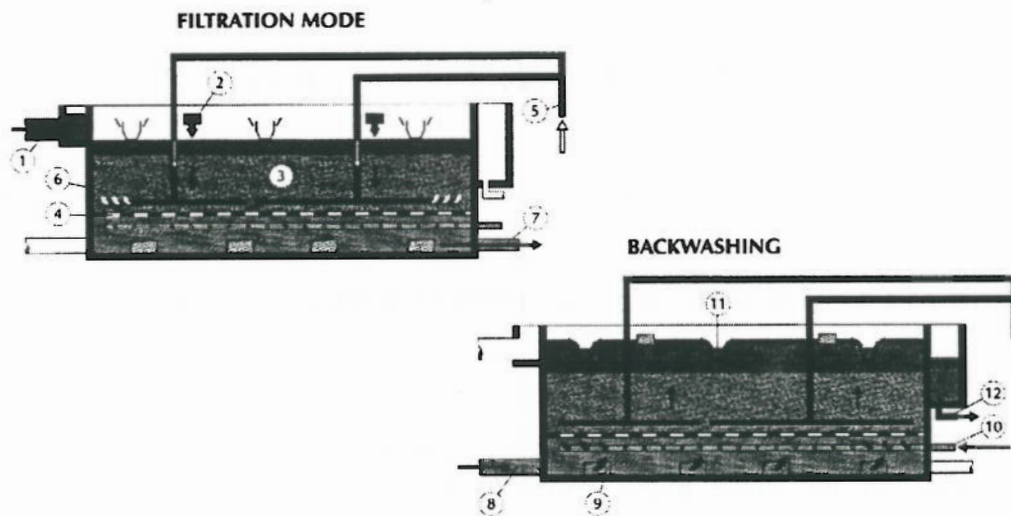


Figure 1: Biocarbhone process - Section

The water to be treated enters the upper section of the structure and passes down through the filtration media where the purifying bacteria are located. These micro-organisms utilise the constituents of the pollution, together with the oxygen derived from the injected air for their own development.

The submerged filter bed exists on a suspended floor equipped with nozzles through which the treated water is drained.

Aeration within the media is provided by an aeration grid located twenty to thirty centimetres above the floor and this process air is blown into the filtration media counter-current with the water flow. The layer of non-aerated media below the air grid fulfils the role of final filtration of the effluent.

The filter media is washed periodically (typically every twenty-four hours) to remove suspended matter and excess biomass, which accumulates in the spaces within the media. The backwashing process is performed using air and water entering the lower sector of the reactor i.e. the excess sludge is discharged to the top of the structure and, since the majority of the biomass is retained in the top layer of the filtration media it only has to pass through this section and exits via a decanting trough, and does not pass through the nozzles or the whole of the filter media.

The filtration media used in the **BIOCARBONE** process comprises expanded clay approximately 3.3 millimetres in diameter, with a density of 1.6 grammes per centimetre cubed. This media selection is the optimum between the two basic requirements of a fine media to achieve filtration performance and a coarse media to allow the development of the biomass to perform the duty of carbonaceous pollution removal.

The counter current system i.e. water in the downflow direction and air in the reverse direction enables the **BIOCARBONE** process, after successive backwashes to retain the bio film around

the particles of media such that under any shocks of temperature, load or toxicity etc the process will quickly return to its original performance level.

Since the **BIOCARBONE** system is of modular design, it can be used and is highly adaptable for plant extensions, flow variations, load variations etc, and the use of the media selected by OTV, **Biodagene**, ensures optimum bacteria retention, coupled with filtration and the need for infrequent washing. It has the essential criteria of large specific surface area, high macroporosity, low apparent density and a high resistance to mechanical wear.

3. Dual Media Downflow

In order to extend and improve the performance of the single media **BIOCARBONE**, the next development by OTV in the field of biological aerated filters was to replace the single media with a dual media system which has been designed and installed as a full scale plant Le Touquet in France. With the single media system the filter bed depths are approximately 2 metres and the single media **Biodagene** has granulometry of 3.3 millimetre and density of 1.6 grammes per centimetre cubed. This filter has a run time typically of 24 hours, but, in order to increase the loading rate, yet retain the filter run time of 24 hours, OTV decided that it may be possible achieve a better performance using a dual media approach. In this system the top layers of **Biodagene** are replaced by pumice with granulometry of 4.6 millimetre and density of 1.1 grammes per centimetre cubed.

Under the initial experimental conditions, the applied load on the single media filter was 5.5 kg/M³ day COD and on the dual media filter this was increased to 6.6 kg/ M³ day COD It was demonstrated that under these conditions the single media filter required backwashing after twelve hours service whilst the dual media system remained in operation even after 24 hours continuous running without the filter being clogged. The outlet conditions in respect of COD from the dual media filter and from the single media filter were almost similar (there was a slight deterioration of the dual media filter from 79mg/l COD to 89 mg/l COD) but both filters satisfied the discharge consent conditions.

The main problem with the operation of the dual media filter, despite its obvious advantage of having to be backwashed on a much less frequent basis, was the re-classification of the pumice and **Biodagene**, after backwashing coupled with the fact that the pumice is a very expensive media and, because of these two disadvantages, the development of the dual media downflow BAFF did not proceed further.

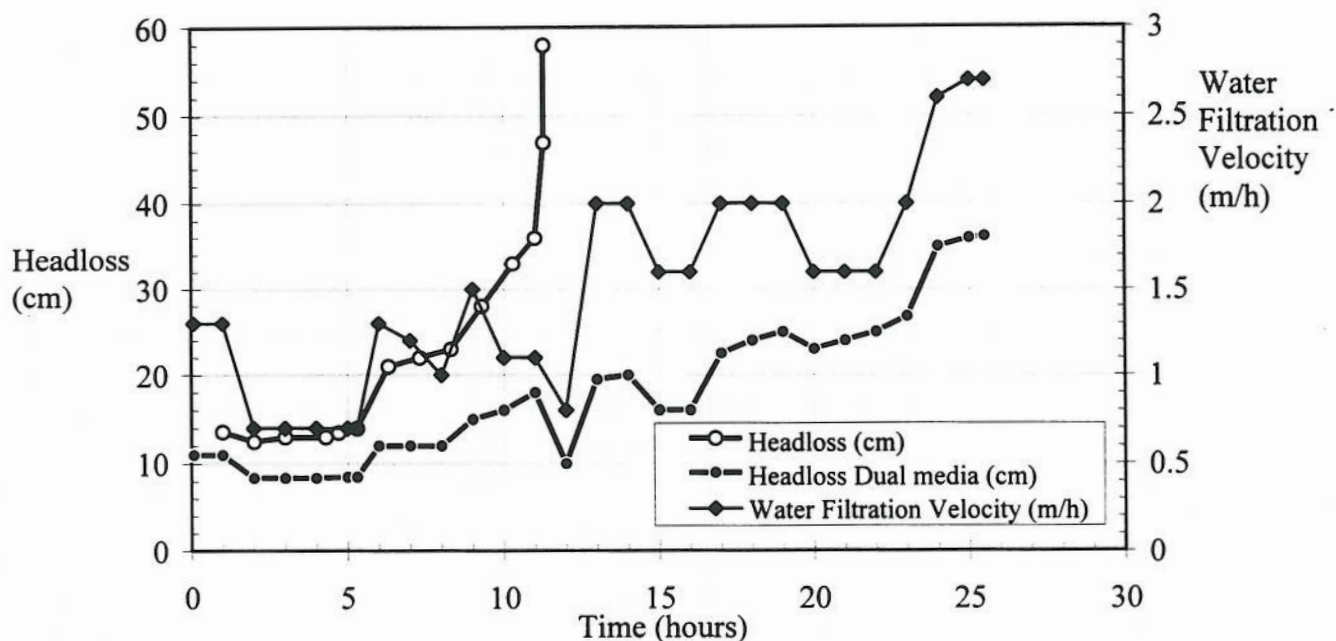


Figure 2: Dual media filter and classical media filter - comparison run time

4. Single Media Upflow BAFFs

It was realised that with the introduction of nitrification and denitrification, with the downflow BAFF design of filter, the effective denitrification could only be achieved by using a separate filter operating in anoxic mode. This led to a very expensive installation and defeated totally the need for a system, which could achieve the nitrification and de-nitrification with minimum area requirements.

In view of this, it was decided that the best approach was to have an upward flow single media design, leading to the introduction of the **BIOSTYR** process. This process is essentially the same layout as for the **BIOCARBONE** process, but with the flow in the opposite direction and the media on this occasion is the lighter than water polystyrene beads.

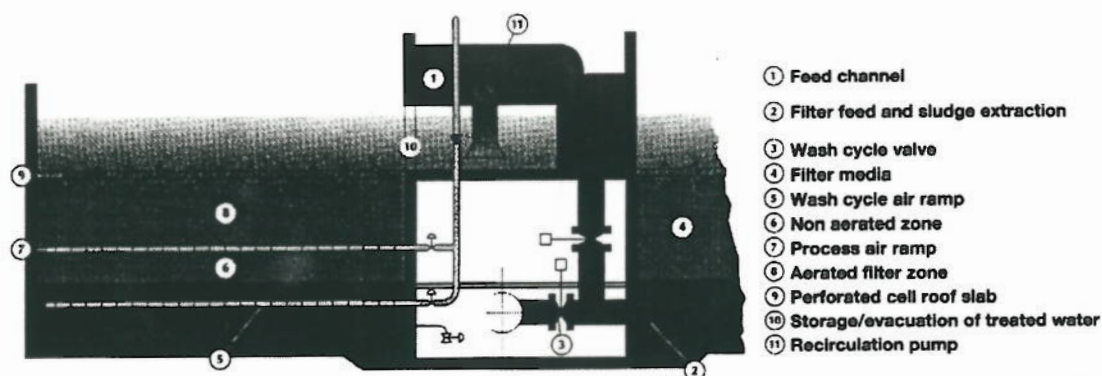


Figure 3: Single Media Upflow - Biostyr

The **BIOSTYR** process combines in a single structure, a highly compact biological reactor that degrades pollution, together with the ability to separate suspended solids from the treated water passing through the system. The **BIOSTYR** process has now been in operation for more than 10 years and there are in excess of more than 100 reference plants throughout Europe, the UK, North America etc.

The **BIOSTYR** process is an upward flow filtration process with the biomass suspended on a floating fine granular media called **Biostyrene**. Air is injected either into the base of the bed or into the media itself and, in the latter case, the filter can be simultaneously used for both nitrification and de-nitrification on re-circulation of the filtered water. It is capable of removing all biological degradable pollutants, ie. COD, BOD, suspended solids, ammonia, nitrogen and nitrates, and the bacteria present are attached to the filtration media in exactly the same way as they are for the downflow **BIOCARBONE** system.

In contrast with other upflow filters (where the media is denser than water), the headloss across the filter media ensures that the effluent is distributed equally without the need for special nozzles on the inlet side of the filter which could be the subject of blocking, or distribution pipework and without the need to screen the effluent prior to treatment. Filtration takes place in a direction, which compacts the media, and thus the enhancement of the retention of suspended material.

Filter backwashing is still necessary, typically on a twenty four-hour basis, with the counter-current washing system being preferred. The excess biomass retained at the bottom of the filter media together with suspended solids are removed by a downward flush of filtered water retained in the storage area above the outlet nozzle plate system. Thus the biomass is removed from the system without it passing through the whole of the media areas using the shortest route to exit the filter. The media is retained by the cell roof slab which is fitted with nozzles, which can be removed from the top and it is these which are only in contact with the filtrate and cannot therefore be subject to clogging. In addition, only the filtrate is in contact with air and this post-treatment liquid suffers from no foul odour or smell.

Should the system be required for denitrification then it is possible to position the aeration grid in the centre of the media bed. This gives a non-aerated zone below the aeration grid, and an aerated zone in the upper part of the media, thus nitrification and denitrification can be achieved in the same unit on recirculation of the filtrate, and reducing the space requirements when compared with the **BIOCARBONE** process.

5. Multi Media Upward Flow

The dilemma, on the one hand the need for coarse media to retain high levels of suspended matter and on the other hand, a fine media to retain biomass and achieve the best quality outlet, cannot be easily overcome with a single media filter. This problem led to OTV developing the multi media upflow system called the **B2A** process. In this process, the multi media, denser than water, filtration process is utilised. The media consists of particle sizes ranging from a support level of typically 40 millimetre diameter on the bottom of the filter, leading up to a fine higher layer with a diameter of 1-4 millimetre according to the treatment objectives. The system enables the elimination of both primary treatment (only screening and grit and grease removal are necessary)

together with the elimination of the clarification stage, making it the most compact biological filter developed so far (similar to the **BIOSTYR** process, it can be used for nitrification and denitrification).

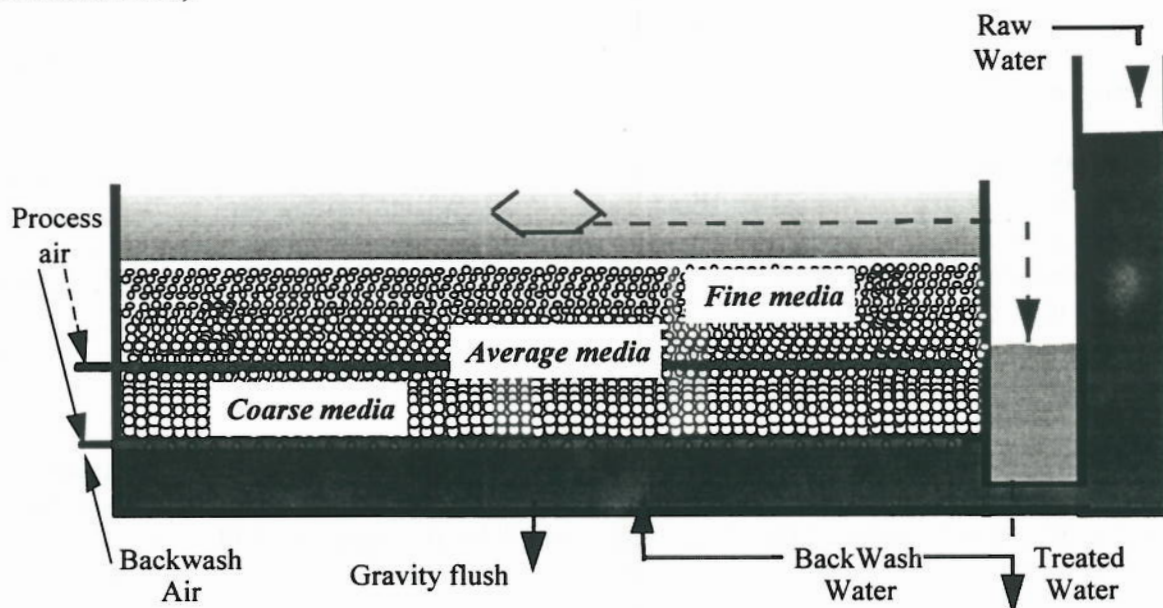


Figure 4: Diagram of the B2A multi layer filter

6. Upflow Filters : The B2A

For the treatment of wastewater, the use of upward flow BAFFs is now becoming more and more acceptable either as secondary or as tertiary treatment stages and these plants are being recognised for their performance and small plant area requirements. Typically such processes are operated after preliminary treatment i.e. screening, grit and grease removal and primary settlement but to further reduce the size of the plant, the solution would be to use the BAFF process directly on the raw water.

Since the upflow BAFFs so far were mono media, it is necessary to compromise between the clogging effect of the high suspended solids load, the area for the biomass to develop and the treatment to the required discharged consent standards. Using raw water directly in such systems is therefore not recommended and for this reason a new upflow BAFF design has been developed by OTV which is capable of receiving raw water which has received only screening and grit and grease removal as a preliminary treatment.

The multi-media upflow BAFF, the **B2A** process however overcomes these problems.

7. Filter Description

The **B2A** process is based on the multi media concept described previously, and the knowledge of the biological aerated filter designs already accumulated by OTV. Particle sizes in the support media are specified to be 40 millimetres with the higher final layer having a diameter of 1-4 millimetre according to design or treatment objectives. The raw municipal wastewater is introduced at the bottom of the filter, after screening, grit and grease removal. Air is blown into

the distribution grid positioned either in the bottom of the filter or should denitrification be required at some point in the multi layer media. A diagram of the filter is presented in Figure 4.

To remove the particulates retained in the filter and the surplus biomass, a backwash of the filter bed is required, typically on a twenty four hour cycle basis. This backwash is executed in two stages, the first step consists of a gravity flush to remove the large particulate matter accumulated within the coarse media at the bottom of the bed. The second step of the filter backwash is achieved by the use of air and water to push the surplus biomass out of the filter and finally a water phase is introduced to re-classify the different grades of media utilised.

On pilot plant installation standard daily analyses of the influent and effluent and two hour averages were performed for total COD, SS, TKN, $NH_4(N)$. The use of turbidity measurements was carried out continuously to ascertain influent and effluent suspended solids concentrations and the performance of the process used as a primary treatment to remove either the carbon pollution or the carbon and the nitrogen pollution was studied.

8. Carbon Pollution Removal

The study was carried out to define the performance of the **B2A** in achieving secondary treatment standards for various hydraulic conditions. To the test the process, a large scale pilot plant having a surface area of 1 square metre and a 4 metre deep media bed was filled with media ranging from 40 millimetre as the support media down to 3 millimetre sand as the final filtration media. The pilot plant was fed with pre-screened raw water only and to test the affect of the upward flow velocity on the carbon removal efficiency both weak raw water and strong raw water were used. The main characteristics of the experiment summarised in Table 1.

Table 1: Experimental conditions

Inlet COD concentration	300-600 milligrams per litre
Inlet SS concentrations	150-300 milligrams per litre
Water velocity	3-10 metres/hour
COD applied load	8-30 $kg/m^3/d$

Using the **B2A** multi media approach the filtration process is very efficient. It was shown that for a given upward flow filtration velocity, the removal of suspended solids on a daily basis remains constant. To satisfy the European Directives (125 milligrammes per litres COD and 25 milligrams per litre BOD on a 95% ile basis) the COD applied load has to be from 10-15 $kg/m^3/d$ - however, the requirements on occasion could be less stringent when only 75% of the carbon pollution needs to be removed, in which case, a COD load from 20-25 $kg/m^3/d$ could be applied.

The use of the **B2A** process to upgrade a plant was evaluated and a comparison between primary settled water and raw screen water was carried out. In terms of the removal of COD, the results are similar for the two types of water. However, since raw water has a higher concentration of suspended solids the headloss across the filter was increased and the filter run times were therefore reduced.

Figure 5 indicates the relationship between the COD applied load, the inlet COD concentration and the outlet COD objectives. This curve was based on the results obtained with primary settled water used as the feed to the **B2A** plant. It indicates that when the inlet water is concentrated the COD applied load is lower than the one corresponding to the dilute or weak wastewater.

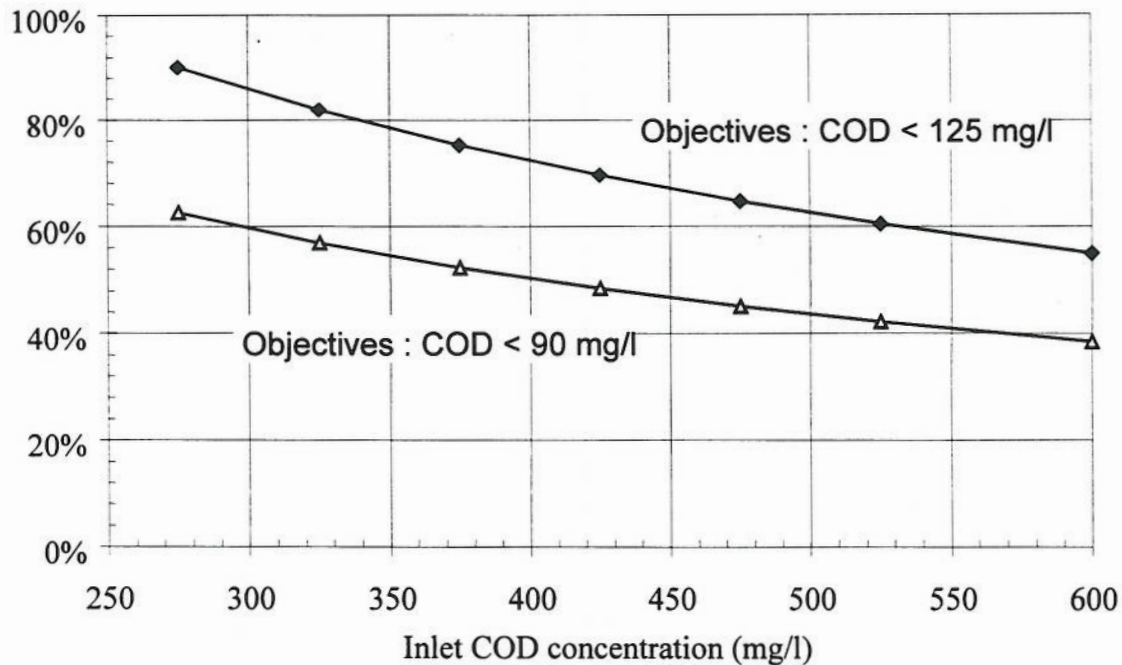


Figure 5: Carbon removal dimensionless COD applied load versus inlet concentration and treated water

9. Primary Nitrification

Typically it is necessary that the first stage of the sewage treatment plant process removal the carbon pollution followed by nitrification. With the **B2A** process, it was required to prove that both carbon pollution removal and nitrification could take place in the one stage and that both could be removed without a problem. Table 2 summarises the main characteristics of the test.

Table 2: Experimental concentration conditions

Inlet COD concentration	300-600 milligrams per litre
Inlet SS concentration	150-300 milligrams per litre
Inlet NH ₄ (N) concentration	30-70 milligrams per litre
Water velocity	1-3 metres/ per hour
COD applied load	2-12 kg/m ³ /d
NH ₄ (N) applied load	0.5 – 1 kg/m ³ /d
Temperature	14-17 degrees C

When compared with the carbon removal configurations the upward flow velocities for the primary nitrification are lowered to limit COD applied loads. These parameters varying from

2kg/m³/d up to 12 kg/m³/d which corresponds to an ammonia applied load of 0.2 kg/m³/d up to 2.9 kg/m³/d.

Figure 6 below indicates where the inlet and outlet CODs and ammonia concentrations are plotted versus time and shows results obtained from the **B2A** process when used as a primary nitrifying BAFF. For all COD loads where ammonia applied loads is less than 0.7 kg/m³/d, the **B2A** is able to achieve more than 80% removal efficiency (average 90%).

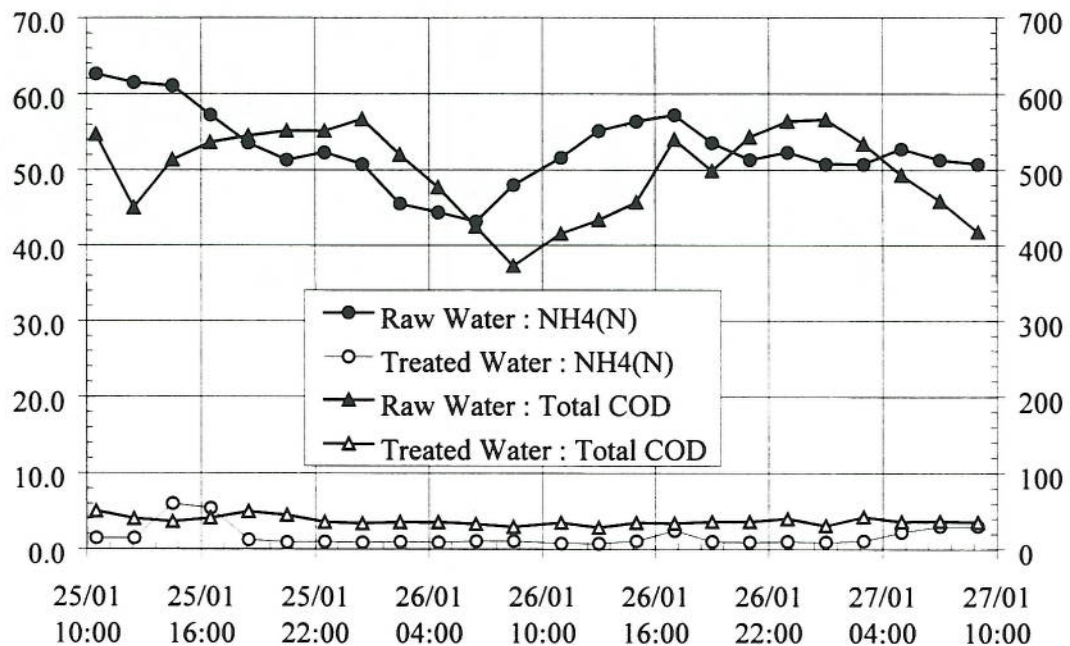


Figure 6: Primary nitrification : Typical results for the ammonia and COD

10. Primary Nitrification and Denitrification

In order to achieve denitrification it is necessary to install the process air supply grid within the filter media itself, and utilise the space beneath this grid as an anoxic zone. The raw feed water is fed to the base of the **B2A** filter, passes up through the coarse media and is then aerated by the high level air supply grid. Treated water is re-circulated from the top of the filter and mixed with incoming raw water and denitrification is achieved in the lower section. Hence the **B2A** process can be used as a primary nitrification and denitrification BAFF. A full scale filter plant, based on this configuration has been in operation since 1992 at Gratentour in France.

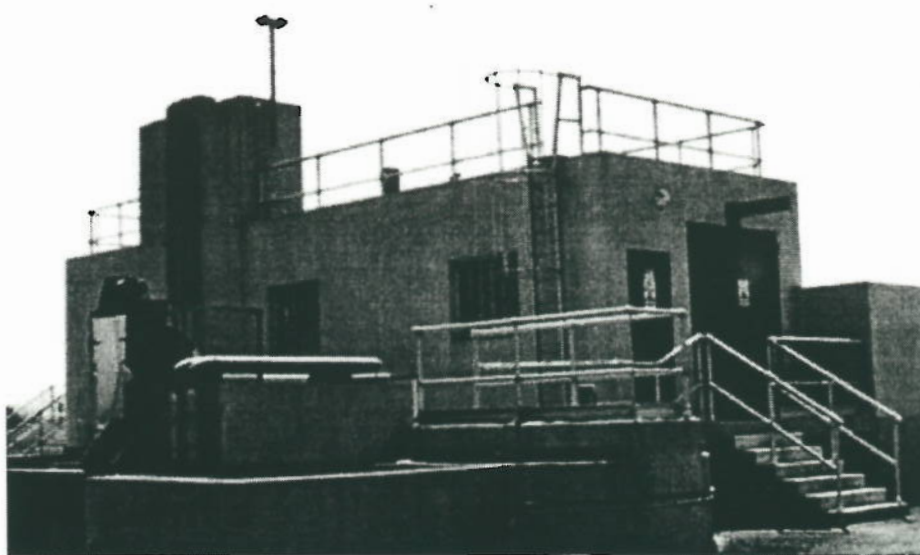


Figure 7: View of the plant using the B2A process as a primary nitrification and denitrification.

The main design characteristic of the Gratentour plant and the qualities of effluent achieved are indicated in Table 3 below.

Results from a 6 month trial period are represented in figures 7a and 7b below where the daily inlet and outlet concentrations of COD, NH_4 , (N) and NO_3 are plotted versus time.

Table 3: Experimental conditions for the Gratentour site

Inlet COD concentration	300-600 milligrams per litre
Inlet NH_4 (N) concentration	35-70 milligrams per litre
Water velocity	3-5 metres/per hour
COD applied load	2-14 $\text{kg/m}^3/\text{d}$
NH_4 (N) applied load	0.41 $\text{kg/m}^3/\text{d}$
Temperature	15-19 degrees C
Average COD outlet concentration	25-40 milligrams per litre
Average NH_4 (N) outlet concentration	0-4 milligrams per litre
Average NO_3 (N) outlet concentration	10-15 milligrams per litre

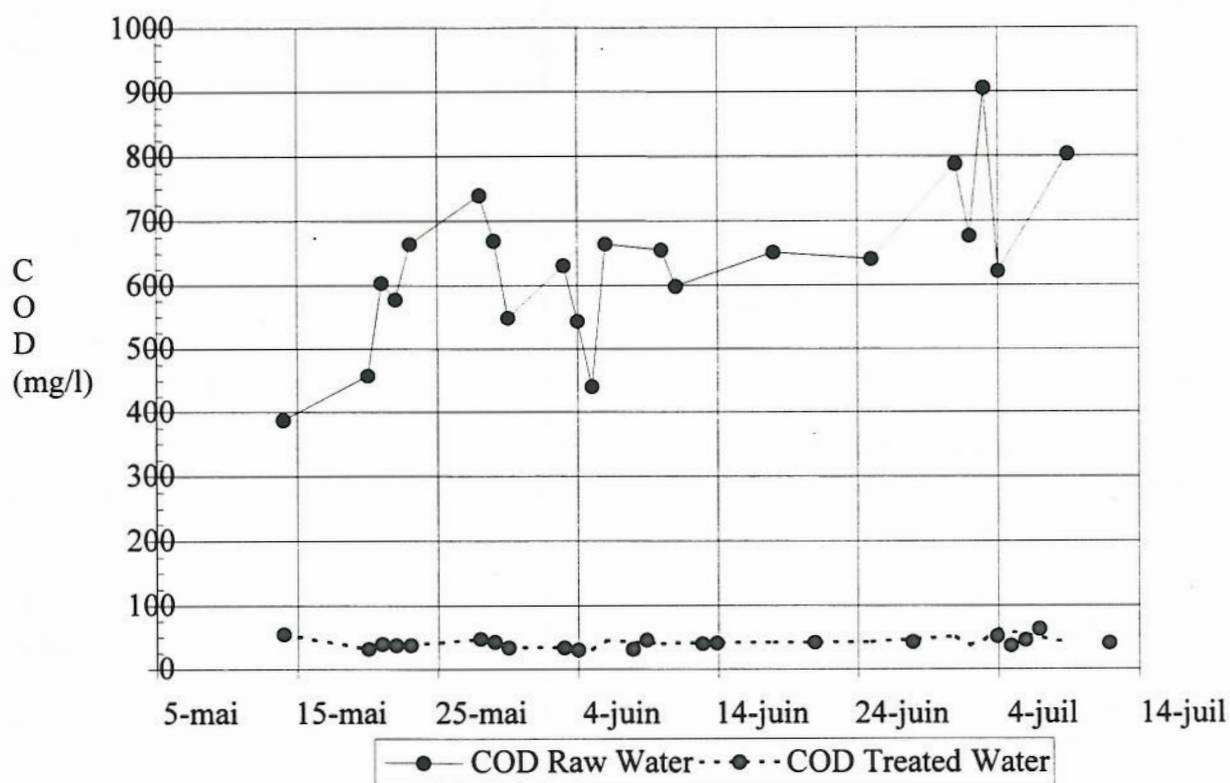


Figure 7a: Primary nitrification and denitrification : inlet / outlet COD concentrations

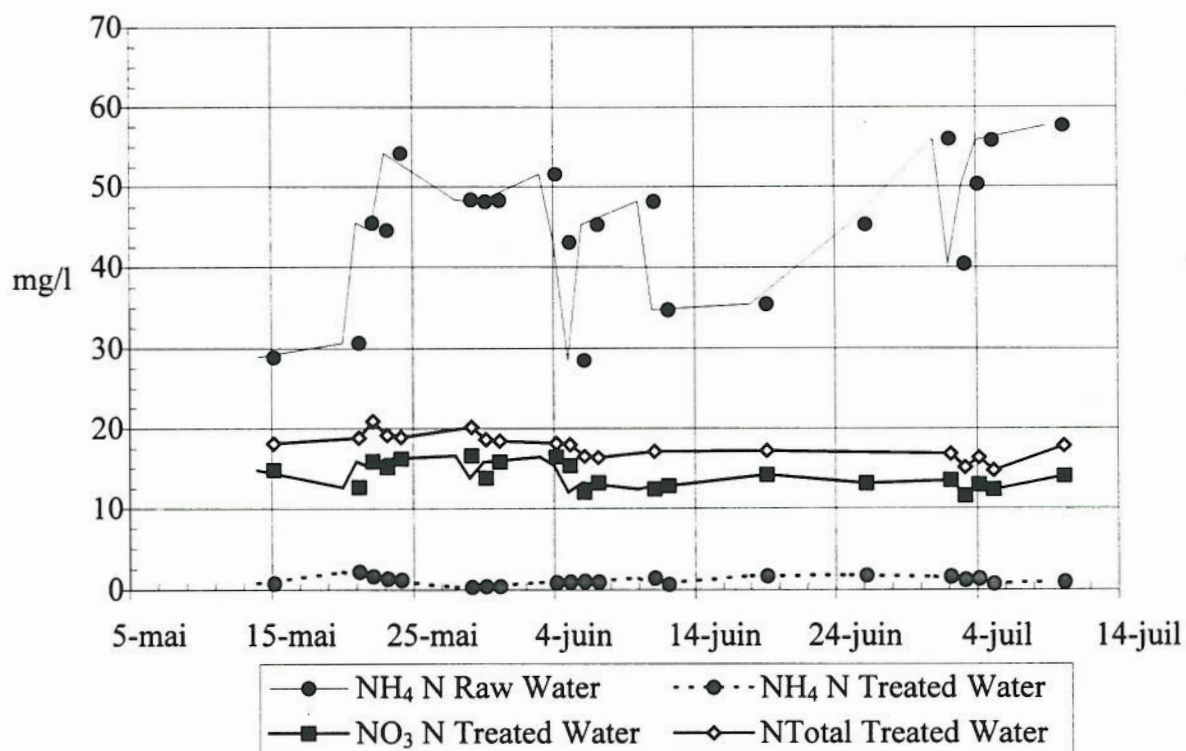


Figure 7b: Primary nitrification and denitrification : inlet/outlet NH₄ concentrations

In addition, the **B2A** process is used for the removal of phosphorus down to a concentration of 2 milligrams per litre with the addition of a precipitation chemical. The precipitating phosphorus is removed with the backwash sludge without any clogging problems within the filter.

11. Conclusions

This paper demonstrates the new compact multi layer filter is a basic improvement in BAFF technology. The process allows the achievement of strict discharge consent conditions with very simple operation techniques. Coarse media at the bottom of the filter allows the direct treatment of raw water after just pre-screening and the concentration of particulates retained is very high without decreasing the filter run times. The use of the fine media at the top of the bed leads to a very high specific area for biomass growth and an efficient biological activity takes place. The **B2A** process is and can be used for treatment in sewage for removal of carbonaceous pollution, primary nitrification and denitrification. In all cases good effluent standards can be achieved with high applied loads.

The operation of the waste water treatment plant located at Gratentour over a six year period shows that multi layered filters fed with screened raw municipal water perform excellently on a full scale, and, from this plant together with other pilot plants, details have been ascertained for the design of future **B2A** plants which are currently under construction with a design capacity about 50,000 p.e.