Tertiary Treatment of Sewage Effluent using AFM

By

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Abbreviations

BOD	biochemical oxidation demand
COD	chemical oxidation demand
AFM	active filter media
BAF	biologically aerated filter bed
STW	sewage treatment works
NTU	normal turbidity units
ppm	parts per million
mg/l	milli grams per litre

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1. Introduction

The treatment of sewage effluent involves a number of different processes but typically it includes; screening to remove large items, followed by primary sedimentation and then biological filtration.

The biological stage is usually trickling down-flow biofiltration on a substrate, or the use of a suspended bacterial cell biomass known as activated sludge. After the biological stage the effluent will have a high concentration of bacteria. It is important to prevent the discharge of these bacteria back into the environment on two accounts, 1. The bacteria would cause serious pollution, 2. The bacteria are required by the treatment system and must be recycled to insure the continued performance of the treatment system.

The secondary sedimentation stage after the biological stage is very effective and the vast majority of bacteria are captured and returned to start of the process. However solids are still discharged, the concentration of which relate to the type of effluent entering the treatment system, and the design of the treatment system. Typically the concentration of solids in the effluent is around 20 to 30mg/l, however sewage works will occasionally fail their consent to discharge.

The solids discharge will contribute to the BOD (biochemical oxidation demand) and COD (chemical oxidation demand). In addition, the solids may contain toxic chemicals as described in Annex 3. Irrespective how efficient a sewage treatment works is performing, if improvements can be made at a reasonable cost, then this can only be only be beneficial to the environment and public health.

The water companies will shortly be required to comply with new water directives that will tighten their consent to discharge conditions. In order to comply with the conditions, many sewage works will need to consider tertiary treatment, such processes include BAF (Biologically aerated filtration), membrane filters and sand filtration. Membrane systems provide an excellent water quality, however they are expensive. BAF systems also provide a good water quality, but they still discharge solids. Sand filtration is a lower cost very effective technique, unfortunately however, due to the biologically active nature of the water, the sand suffers from extreme problems due to biofouling.

Dryden Aqua has developed AFM (Active Filter Media) which offers an alternative to sand. The AFM media is manufactured from recycled coloured glass bottles to produce a filtration media that offers performance benefits over conventional sand. AFM is an active media that resists biofouling, and as such it largely eliminates the problems encountered by sand filters when trying to treat the effluent. AFM therefore offers a solution by permitting the use of simple low cost filtration system to be employed in the treatment of sewage effluent.

2. Executive Summary

The present investigation covers the results from three pilot scale trials and one long term full scale system on a sewage works for the tertiary treatment of sewage effluent.

AFM is unique on several levels, however it is the ability to resist biofouling and contamination that are key to the performance of the product in wastewater treatment. Sand and conventional media will become biofouled and blocked after a few weeks or months. The pilot scale and long term trials have proved that AFM does not become biofouled and that the performance can be maintained in systems lasting many years.

Without exception the results have demonstrated that a sewage works can achieve 100% discharge compliance, and greatly improve the quality of the discharge water to produce a clear, bright effluent. In addition, the results also show that AFM can cope with high solids loading without adverse effect on water quality.

AFM filters are normally placed on the end of the water treatment process as a final polishing stage. However the trials show that AFM could take the place of the humus tank, and still provide excellent water quality in the discharge. Further testing will be required, but it would appear that effluent discharge water quality can be greatly improved whilst eliminating humus tank sedimentation from the treatment process.

3. Pilot scale system

Three identical test beds were constructed and installed on skids (see annex 1 for system specifications). The system comprised of a small pressure sand filter, which contained the AFM. All valves on the filter were pneumatic, and automatically controlled by a panel. The skid was also fitted with a discharge clean water tank, which acted as a reservoir for back-flush water.

The first pilot scale unit was installed in a sewage works (which were A,B & F) in June 2003, and has been operating on a continuous basis with no attention or deterioration in performance for the last 9 months. Site H system has been treating sewage effluent continuously over the last 5 years.

Trial sites

The trials were conducted in co-operation with Scottish Water, United Utilities, Northumbrian Water and Thames Water. The sewage works are identified as Site A, B, F and H, it should be noted that the water companies and site identification are not in respective order.

Site A

Sewage works employing gravel filter beds, humus tanks and BAF tank. The AFM filter was connected onto the discharge from the BAF

Site B

Sewage works using filter beds and rectangular humus tank. The AFM filter was connected onto the discharge from the filter bed, but before the humus tank. The water feeding the AFM filter was taken from the beginning of the humus tank at a point where the filters discharge into the humus tank.

Site F

Sewage works using activated sludge and humus tank sedimentation. The AFM filter was connected onto the discharge of the humus tank, then the discharge from the activated sludge tanks.

Site H

Sewage works using gravel filter beds and humus tanks. The AFM filter was connected onto the discharge from the humus tanks at the point where the filter beds discharge into the humus tank. The water is therefore has a reduced solid load and is aerobic entering the AFM filter.

Trial protocol and analytical parameters

The trial protocol is detailed in annex 2.

Test bed scale-up issues need to be considered. The test bed diameter was 500mm, bed surface area approx. 0.25 m^2 and bed depth 350mm. The water flowrate through the filter was $3m^3hr^{-1}m^2$, this is quite a slow flowrate; the standard flowrate for a full-scale system is 5 to $6m^3hr^{-1}m^2$. With AFM there are surface area influences, and depth effects.

AFM removes sub 10 micron particles by surface adsorption, so the depth of the bed is important. In full scale systems, the bed depth is normally 750mm to 1000mm. An increase in water flowrate to 6 $m^3hr^{-1}m^2$ is therefore reasonable when bed depth is taken into account. Flowrate up to $10m^3hr^{-1}m^2$ have been tested in sewage effluent, however performance starts to become affected. More experimentation and trials are required to optimise the flowrate for different conditions, but until this information is available 6 $m^3hr^{-1}m^2$ is considered as the maximum recommended flowrate.

Presentation of the results

The data is presented in graphical format, in the legend ***influent*** refers to the water entering the AFM filter that would otherwise be discharged. The legend ***effluent*** refers to the discharge water from the AFM filter, or the quality of the water that would be discharge if the sewage treatment works were fitted with an AFM filtration system.

Data from site A has been collected from June 2003. The trial started with frequent water analysis followed by gap of 4 months. In order to clearly present the results, the graphical data has been presented on two separate graphs with different time frames.

4. Results

AFM filtration is a mechanical process with a degree of surface adsorption, catalytic, and oxidative reactions, which help to remove heavy metals and crack dissolved organics. With regards to the tertiary treatment of sewage effluent, the focus is on solids and BOD/COD reduction, suspended solids and prescribed substances

Prescribed substances are occasionally present in sewage effluent, there are serious environmental implications with regards to the discharge of persistent bio-accumulated toxins into the environment. Results have shown that AFM can be used for the removal of these components.

The key parameters of the present study include; suspended solids, BOD and COD. The waste material is trapped in the AFM filter and, every 4 hours, the filter is back-flushed. The AFM filter virtually prevents the discharge of any solids including the bacterial cell biomass, which is recycled back to the beginning of the works. A secondary consequence of AFM filtration is an improvement in the performance of the effluent treatment system by eliminating the loss of nitrifying bacteria.

AFM is resistant to biofouling, and it can cope with a very high level of solids. On some sites AFM is used directly on activated sludge effluent. In the present trial, the site B system is connected after the filter beds, taking the wastewater before it has passed through the humus tank. The results obtained show that an AFM filter can take the place of the humus tank, and provide a greatly improved water quality. The results indicate that the conventional solid separation process can be eliminated, although more tests on different sites are required to support this mode of operation.

Suspended solids reduction

Site A suspended solids

The discharge consent limit for site A is 25mg/l, and Fig 1 and Fig 2 show that the influent suspended solids load was higher than the consent limit. However the discharge water from the AFM filter consistently delivered suspended solids concentrations between 5 and 12 mg/l

Fig 1 site A suspended solids concentration

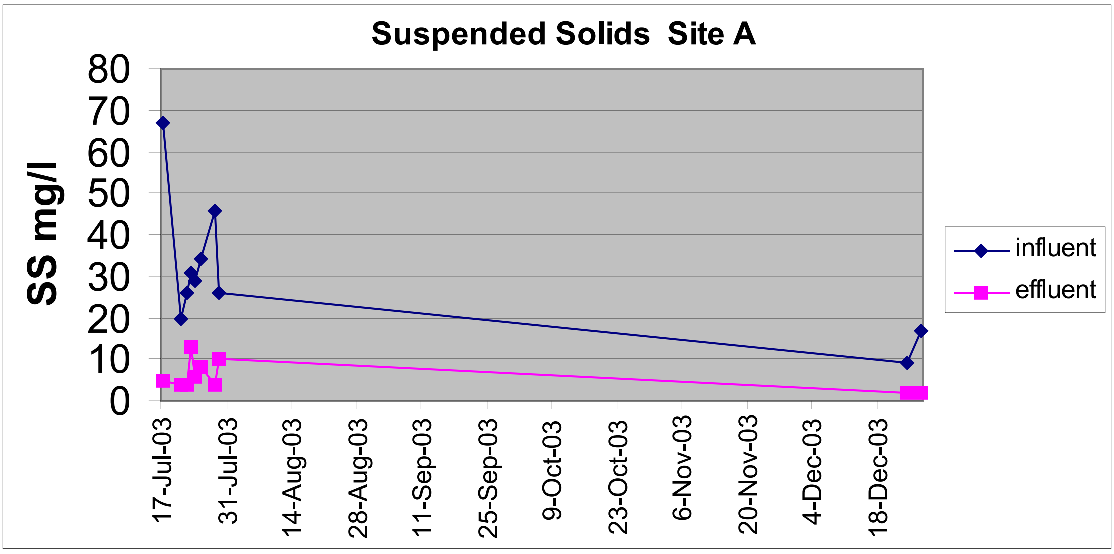
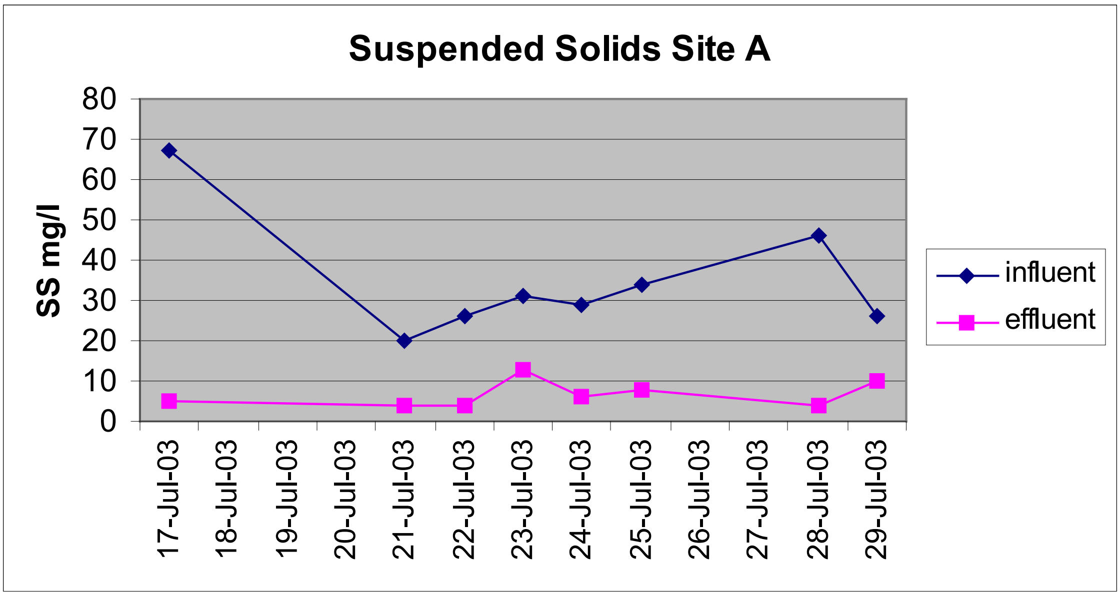


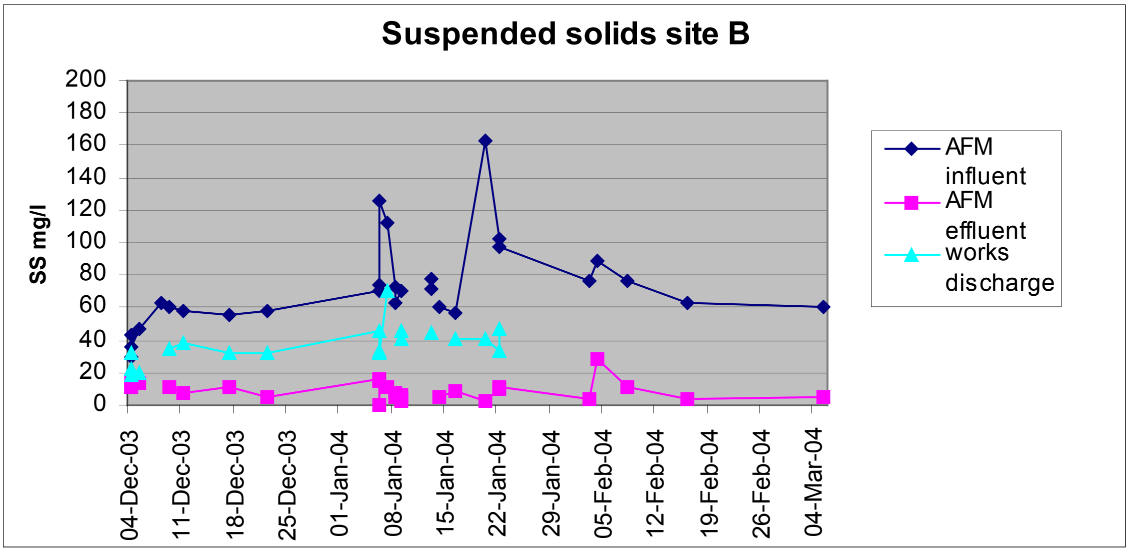
Fig 2. Site A suspended solids concentration over the duration of the trial



Site B suspended solids

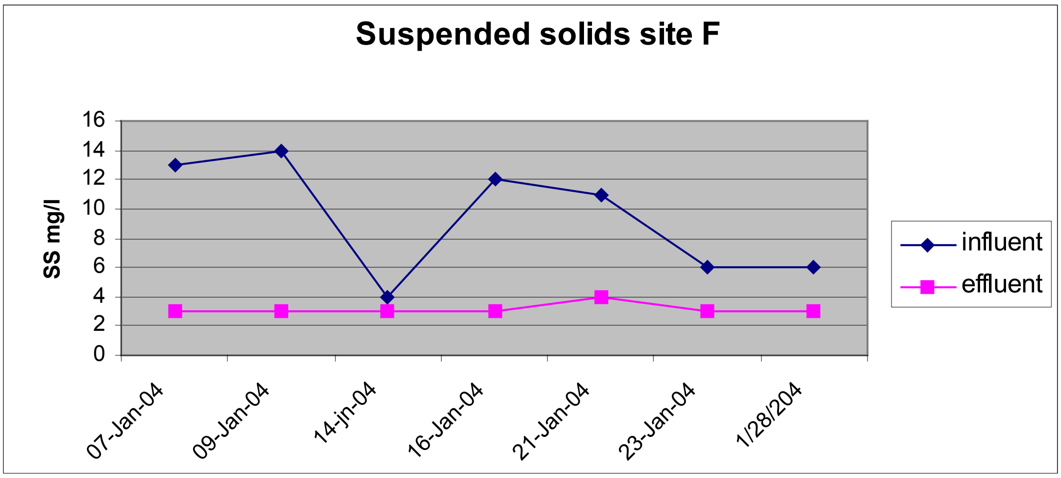
The influent to the AFM filter was taken after the filter beds but before the humus tanks. Graph 3, shows that the solids level entering the AFM filter and humus tanks to be approximately 60mg/l average. The effluent from the humus tanks averaged around 35mg/l and the effluent from the AFM filter was approximately 10mg/l.

Fig 3 Site B suspended solids concentration



Site F suspended solids concentration

Fig 4 Site F suspended solids concentration



Site F had an excellent discharge water quality, so it wasn't an arduous water for the AFM to treat. The discharge water quality was very stable, with solids concentration below 3mg/l SS. The limit of detection was 3mg/l so the actual readings were lower.

BOD

Site A BOD concentrations

Fig.5 Site A , BOD concentration

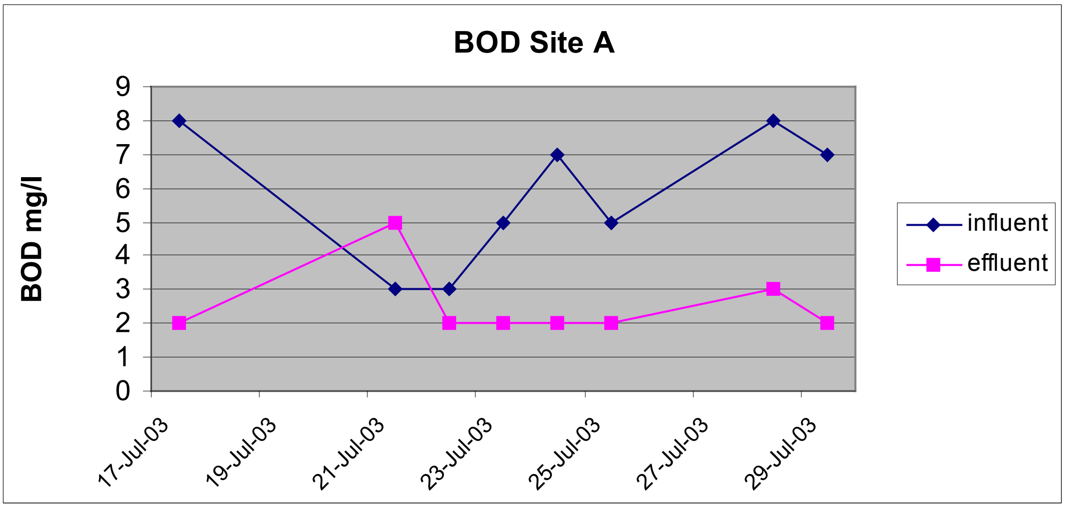
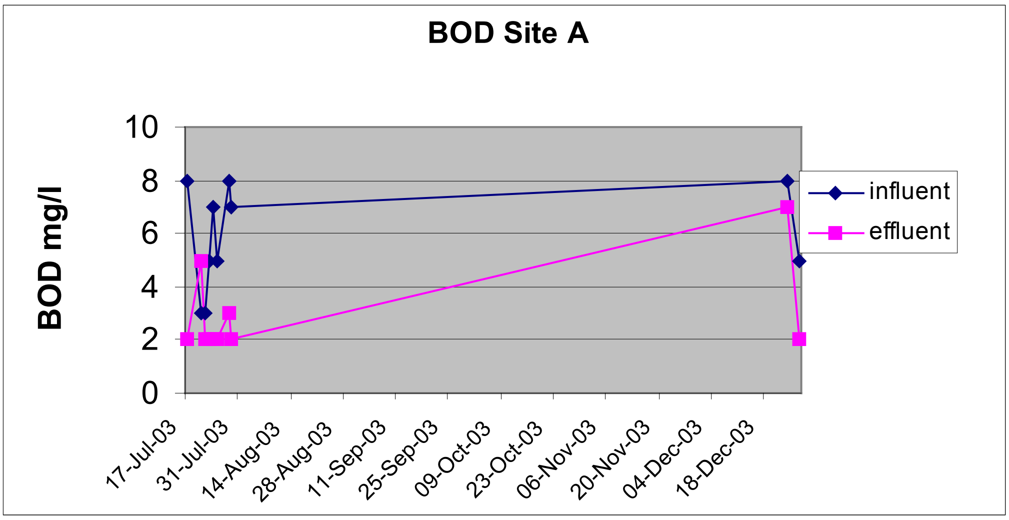


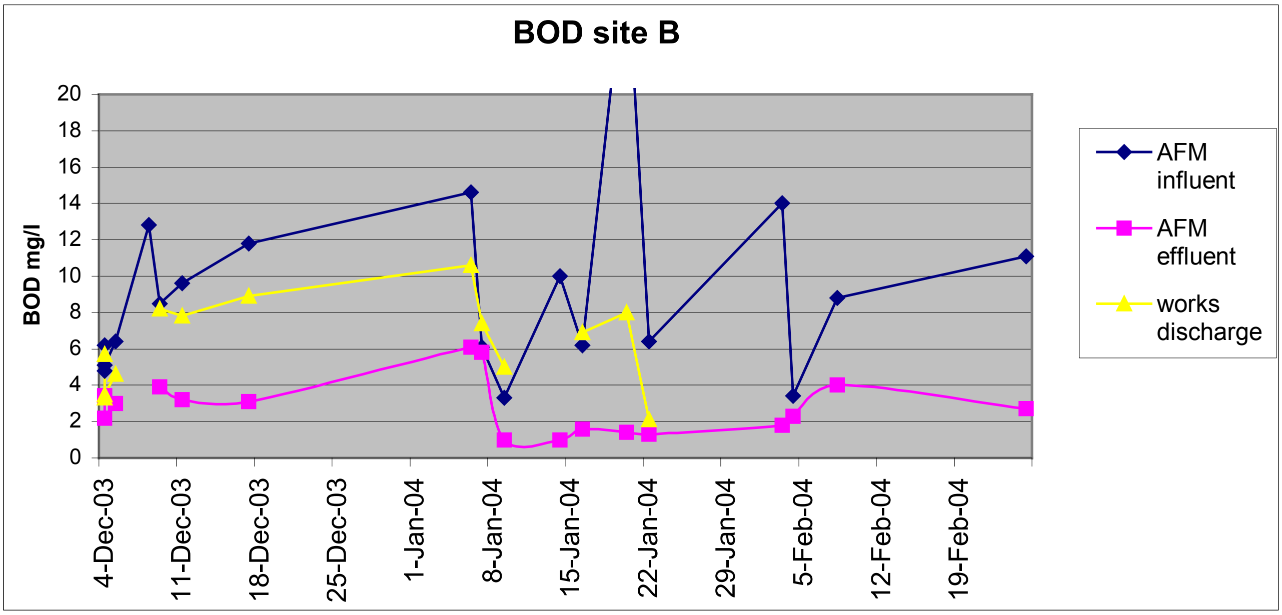
Fig 6 Site A BOD concentration over the duration of the trial



Site A was in compliance with their discharge water quality of 10mg/l BOD. However the AFM improved the already high quality of the discharge by reducing the BOD by a further 70%.

Site B BOD

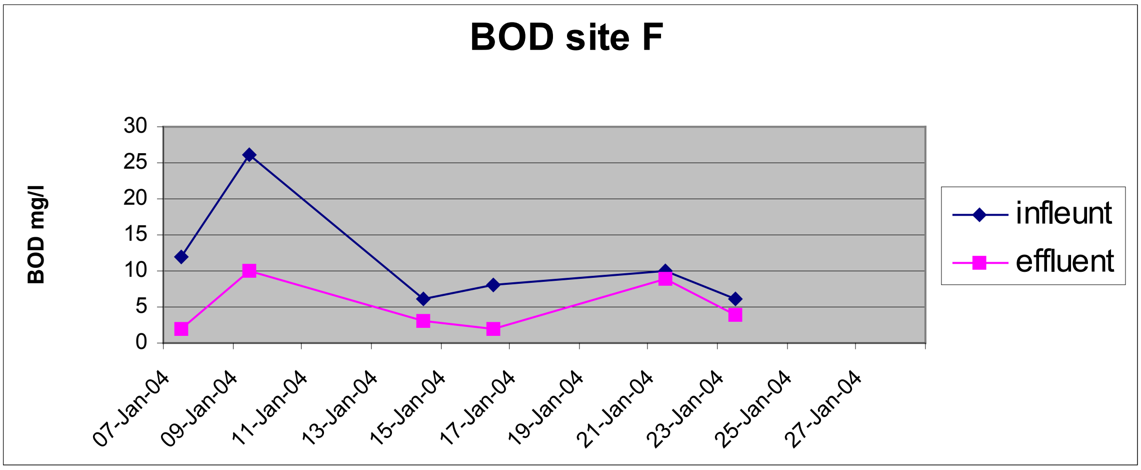
Fig 7. Site B BOD concentration



The AFM filter was fitted before the humus tank on site B. The filter receives water directly from the filter beds. Fig 7 shows that the AFM filter reduced the BOD to a low concentration, which was consistently better than the humus tank on the facility. Indeed the humus tank had been upgraded with a gravel filter on the back end of the humus tank, so the AFM filter was being compared against more than just a standard humus tank

Site F BOD

Fig 8 Site F BOD concentration



The final data point on site F is the 24th January, however samples will continue to be collected, over the critical period up to the end of May. The bacteria in sewage treatment works become unstable late spring early summer, so it will be important to continue the trial over this critical period.

Site F is an activated sludge sewage system followed by secondary humus tank sedimentation. In order to test the limits of the AFM filter, the position of the filter influent was change to before the humus tank. The influent loading was now 2500mg/l suspended solids.

The filter was able to cope with the loading, however the area above the filter bed rapidly filled up with collected sludge and stopped the filter. The test demonstrated that the filter could cope with extremely high loadings, but physically the filter wasn't large enough to cope with the collected sludge.

The photograph on the right shows the influent and effluent water to the AFM filter.

The AFM filter can be connected directly onto the discharge from filter beds. In activated sludge systems it would be more logical to have a simple in-tank sludge separation process to limit the loading on the AFM system to several hundred ppm.

If a sand filter had been exposed to the extreme loading to which we subjected the AFM filter, it would be unlikely that the filter would have coped. Indeed it would probably have been necessary to open the filter and dig out the sand bed. However with the AFM filter, the unit was placed onto back-flush, and the cycle was repeated several times before the system went back on-line with the effluent from the humus tanks.

The photograph on the right shows the quality of the humus tank discharge and AFM discharge water quality. The photograph shows that the AFM filter is producing a clear, bright discharge with virtually no colour. The result indicates that the AFM filter has fully recovered from exposure to extreme conditions.

COD

Site A COD

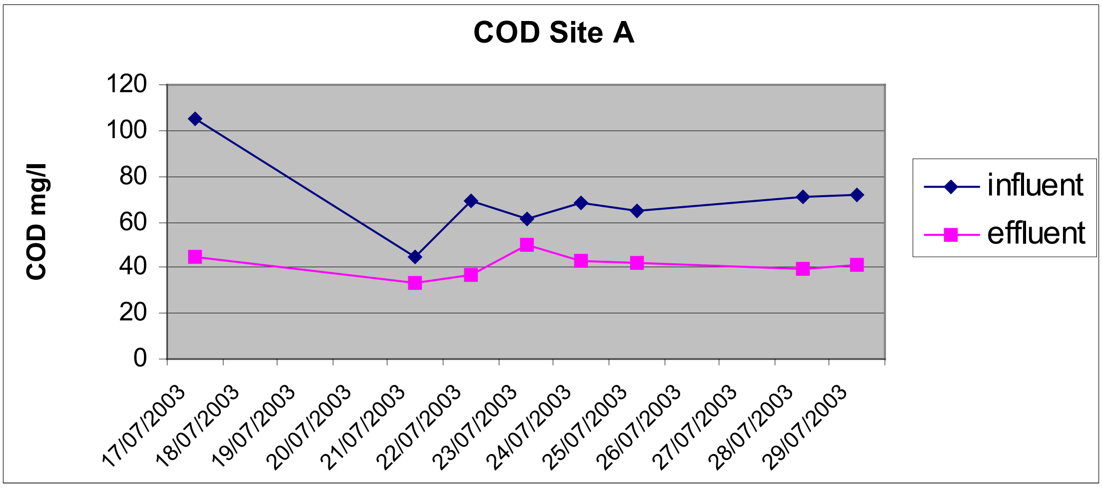
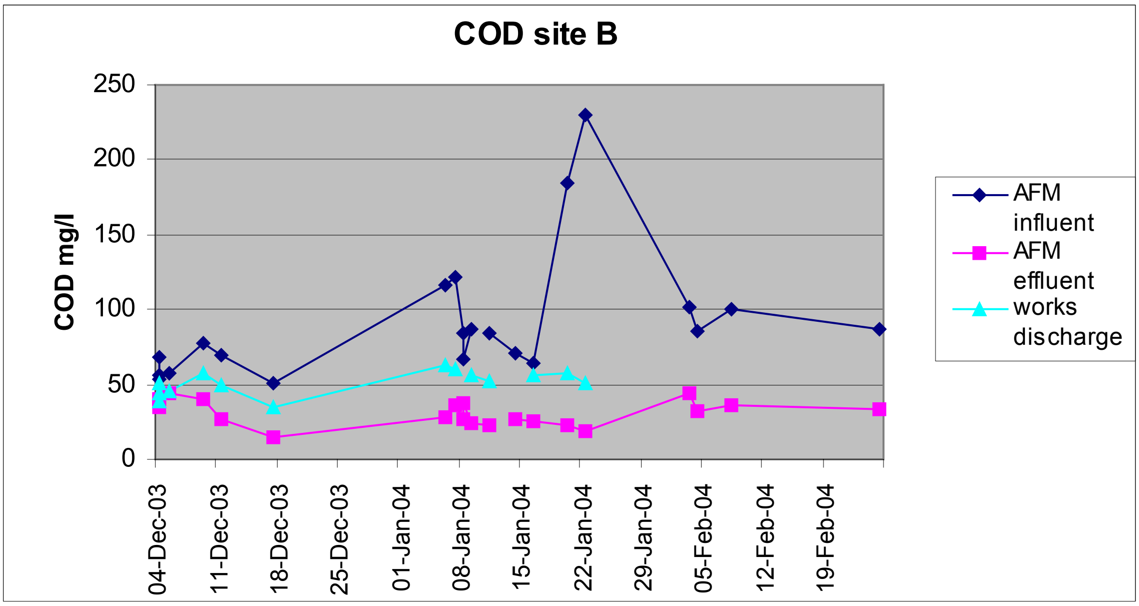


Fig9 Site A COD concentration

A characteristic of the AFM filtration, is the predictable and consistent nature of the process. Fig 9 site A COD performance graph shows that AFM is reducing the COD by approximately 50% and consistently provides a discharge water quality of 40mg/l. It may be that the dissolved COD component is constant while the suspended solids COD are a variable.

Site B COD

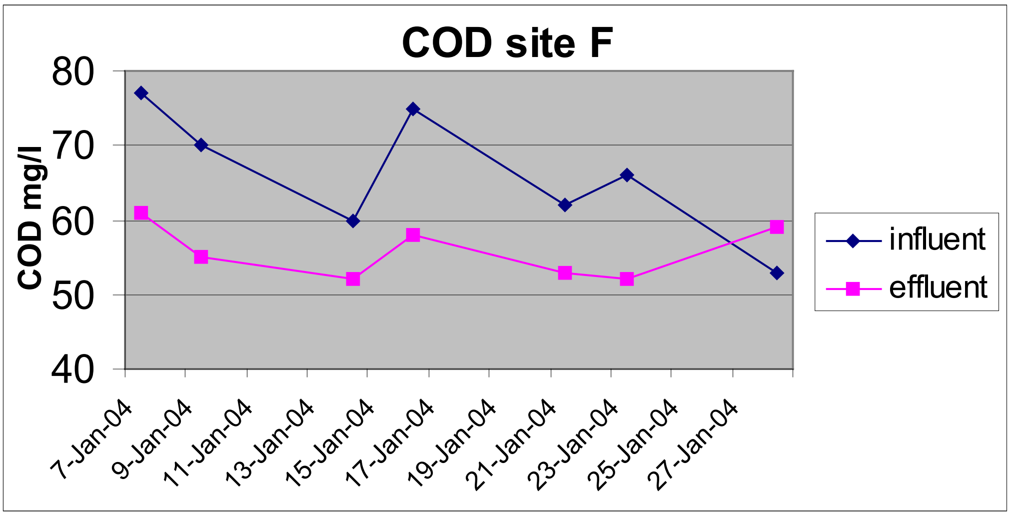
Fig 10 Site B COD concentration



Site B is a small sewage works in which the AFM filter was installed after the gravity filter beds. The AFM filter performed consistently better than the existing humus tank and gravel filter combination, to provide a consistent bright effluent discharge.

Site F COD

Fig 11   Site F COD concentration



Site F is a sewage works with activated sludge water treatment followed by humus tank sedimentation. The bacterial sludge and water immediately prior to the AFM filter was anoxic. The bacteria have therefore been subjected to oxygen deprivation stress, stability of the bacterial floc may therefore have been affected.

The AFM filter was effective in reducing the COD, however the performance of the system was reduced to around 20% reduction as opposed to a 50% to 60% reduction that can be expected from an aerobic effluent as demonstrated by sites A, B & H

There are two issues that need to be clarified, the anoxic humus tank sedimentation phase will have stressed the aerobic bacteria. This may have resulted in a break down of the bacterial floc structure into smaller components that then passed through the filter, or the bacteria have ruptured releasing their contents into the water.

The BOD results for the site as shown in Fig 8 show that the AFM filter performed well with regards to BOD removal, but Fig 11 shows a reduced performance with COD removal. The results suggest that filter is removing the bacterial cell biomass but the COD component is in solution. The result indicates that exposure of the bacteria to anoxic conditions in a conventional humus tank, results in the release of COD from the bacteria into solution.

Ammonium

Ammonium is a metabolic by-product resulting from the metabolism of protein and excretory human products such as urea. Ammonium can be very toxic to aquatic life and levels as low as 1 mg/l can exert chronic sublethal toxicity. Ammonium is a nerve toxin but it will also cause fish gill hyperplasia leading to myxobacterial gill infections and secondary saprolignea fungal infections. In more alkaline water the pKa equilibrium value for ammonium shifts in favour of a higher concentration of ammonia which is believed to be much more toxic than ammonium. A simple shift in pH may therefore result in fish mortalities from direct ammonia toxicity.

The AFM filtration system will not remove ammonium from solution, however the data is present to demonstrated that autotrophic bacterial nitrification by *Nitrosomonas spp* and *Nitrobacter spp* is not developing, and hence the AFM is not becoming a biofilter.

Site A Ammonium

Fig 12 Site A ammonium concentration

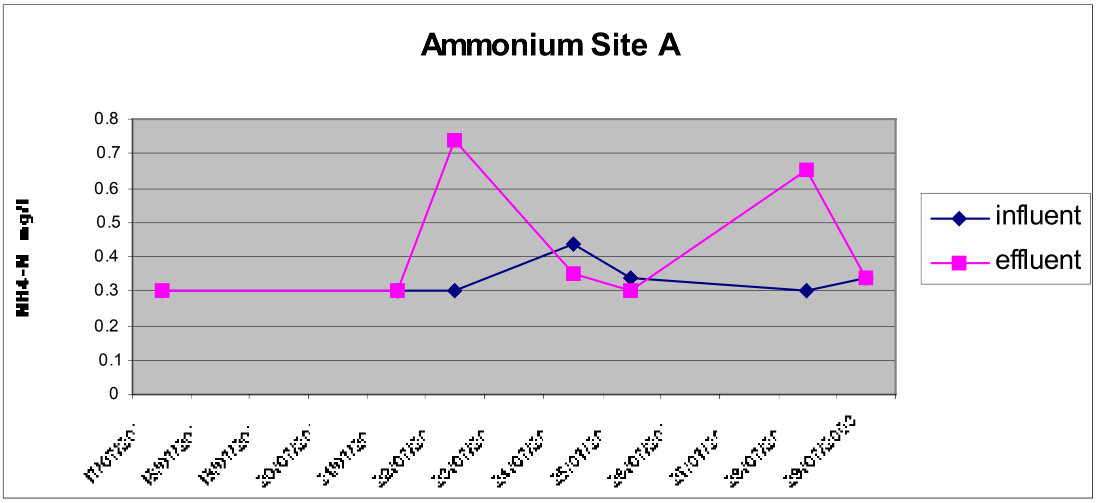
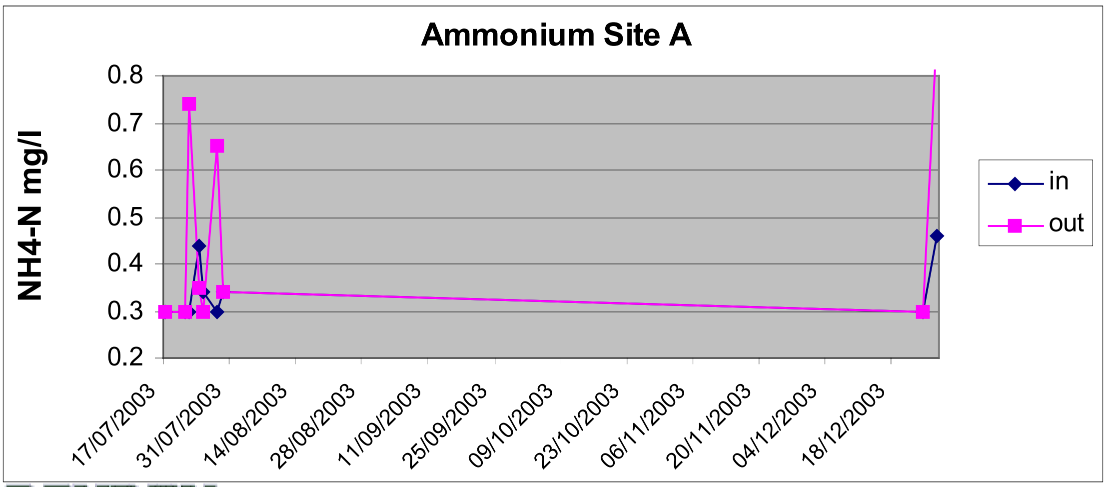
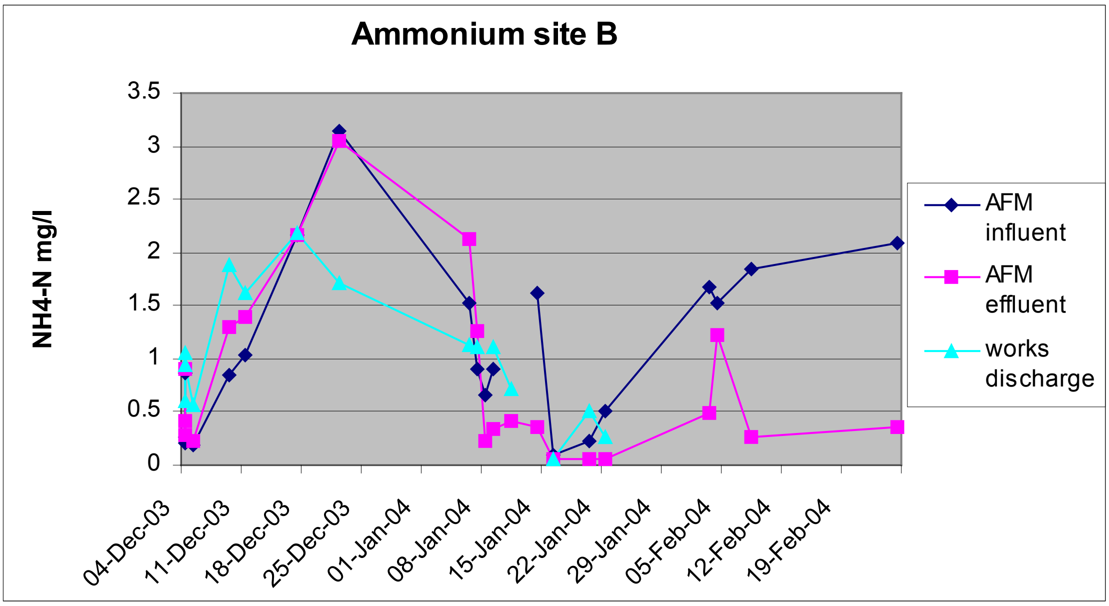


Fig 13 Site A ammonium concentrations over the duration of the trial



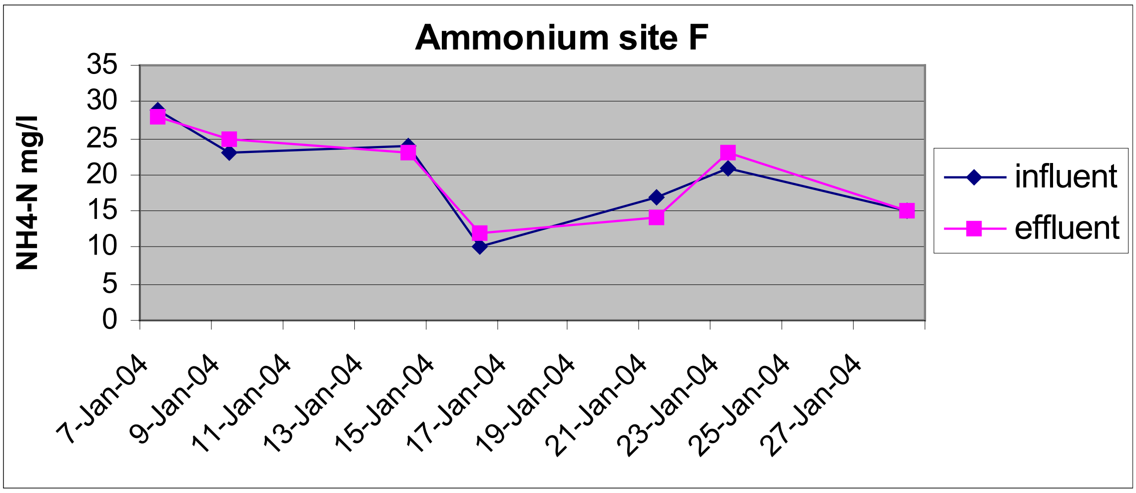
Site B Ammonium

Fig 14 Site B Ammonium concentrations



Site F Ammonium

Fig 15   Site F ammonium concentrations



The ammonium results from the trials show that the influent ammonium concentration tracks the AFM discharge ammonium concentration. There is no net removal or addition of ammonium to the discharge water. However, on the 14th January at site B, it would appear that the gravel filter beds started to discharge and increased solids load (bacteria) into the discharge water. The discharge water (influent to AFM filter) was treated by the AFM filter and the filter physically captured the nitrifying bacteria and reduced the ammonium levels in the discharge from the AFM filter

Long Term effluent treatment trials site H

A full scale AFM tertiary treatment system was installed on site H in 1998. The facility included a standard stainless steel, horizontal pressure filter operating at a flowrate of approx 4 cubic metres per hour per square meter of filter bed surface area. The total surface area of the filter was three square meters. Total treated water flowrate was therefore 12 cubic metres per hour.

The system was one of the first AFM units. Since the installation there have been many improvements in the quality of the AFM, design of the filtration system, and operating parameters. However the results are still impressive, and are presented in this report to demonstrate the long term performance of AFM filtration systems for the tertiary treatment of sewage effluent.

The pressure filtration system was operated manually with no automatic back-flush. Back-flush frequency was approximately once every 2 to 3 days. The back-flush flow rates were only 25 cubic metres per hour, we now know that the flowrates should be 40 to 50 cubic metres per hour. In addition there was no air scouring of the bed, while AFM does not require air scouring, the process does improve the performance of the system.

Data has been collected over the last six years and is presented in this report.

Date period	April 1996 to Sept 2002
AFM filter went on-line	April 1998

The AFM filter went on-line in April 1998 with the first data point being 22/4/98. The influent relates too the water entering the humus tank and the effluent is the discharge from the humus tank. After 22/4/98, the effluent relates to the discharge from the AFM filter

Suspended solids site H

Fig 16 Site H suspended solids, large scale

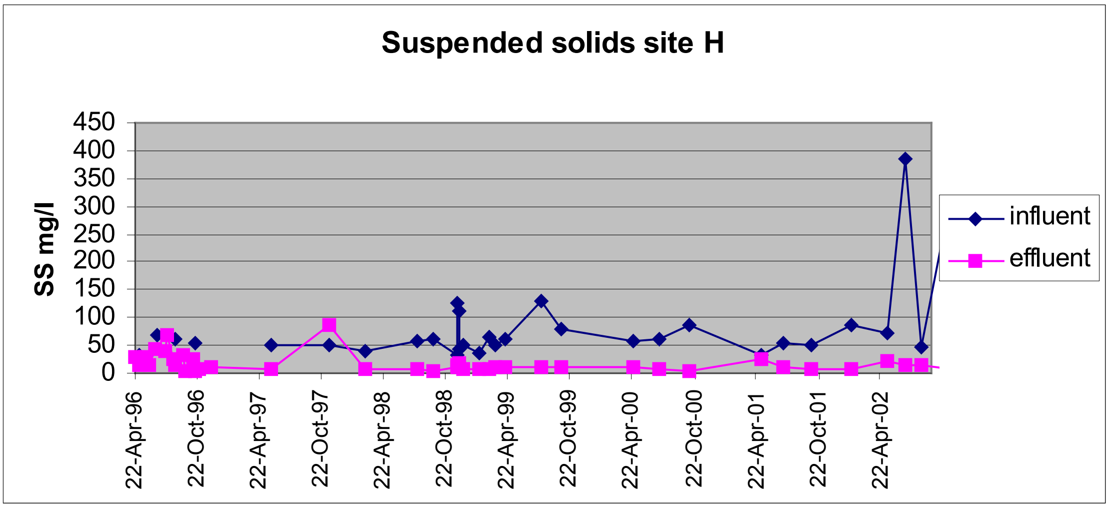
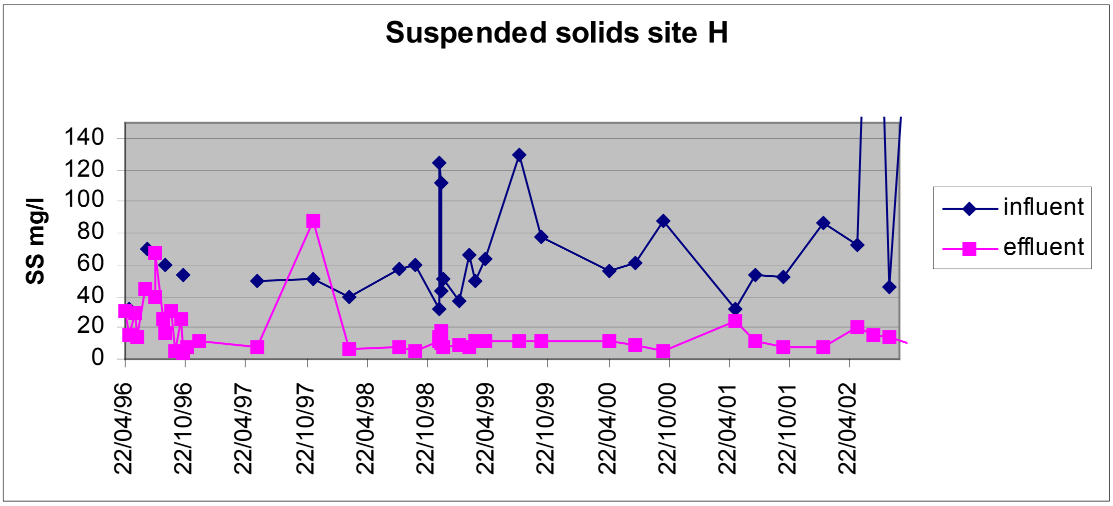


Fig 17 Site H suspended solids, small Y scale



Figs 16 & 17 show the period from 22/4/96 through to 22/9/02. The AFM filter was started 2/4/98. Prior to the AFM filter coming on-line the effluent suspended solids concentration averaged 30mg/l, with several large peeks in discharge concentrations. After the AFM filter went on-line the maximum discharge peek recorded was 20mg/l (on 22/4/01). The above graphs show that the average influent suspended solids concentration was approximately 50 mg/l and the effluent level was 10 mg/l after the AFM filter, giving an 80% reduction of the solids load discharge by the sewage works, and a 60% improvement over the existing humus tanks. The results demonstrated the greatly improved performance over conventional humus tanks.

BOD site H

Fig 18 BOD site H, large scale

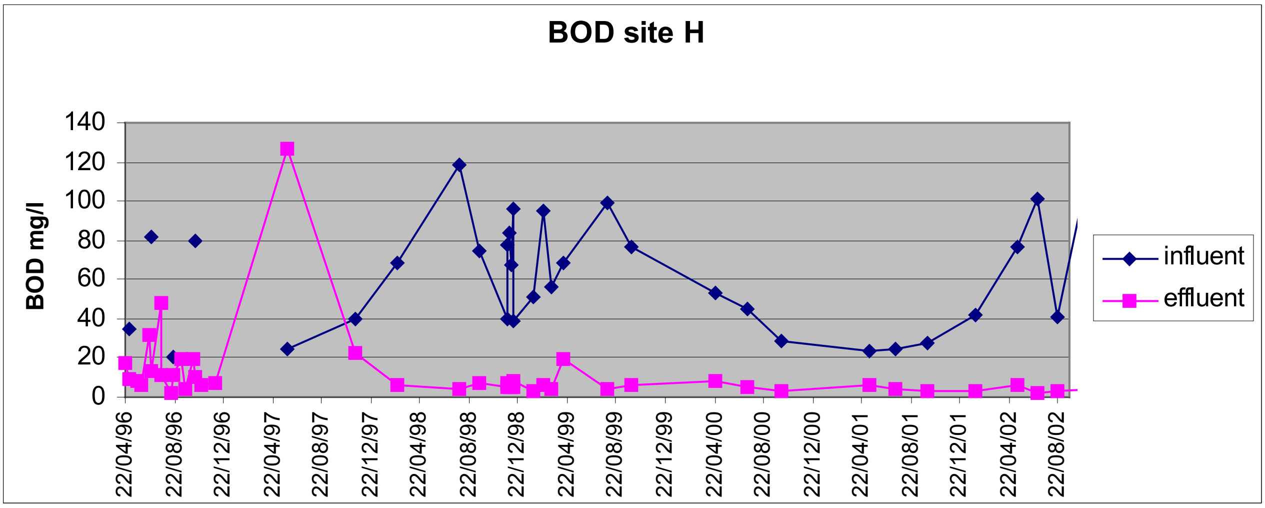
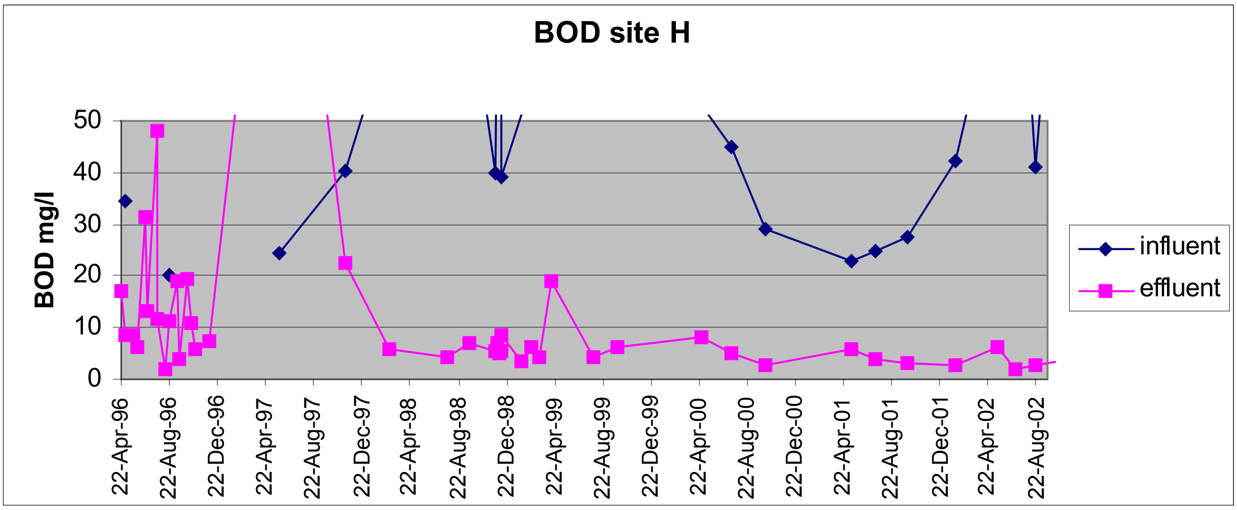


Fig 19 BOD site H small scale

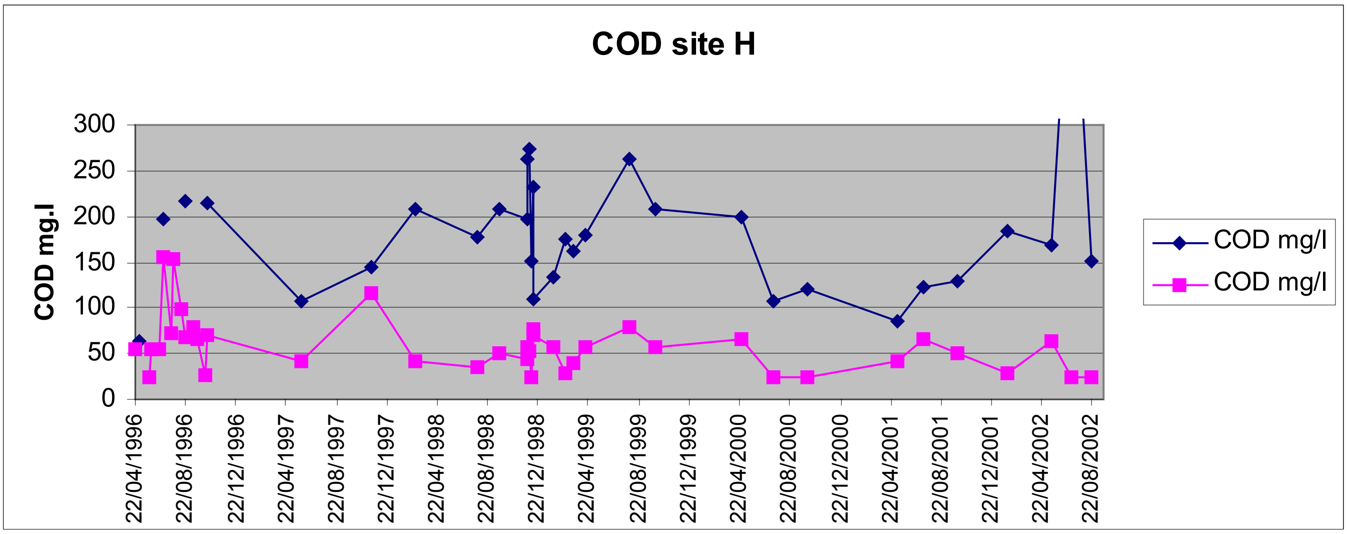


Prior to the AFM filtration system going on-line in March 98, the BOD from the humus tank gave an average figure of approximately 20mg/l. However the system was unstable as indicated by large BOD discharge peeks.

After the AFM filter went on-line the BOD averaged 5 mg/l with only one result at 20mg/l.

COD site H

Fig 20 COD site H



Site H has a high COD levels entering the humus tank and AFM filter of approximately 175mg/l. After passage of the water through the humus tank, (data from 22/4/96 to 22/4/98), the COD levels ranged from 25mg/l to 155mg/l. After passage of the water through the AFM filter the COD levels ranged from 25mg/l to 75mg/l.

Conclusion from long term site H results

The AFM filtration system at site H, was only back-flushed two to three times each week, also the back-flush rate was too slow, the flowrate should have been increased from 25 to 40 cubic metres per hour. Also at site H there was no air scouring of the filtration media.

The data clearly shows that the AFM filter has had a major impact on the final effluent quality, and confirms the long term stability of AFM as a filtration media for the tertiary treatment of sewage effluent.

5. Prescribed substances

Prescribed substances are chemicals and elements which must not be allowed in the discharge from sewage effluent or any industrial waste discharge. The substances are prescribed because they can bio-accumulate in the ecosystem, and because they are extremely toxic. Details of the "Black List" and "Red List" substances are presented in Annex 3.

There can be no safe discharge level for prescribed substances because through chain amplification a low level discharge will become a high concentration in animals at the top of the food chain. For example, bacteria absorb the substances in sewage treatment works, the bacteria are discharged to rivers and the sea, and are in turn consumed by rotifers and other organisms, until it reaches fish and aquatic mammals.

The concentration of toxins will have increased by several orders of magnitude by the time it reaches the top of the aquatic food chain. The levels are such that they can have an impact on the fecundity of aquatic animals and thereby the whole of the aquatic ecosystem. Also fish are harvested for human food as well as for the production of fishmeal. The fishmeal is converted into high protein pellets and fed to farm animals. Consumption of the animals, milk, and milk products, eggs and fish introduces the prescribed substances back to human food chain. The prescribed substances are persistent biotoxins and must be eliminated from effluent discharges.

One of the most toxic components to the aquatic ecosystem, is Tributyl Tin. The Marine Environment Protection Committee - 41st session: 30 March - 3 April 1998, eventually prohibited the use of toxic antifouling paints containing organotins such as Tributyl tin (TBT). However TBT is still in the environment and continues to go around the ecosystem circuit.

The prescribed substance will to a large extent be absorbed by the bacteria in the effluent treatment system..Some preliminary work is being conducted on site A with the analysis of selected prescribed substances, including TBT

Table 1 TBT levels before and after AFM filtration and in the back-flush water, limit of detection 0.0038mg/l

Sample date	Influent mg/l	AFM effluent mg/l	AFM back-flush water mg/l
24-Jul-03	0.0046	0.0038	0.0063
28-Jul-03	0.0038	0.0038	0.0045
29-Jul-03	0.0038	0.0038	0.0118
24-Dec-03	0.0052	0.004	0.0104
27-Dec-03	0.0061	0.0038	0.0099

Table 1 shows that the AFM filter was removing TBT to below the limit of detection in all but one of the analysis. The results also demonstrate that the AFM filter is concentrating the TBT in the back-flush water. The implication of these result are very serious. We now know that if a toxic prescribed substances are being discharged from a facility below analytical detection level, it does not mean that there are no prescribed substances in the water. The data clearly indicates that the AFM filter is able to trap the toxins and reduce their discharge into the environment.

6. Environmental Legislation Relating to the Discharge of Effluent from STW's

Introduction

There are numerous pieces of European legislation, which require the UK water industry to improve the quality of their effluent discharges, and thereby reduce the impact on the receiving environment.

The improvement to the discharge standards required under legislation will necessitate significant investment throughout the UK water industry. The use of tertiary treatment is one of the treatment techniques available that can be used to achieve compliance with some of the tighter restrictions. Any application of sand filtration is a possible market for AFM.

Some sections of the following legislation have been implemented already. The relevant sections that could benefit by the use of AFM are summarised as follows:-

Urban Wastewater Treatment Directive (91/271/EEC)

1. The directive places a timescale, and quality objective, for the treatment of wastewater from domestic properties, industrial wastewater and includes run-off rainwater.

2. Secondary treatment will be required from all works with a population equivalent (PE) of between 10 000 and 15 000 by 31/12/05.

3. Secondary treatment will be required from all works with a population equivalent (PE) of between 2 000 and 10 000 by 31/12/05 if discharged to fresh water or an estuary.

4. Secondary treatment will be required to achieve the following standard:-

    i) BOD 25mg/l or 90% reduction compared with influent
    ii) COD 125mg/l or 75% reduction compared with influent
    iii) SS 35mg/l or 90% reduction compared with influent, for works >10 000PE, or 60 mg/l or 70% reduction compared with influent, for works 10 000 to 2000PE
    iv) Phosphorus 80% reduction compared with influent or 2mg/l for works 10 000 to 100 000PE and 1mg/l for works >100 000PE.
    v) Nitrogen 80% reduction compared with influent or 15mg/l for works 10 000 – 100 000PE and 10mg/l for works >100 000PE.

Dangerous Substances Directive (76/464/EEC) and Daughter Directives

a) The directive eliminates the discharge of list 1 substances and minimises the discharge of list 2 substances to the aquatic environment.

b) List 1 substances are categorised by their toxicity and potential for bio-accumulation.

c) List 2 substances are considered to be less harmful than List 1 substances, and they require reduction to levels which do not breach environmental quality standard (EQS). List 1 and List 2 substances have each been prescribed an EQS target level.

d) Some 1700 sewage treatment works and industrial discharges are monitored for List 1 substances and 4400 discharges are monitored for List 2 substances by the Environment Agency in the UK.

e) Results from Landfill sites and site A, STW have shown that AFM is capable of eliminating List 1 and 2 substances from a biological treatment system.

Freshwater Fish Directive (78/659/EEC)

a) The directive is for designated stretches of water (rivers, lakes or reservoirs) to achieve a minimum standard for the protection of salmon, trout and coarse fish.

b) Fourteen parameters have been selected for control, including BOD, dissolved oxygen, temperature, ammonia, chlorine, suspended solids, copper and zinc.

c) Guideline standards have been set by the Environment Agency for target river quality for salmon and trout as follows:-

Suspended solids	25mg/l
BOD	3mg/l
Nitrite	0.01mg/l
Non-ionised ammonia	0.005mg/l
Total ammonium	0.04mg/l
Zinc (depending on water hardness)	10 – 100mg/l

d) Imperative (i.e. mandatory, which must never be exceeded) river standards for the designated stretches of water have been set as:-

Non-ionised ammonia	0.025mg/l
Total ammonium	1.0mg/l
Zinc (depending on water hardness)	0.03 – 0.5mg/l

e) Tertiary treatment will be a suitable treatment option for works, which cause a deterioration of the receiving water above the guideline and imperative limits. AFM has proved to be very successful at the removal of BOD, reduction in suspended solids and bio-accumulation of metals. The ammonia limits will require many works to achieve nitrification. Biomass interception, and salvage, for return to the activated sludge process has been successfully achieved using AFM.

f) Capital expenditure to comply with the directive is expected to be £140 million per year, with additional operating costs of £20 million per year by 2010.

Asset Management Period 4 (AMP 4)

a) Capital investment by the UK water industry is subject to approval by the Environment Agency and the industry regulator OFWAT. Draft investment plans are submitted for a five-year period, which are called asset management periods. The fourth period (AMP 4) has recently been prepared by all water companies for the period 2005 – 2010.

b) The draft proposals are submitted to the Environment Agency for verification that the water company's investment plans will satisfy the standards required by European Union and national legislation.

c) The costs of the improvements are submitted to OFWAT for inclusion in the consideration of the "K" factor, which is a value over and above inflation that a water company can increase its charges. There will be considerable argument over cost/benefit analysis of the proposals and there is rarely agreement between the Environment Agency and OFWAT on one side and the water companies on the other over the capital cost of projects. For the draft AMP 4 proposals, the water companies have given a range of investment between £4.8 - £10billion. The Environment Agency range is £519 million - £1.2 billion. Before the final decision, in November 2004, there will be numerous reviews by the Environment Agency, the water companies, DEFRA and OFWAT.

Potential for AFM in the Water Industry

The results obtained using AFM have demonstrated a superior performance over sand filtration systems. Impending legislative compliance will require water companies to upgrade many hundreds of their sewage treatment works to comply with the Dangerous Substances Directive, Freshwater Fish Directive and they have submitted their draft proposals for investment under the AMP 4 programme.

Proposals submitted to date by the water companies have not included AFM. As the review programme for the AMP 4 budgets are reviewed it is likely that compromises will have to be made to prevent excessive increases in water bills. United Utilities have indicated that water charges will need to rise by 71% to pay for the required capital investment. This will not be acceptable to OFWAT or United Utilities customers.

AFM, in addition to use as a substitute filtration media, could for example reduce the projected expenditure on humus tanks, which would be a major capital saving on some projects. The decision makers for AMP 4, i.e. water companies, government ministers, the Environment Agency and OFWAT need to be made aware of the benefits of AFM and its application in biomass salvage, secondary settlement replacement and List 1 and List 2 substance removal.

7. Discussion

The initial results show that AFM can reduce the discharge of prescribed substances from sewage treatment works. The environmental implications of these results are huge, and will be examined in more detailed in subsequent reports.

The present report concentrates on the general water quality parameters;

- Suspended solids
- BOD
- COD
- ammonium

Suspended solids

The primary function of a tertiary treatment mechanical filtration system is the removal of suspended solids from the wastewater stream. The suspended solids discharge from sewage works normally consists of viri, bacteria floc, fungi, protozoa, nematodes, higher organisms, metabolic by-products, organic and inorganic components.

Biofouling of conventional filtration media such as sand, occurs almost immediately, and within 3 days there will be 100% coverage of the sand grains by bacteria. The bacteria continue to grow, and develop a polysaccharide jelly that protects the bacteria and binds the sand grains or gravel. It becomes extremely difficult to clean the sand, and maintain the performance of filters in biologically active wastewater stream. Aggressive cleaning may be required, or chemical cleaning to remove the bacteria. In some cases larger sized filtration media is used to help minimise fouling issues and bed blockage. However all of the cleaning strategies and operating procedures reduce the performance of the conventional systems and increase the running costs. With AFM filtration media, we have proved that we can use a relatively small filter media (0.50mm to 1.0mm) in simple pressure filters. The filters were cleaned by back flushing, no air scouring or chemical were used to maintain the media. One of the trials has been running for 9 months, with no deterioration in performance or fouling of the media.

The suspended solids discharge consent will vary depending on the receiving water coarse, however the new surface water and fisheries directive will result in tighter discharge conditions. The results obtained in the present trial shows that AFM will result in an excellent water quality and 100% compliance with the new directives, problem solved!

BOD

The BOD concentration is the biochemical or bacterial oxygen demand of the wastewater. Water containing a high BOD will exert an oxygen demand on the receiving environment, and this will be detrimental to the aquatic life.

The discharge from sewage works is normally around 20 mg/l, however this level is also going to be tightened over the coming months and years. The BOD is associated with both dissolved and suspended solids. However the majority of the BOD is usually in the form of viable organisms.

In all three trials there was a major reduction in the BOD discharge from the AFM filters. The discharge concentration also appears to be relatively constant and independent of the influent concentration.

COD

COD is the chemical oxidation demand of the water. The figure will include viable organism, biodegradable organics, non-biodegradable organics, and chemicals that can be chemically oxidised. The COD is usually several times higher than the BOD.

In all three trials the AFM was effective in reducing the COD in the discharge. However in the case of site B, where the AFM was fed with water directly from the filter beds, the performance was even better. It could be argued that there is a release of COD into solution during the anaerobic humus tank sedimentation phase. Prior to this stage a higher percentage of the COD chemicals may be associated with the solids, and because of this, the efficiency of the AFM filter was better in the raw filter bed water, as opposed to the final effluent.

It is likely that prescribed substances and non biodegradable chemicals that contribute to the COD are adsorbed and absorbed by the bacterial cell biomass in the discharge from the filter beds. A proportion of these chemicals is then eluted from the bacterial cell biomass during the reduced oxygen tension or anaerobic phase whilst the sludge is in the humus tanks.

This data needs to be confirmed, however if supported then it will have huge implications with regards to the design and operation of effluent wastewater treatment systems. It will also result in major capital cost benefits as well as operational savings.

Ammonium

Ammonium is a product derived from the mineralisation and biological degradation or protein and organic molecules containing nitrogen, such as urea. Ammonium levels are oxidised to nitrate by aerobic nitrification. Reduction by dentrification of nitrates back into nitrogen can occur under anaerobic conditions, but if there are proteins and organics present then ammonium can also be produced at this stage. During the humus tank sedimentation phase there will be biological activity under anaerobic conditions or at a low oxygen tension. Under these conditions there can be a net production of ammonium.

AFM will have no impact on the ammonium levels in the water because there is little to no biological activity in an AFM filter bed. However, we know that there could be a release of ammonium, COD and chemicals fed back into solution during the humus tank sedimentation stage. We also know that AFM filtration can cope with the high solids load directly from activated sludge tanks or filter beds. It would therefore appear that on several levels, it would be better to by-pass the humus tanks, not only will this provide cost savings, but there may also be an improvement in water quality.

8. Conclusion

Installations using AFM have been in place for up to 5 years, and continue to show excellent performance. The three trials on sewage works have performed extremely well and demonstrate that in all cases the suspended solids level, BOD and COD have all been reduced to low levels which would be in compliance with the new water directives. The systems have performed this task automatically with no attention from personnel.

The AFM filters bring the discharge water quality into 100% compliance, moreover the performance of AFM is improved by taking the feed water from before the humus tanks. If the results are supported by additional demonstration trials, then humus tank sedimentation can be eliminated from sewage treatment works. The performance of AFM can be summarised in the three points below.

a) Improve water quality and bring existing works into compliance with the new water directives. At present there is no economic means by which the water companies can achieve this task.

b) Revenue cost savings because of the high performance, reliability and simplicity of the system.

c) Capital cost savings, because AFM filters are lower cost than the alternatives, and the system does not need a humus tank.

9. Annex index

1. Pilot scale system specification
2. Trial protocol
3. Black list and Red substances
4. Water directives

Annex 1

Pilot Scale System Specification

Test bed area	1m x 2.5m
Height	1.2m
Power requirements	230v 1 phase 50hz, 3kw
Filter diameter	500mm
AFM bed depth	350mm
Back-flush tank volume	500 litres
Default back-flush sequence	4 hours run phase 2minutes back-flush
Run phase flowrate	750 litres/hr = 3 cubm/hr.sqm
Back-flush flowrate	150 litres min = 30 cub/hr
Bed depth	300mm
filter media base	50kg pea gravel
AFM grade 1	100 kg
Materials of construction	stainless steel, frame, filter and control panel, pipework in PVC
Mode of operation	100% automatic
Water feed connection	3/4" hose, pump will self prime to approx 3m.
Discharge connection	1.5" hose gravity feed from top of back-flush tank
Back-flush connection	1.5" hose, pressurised discharge
IP rating	55
Electrical installation	kit supplied with armoured 15m of 1 phase wire fitted with three pin water protected round plug
Electrical protection	RCD protected in panel, it is also recommended that power supply is RCD protected.
Installation requirements	The frame must be installed on a perfectly level base. Frame is fitted with legs to adjust levels

Annex 2

AFM Waste Water Treatment project
Trial water analysis protocol.

Water Flowrates

Product water flowrate is set and can not be changed	750 litres per hour
Back-flush water flowrate is set and can not be changed	150 litres per minute
Back-flush duration	2 minutes
Back-flush frequency	4 hours

Water Analysis

Water analysis to be conducted on the inlet and discharge water from the pilot scale test bed. Samples of water to be taken at the same time.

Sample frequency minimum	once a week
Sampling frequency preferred	twice a week
Type of sample preferred	24 hour composite
Minimum time scale	12 weeks

Analysis to be conducted

Essential water analysis	**Secondary analysis**	**Tertiary analysis**	**Prescribed substances**
Frequency to be once or twice each week	Frequency to be once or twice each week	Frequency to be every one to two weeks	Frequency to be every 2 to 4 weeks
suspended solids	pH	E.coli	Prescribed substances
BOD	Turbidity	Faecal bacteria	Particle size analysis
COD	Redox potential	Total bacteria @ 22deg C	
Ammonium		Total bacteria @37 deg C	

Annex 3 Black list and Red list substances

The "BLACK LIST"

The Dangerous Substances Directive 76/464/EEC listed 129 so-called "black list" substances which were considered to be so toxic, persistent or bio-accumulative that efforts to control chemical releases and prevent pollution should be given the highest priority.

Aldrin
2-Amino-4-chlorophenol
Anthracene
Arsenic & its mineral compounds
Azinphos-ethyl
Azinphos-methyl
Benzene
Benzidene
Benzyl chloride (a - chlorotoluene)
Benzylidene chloride (a ,a - dichlorotoluene)
Biphenyl
Cadmium and its compounds
Carbon tetrachloride
Chloral hydrate
Chlordane
Chloroacetic acid
2-Chloroaniline
3-Chloroaniline
4-Chloroaniline
Chlorobenzene
1-Chloro-2,4-dinitrobenzene
2-Chloroethanol
Chloroform
4-Chloro-3-methylphenol
1-Chloronaphthalene
Chloronaphthalenes (technical mixture)
4-Chloro-2-nitroaniline
1-Chloro-2-nitrobenzene
1-Chloro-3-nitrobenzene
1-Chloro-4-nitrobenzene
4-Chloro-2-nitrotoluene
Chloronitrotoluenes (other than 4-Chloro-2-nitrotoluene)
Coumaphos
Cyanuric chloride (2,4,6-Trichloro-1,3,5-triazine)
2,4-D (including 2,4-D-salts & 2,4-D-salts)
DDT (including metabolites DDD & DDE)
Demeton (including Demeton-o, Demeton-s, Demeton-s-methyl & Demeton-s-methylsulphone)
1,2-Dibromoethane
Dibutyltin dichloride
Dibutyltin oxide
Dibutyl tin salts (other than Dibutyltin dichloride & Dibutyltin oxide)
Dichloroanilines
1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
Dichlorobenzidines
Dichlorodiisopropyl ether
1,1-Dichloroethane
1,2-Dichloroethane
1.1-Dichloroethylidene (Vinylidene chloride)
1,2-Dichloroethylene
Dichloromethane
Dichloronitrobenzenes
2,4-Dichlorophenol
1,2-Dichloropropane
1,3-Dichloropropan-2-ol
1,3-Dichloropropene
2,3-Dichloropropene
Dichlorprop
Dichlorvos
Dieldrin
Diethylamine
Hexachloroethane
Isopropylbenzene
Linuron
Malathion
MCPA
Mecoprop
Mercury & its compounds
Methamidophos
Monolinuron
Naphthalene
Omethoate
Oxydemeton-methyl
PAH (with special reference to 3,4-Benzopyrene and 3,4-Benzofluoranthene)
Parathion (including Parathion-methyl)
PCB (including PCT)
Pentachlorophenol
Phoxim
Propanil
Pyrazon
Simazine
2,4,5-T (including 2,4,5-T-salts and 2,4,5-T-esters)
1,2,4,5-Tetrachlorobenzene
1,1,2,2-Tetrachloroethane
Tetrachloroethylene
Toluene
Triazophos
Tributyl phosphate
Tributyltin oxide
Trichlorfon
Trichlorobenzene (technical mixture)
1,2,4-Trichlorobenzene
1,1,1-Trichloroethane
1,1,2-Trichloroethane
Trichloroethylene

2-Chlorophenol
3-Chlorophenol
4-Chlorophenol
Chloroprene (2-Chlorobuta-1.3-diene)
3-Chloropropene (Allyl chloride)
2-Chlorotoluene
3-Chlorotoluene
4-Chlorotoluene
2-Chloro-p-toluidine
Chlorotoluidines (other than 2-Chloro-p-toluidine)
Disulfoton
Endosulfan
Endrin
Epichlorohydrin
Ethylbenzene
Fenitrothion
Fenthion
Heptachlor (including Heptachlorepoxide)
Hexachlorobenzene
Hexachlorobutadiene
Hexachlorocyclohexane (including all isomers and Lindane)
Trichlorophenols
1,1,2-Trichlorotrifluoroethane
Trifluralin
Triphenyltin acetate (Fentin acetate
Triphenyltin chloride (Fentin chloride)
Triphenyltin hydroxide (Fentin hydroxide)
Vinyl chloride (Chloroethylene)

The Red List (List II)

From the original list of 129 substances, Daughter Directives have been adopted providing emission limits and quality objectives for receiving water. The implementation of best available technology (BAT) is required under PPC (pollution prevention and control) authorisation for the elimination of red list substances in discharges to water.

The black list substances covered by Daughter Directives for elevation to red list status are contained in the Environmental Protection (Prescribed Processes and Substances) Regulations 1991 (as amended). They are as follows:-

Mercury and its compounds
Cadmium and its compounds
Gamma - Hexachlorocyclohexane
DDT
Pentachlorophenol and its compounds
Hexachlorobenzene
Hexachlorobutadiene
Aldrin
Dieldrin
Endrin
PCB's
Dichlorvos
1, 2 – Dichloroethane
Trichlorobenzene
Atrazine
Simazine
Tributyltin compounds
Triphenyltin compounds
Trifluralin
Fenitrothion
Azinphos – methyl
Malathion
Endosulfan

Annex 4 Water Directives

European Drinking Water Directive (80/778/EEC)
European Groundwater Directive (80/68/EEC)
European Bathing Water Directive (76/160/EEC)
European Directive On Waters For Freshwater Fish (78/659/EEC)
European Directive On Waters For Shellfish (79/923/EEC)

Source of information for the above tables, http://www.envirowise.gov.uk