

AFM[®] filter media

Filter Media for the treatment of Drinking Water



Rapid gravity filter for drinking water treatment



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2. Scottish Water

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Executive Summary

Filtration is a common process in drinking water treatment, facilitating the removal of suspended matter and associated contaminants in the influent stream. Biofouling of sand, where the media becomes clogged with bacteria, is seen as a major factor contributing to the deterioration of filter performance and product water quality. If these problems can be resolved it would have significant benefits for the water industry. The trials confirm that AFM is a solution to the issues and provides a solution to the water industry to greatly improve water quality, simply by changing the filter media to AFM.

The study trials, undertaken with Essex & Suffolk Water and Scottish Water, compared AFM directly against sand under identical conditions. The results show that around a 30% improvement (and possibly a much higher percentage) in filter performance can be achieved by simply changing to AFM filter media, these benefits being due to improved contaminant removal and linked benefits of backwash efficiency and media longevity. The study outputs indicate that the environmental health, water quality, and potential cost benefits to be gained through the use of AFM are substantial.

The site-specific trial results are summarised below. Detailed results and analysis are presented in the report.

Site J: Un-clarified water

The raw water treated at site J is hard and nutrient rich with high levels of algae and bacteria. As a result, it was predicted that media biofouling would be an issue and that a difference in performance between AFM and sand might be seen after a period of around twelve weeks. However fouling of the sand occurred almost immediately resulting in high pressure drop and greatly reduced water flowrate through the sand bed. The data from the sand filter could not be used because the sand filter was running at 1/10 of the water flow of the AFM filter after the first week of the trial. In contrast the AFM filter continued to perform at the designed water flowrate with low pressure drop for the duration of the trial.

Site J: Clarified water using ferric chloride

For the pre-treated water it was possible to maintain the water flowrate through the sand filter facilitating a direct comparison of the sand against AFM over the duration of the trial.

In addition to analysis of the product water, efficiency of the back-flush cycle was monitored during the trial. If the back-flush is not 100% effective, there will be an accumulation of matter in the filter bed, and the filter will produce poor water quality and ultimately fail.

Back-flush performance is directly related to filter performance. For example, if more solids are back-flushed out of the AFM filter, then this suggests that more solids are being removed by the AFM filter from the influent water. The back-flush data shows that approximately 30% more solids are washed out of the AFM filter bed in comparison to the sand bed. In addition, the back-flush behaviour of the AFM bed was stable and predictable.

Site K trials

The water at site K is soft and of a high quality. The trial results show that the AFM filter performed better than the sand filter for every parameter analysed. The sand filter results showed several peaks indicating the sand filter was discharging high levels of retained matter back into the product water, this was not the case with the AFM filter.

1. Introduction

1.1 Background

One of the best techniques for the mechanical filtration of water is simple sand filtration. However, a common problem where filtration is applied in biological treatment processes is 'biofouling' which involves the media becoming clogged with bacterial matter. Where this occurs, increased backwashing is required to dislodge the matter, along with increased use of energy and chemicals in linked treatment processes due to the reduced efficiency of the filters. Research undertaken by Dryden Aqua in the UK has shown that processed glass material (PGM) has the potential to reduce these problems and thus to provide a more resilient and efficient media in a wide range of pressure and rapid gravity filter applications. Hence there is an identified market demand for recycled glass filtration media.

At the same time, there is a national focus on securing market outlets for recycled glass in a bid to reduce quantities currently sent for disposal. This is a result of legislation and policy placing restrictions on landfill disposal and setting statutory recycling targets.

1.2 Project Scope

One of the underpinning aims of this project was to establish market acceptance by water authorities/companies for the use of high quality filtration media in the treatment of drinking water thus creating a healthy market demand for AFM. In securing progress towards this aim, an industry engagement programme was initiated to identify a number of potential operators willing to host trials of the new media.

Following development of a pilot-scale system to compare the performance of AFM against high quality filter sand and a supporting trial protocol, the trials were conducted on two different water company sites, Site J and Site K during 2002/3. Site J had hard nutrient rich water with high levels of algae and bacteria; site K was a high quality very soft water. Two trials were conducted at Site J with un-clarified (raw) and clarified (pre-treated) water.

1.3 Trial Objective

The tests were conducted under identical conditions with AFM and sand. The respective water companies operated the test beds and samples were analysed by independent laboratories. The objective was simply to operate the filters for as long a period as possible, and note any difference between the performance of sand and AFM.

1.4 Report Structure

Following this short introduction, Section 2 provides information on the test protocol and design. Section 3 summarises the trial findings with respect to backflush efficiency followed by a detailed review of the water quality results in Section 4. Within these sections, findings from both of the trial sites referenced. Discussion and conclusions are provided in Section 5.

2. Test Protocol and Design

A draft test protocol was developed prior to the installation of the media setting out details of the trial duration, test bed configuration, run-phase and backflush procedures and sampling guidance. Direct supervision was provided by Dryden Aqua at the start of each set of trials.

2.1 Site J pilot scale system

The pilot scale system for Site J was supplied and installed by the water company. It was a standard test bed used by the water company for the evaluation of filtration media in different water types. The containerised system had four identical Plexiglass 250mm diameter columns and control systems to operate the beds under identical conditions.

Figure 2.1 shows the sand and AFM test bed for the clarified water, the columns used for the un-clarified water were similar.

Figure 2.1 AFM and Sand Filter Test Bed Columns – Site J



Details of the test specification for the Site J trials are provided in summary form below:

Column diameter	250mm
Bed depth	1000mm
Particle size sand	16 x 30 (0.5mm to 1.0mm) Leighton Buzzard deposit
Particle size AFM	grade 1 (0.5mm to 1.0mm)
Operation flowrate	6 m ³ hr ⁻¹ m ²
Back-flush frequency	once/twice every 24 hours
Pre-treatment of clarified water	iron catalyst/flocculent/chlorination

2.2 Site Test

The test equipment used at site K is shown in Figure 2.2.

Figure 2.2 AFM and Sand Filter Test Bed Columns - Site K



Details of the test specification for the Site K trials are provided in summary form below:

Filter area:	0.33m ²
Working pressure:	0.5 kg/cm ²
Filter diameter:	650mm
Water flowrate	5 m ³ hr ⁻¹ m ²
Back-flush flowrate,	approximately 30 m ³ hr ⁻¹ m ²
Back-flush frequency,	2 x each week
Sand filter media	16 x 30 sand on pea gravel
AFM filter	grade1 AFM on pea gravel

2.3 Analytical Parameters for Operational Phase

The following list details the analytical test conducted on each column and influent water once per week. Further information on these parameters and the trial results is provided in Section 4.

Bacteria

- E.coli
- Total coliforms
- Aeromonas
- Total count at 22 deg C
- Total count at 37 deg C

Nitrogen

- Ammonium
- Nitrite
- Nitrate

Physical/chemical

- Colour
- Turbidity (NTU)

Organics

Dissolved Organic Carbon (DOC)

Metals

Iron

Manganese

Particulate Matter

2-6 microns

7-12 microns

>12 microns

>2 microns

3. Backflush Efficiency

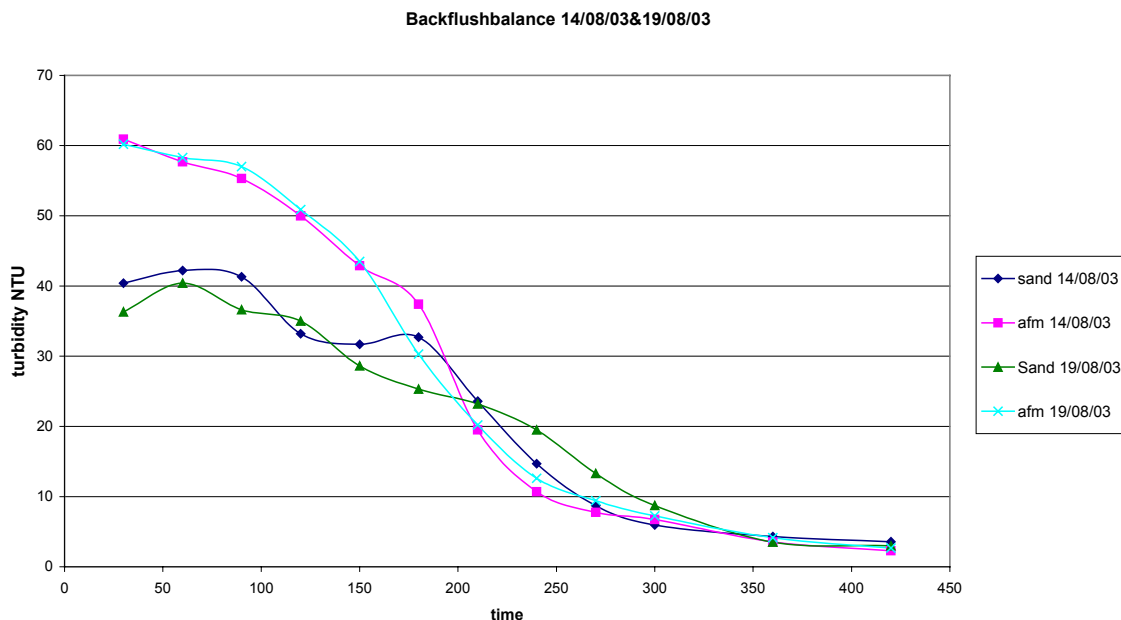
The efficiency of the back-flush is critical to the continued operation of any rapid gravity or pressure media filter. Failure to remove all of the retained solids on back-flush will result in an accumulation of solids within the bed. The solids will usually have an organic component and will be subjected to bacterial decomposition. As the bacteria develop in the bed, back-flush performance deteriorates and the quality of the product water deteriorates. Back-flush performance is a key indicator of filter performance, *what goes in must come out*.

The back flush protocol adopted in the trials is as follows:

Back-flush frequency	24 hours
Air scour	2min 30 secs
Water flowrate	30cubm/hr/squm
Back-flush duration	8 minutes

Details of the backflush efficiency of AFM versus sand are presented in Figure 3.1.

Figure 3.1 AFM versus Sand Back-flush Efficiency - Site J



The graph above clearly shows the turbidity levels in the AFM backflush water are much higher than the sand column, indicating an improvement in the removal of retained solids. The AFM back-flush also forms a smooth curve that is repeatable. The sand back-flush turbidity level is a more linear relationship with a degree of instability.

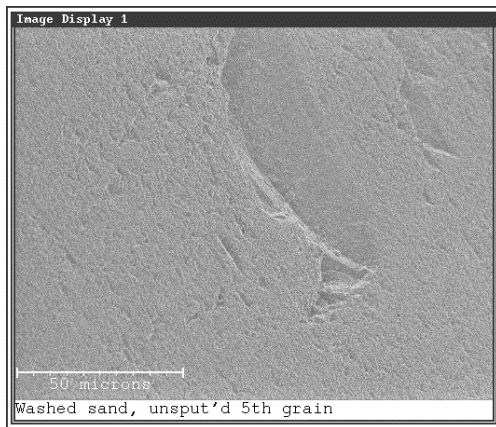
Discussion

Initially the performance of AFM and sand were very similar. However, sand acts as an excellent support media for bacteria and after a few days, sand will be colonised by bacteria¹.

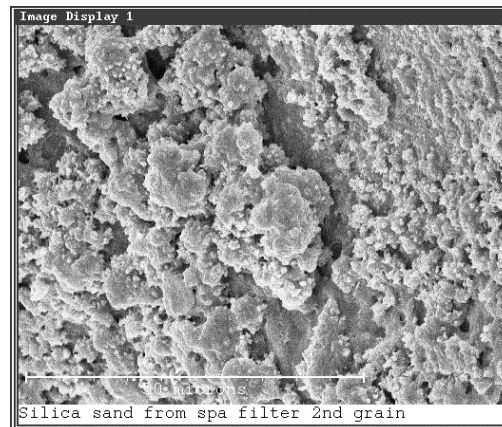
Electron microscope photographs have been taken of sand in a swimming pool filtration system. They show nearly 100% coverage of the sand by bacteria in a few days. Similar photographs of AFM after several years of use show virtually no bacterial fouling (Figure 3.2).

¹ Biofilm formation in Granular Bed filters. P.Kaur C.S.B Fitzpatrick et al, The Journal [v17 N3] August 2003 page 145, Dept of Civil and Environmental Engineering, University College, London UK

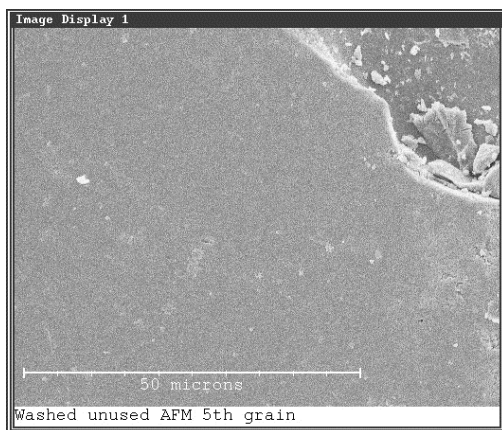
Figure 3.2 Biofouling Photographs of Sand and AFM



Washed silica sand



Silica sand after several days in a spa filter showing near 100% coverage by bacteria



Washed AFM



AFM after several years in a sewage treatment filter

The images in Figure 3.2 show that after the first few days sand is colonised by bacteria whereas the AFM remains clean. The bacteria will bind the sand grains together and promote channelling of water through the sand. It is therefore inevitable that the performance of a sand filter will deteriorate with time.

The growth rate of the bacteria is a function of water temperature and the concentration of bacteria and nutrients present in the feed water. The use of chlorine or oxidising agents prior to the sand filter will help to reduce the rate of biofouling, however they increase the level of TriHaloMethanes (THMs) produced. The swimming pool system shows that biofouling occurs on the sand media after a few days when continually exposed to approximately 0.5mg/l free chlorine. The back-flush data from the operational trial in clarified water on site J show that approximately 30% more solids are back-flushed from the AFM filter in comparison to the sand filter. It therefore follows that 30% more solids are removed by the filter during the run phase. The difference in performance is largely due to the deterioration of the sand filter due to biofouling of the sand grains.

Once the bacteria have become established in the sand, they will progress through the filter bed and cause further reduction in performance through bed channelling. The filter will also have a tendency to dump retained solids (bacteria and organic matter) back into the product water.

4. Water Quality Outputs

This section presents the trial results based on key water quality parameters of interest.

4.1 Bacteria

4.1.1 E. Coli and Coliforms

E. Coli and Coliforms are obligatory bacteria derived from animal sources. These bacteria should not develop within the filters. If high levels of coliform bacteria are seen in the effluent, this indicates the filter has removed them from the water and subsequently dumped them back into the filtered water.

Results

Fig 4.1 shows that the AFM filter has removed the coliform bacteria within the Site J clarified water trial. However, the sand filter has removed the bacteria and subsequently dumped them back into the product water.

Figure 4.1 Total Coliform Level per 100ml (Site J Clarified Water)

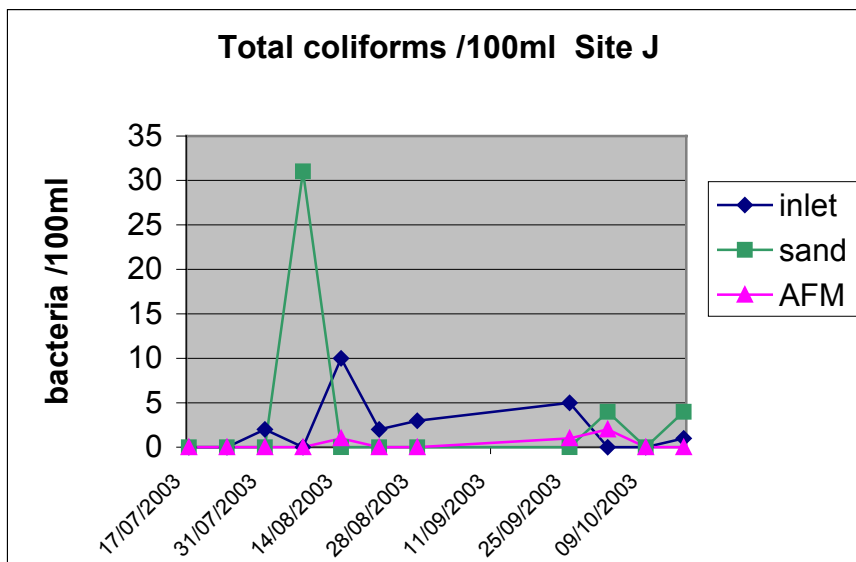
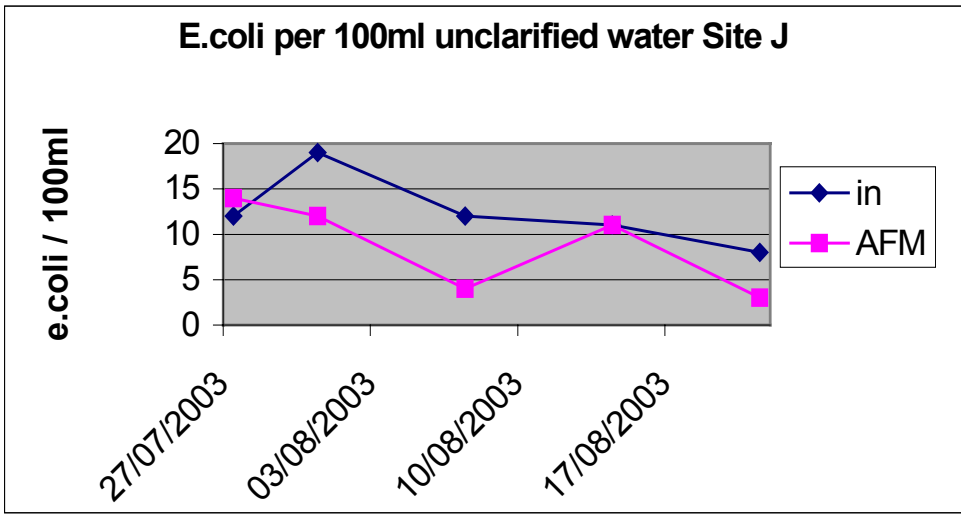


Figure 4.2 again shows that the AFM media has been successful in treating the un-clarified water. Data for the sand filter is not available because the filter blocked.

Figure 4.2 E.coli Level per 100ml (Site J Un-clarified Water)



4.1.2 Total Bacteria Count

Total bacterial count at 37 deg C will be selective for all bacteria from mammalian sources, however some of these species could develop within the filter. If there is an increase of total bacteria counts across the filter it could indicate the filter is incubating organisms that are potentially pathogenic to mammals.

The bacteria count at 22 deg C will include most bacteria present in the water; it will tend to exclude those organisms that are obligatory mammalian organisms. If there is a consistent increase of the total 22 deg C bacteria count across the filter, it indicates that the filter is acting as an incubator for bacteria.

Results

Figure 4.3 and Figure 4.4 present results from site K. Overall the results indicate similar performance levels between AFM and sand. The main point to note is that there is evidence that the sand filter has dumped bacteria into the product water on in the 37 deg C results.

Figure 4.3 Total Bacteria Count at 22 deg C (Site K)

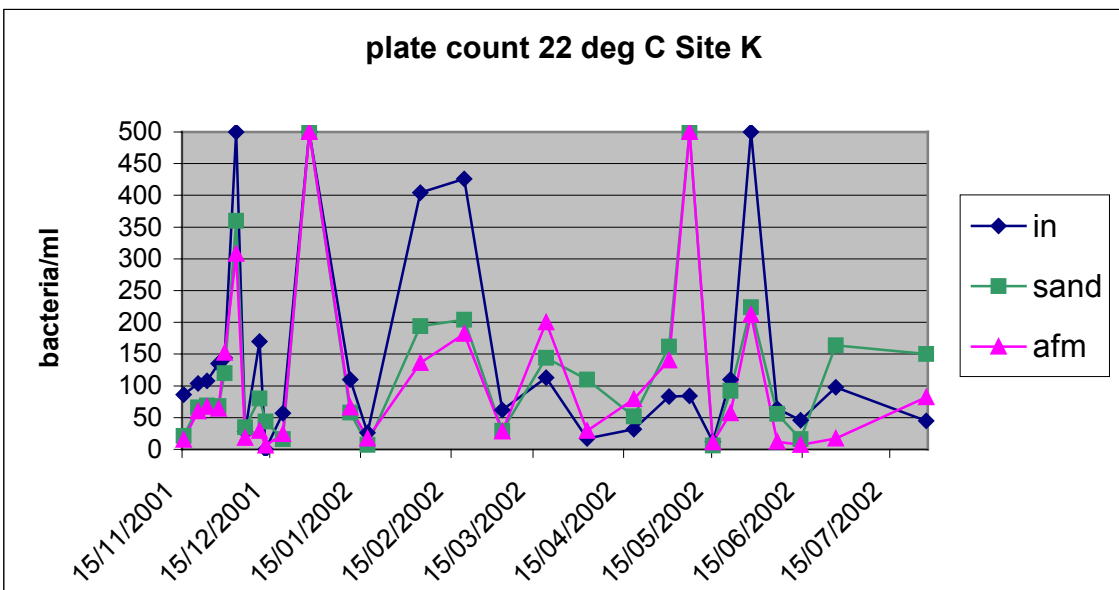
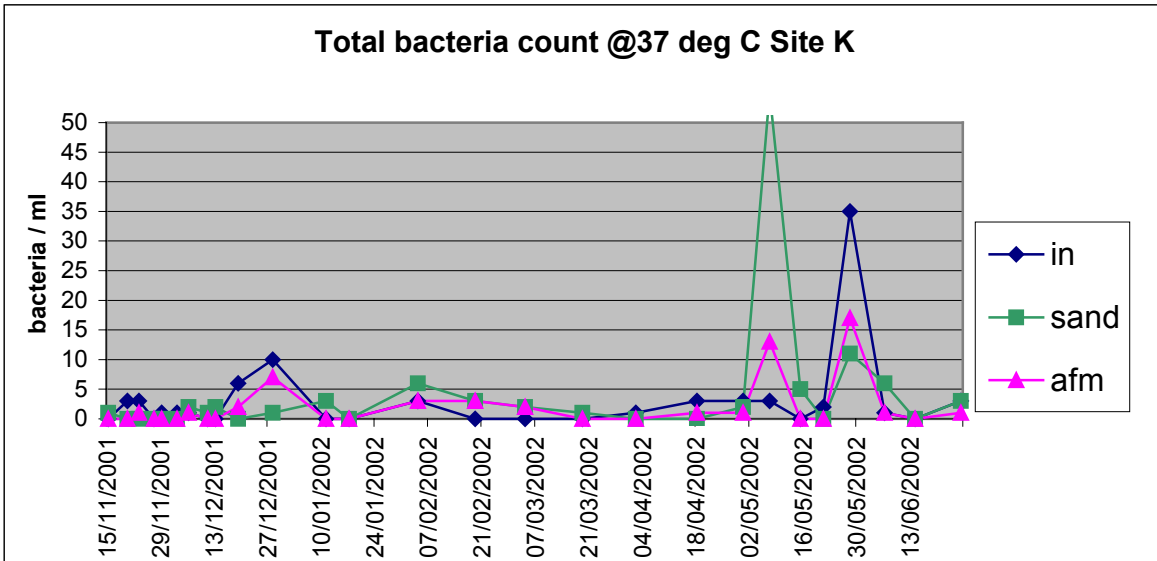


Figure 4.4 Total Bacteria Count at 37 deg C in Clarified Water (Site K)



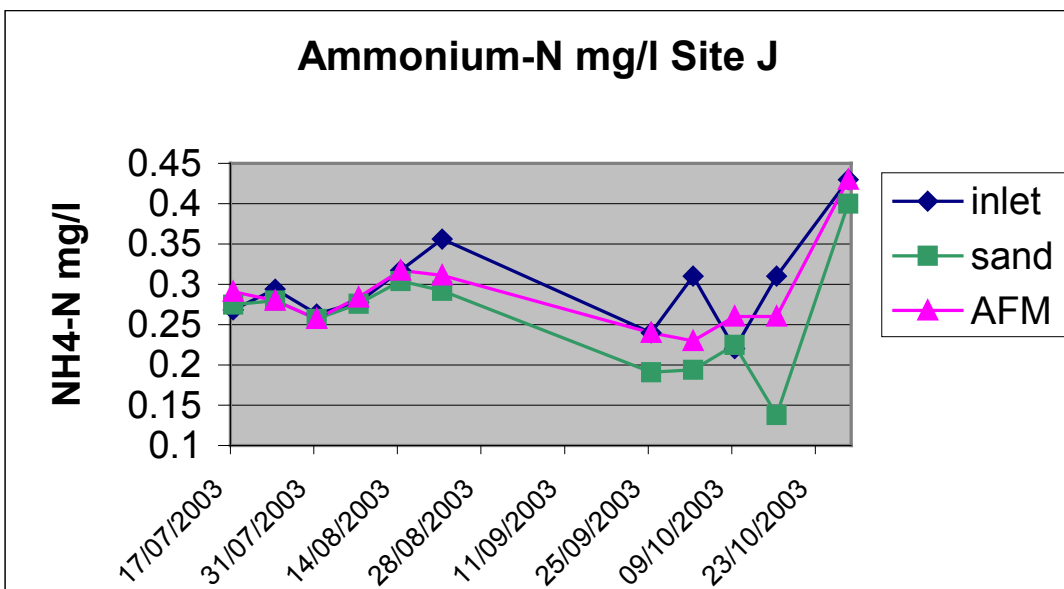
4.2 Nitrogen

Ammonium, nitrite and nitrate have been analysed. The purpose of this analysis is to follow the progression of autotrophic nitrifying bacteria biofouling of the filter beds.

4.2.1 Ammonia Nitrogen

Nitrification of ammonium involves the oxidation of ammonium by nitrifying bacteria into nitrite and then nitrate. A reduction of the ammonium concentration indicates bacteria nitrification, and this is what we see in the case of the sand filter within the site J trial results (Figure 4.5). The AFM filter ammonium concentration follows the influent concentration of ammonium which indicates that there is no nitrification.

Figure 4.5 Ammonium Levels (Site J)

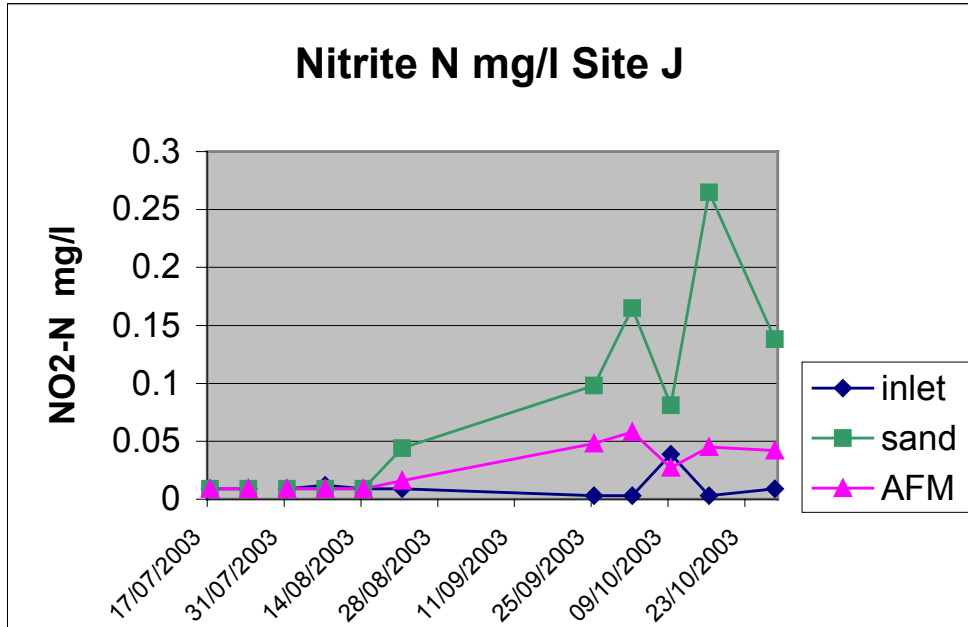


4.2.2 Nitrite Nitrogen

Nitrite is produced only by the nitrification of ammonium. If the nitrite levels increase through the filter bed it is due to autotrophic nitrifying bacteria species *Nitrosomonas* converting the ammonium to nitrite.

Figure 4.6 clearly shows that bacterial nitrification is progressing in the sand filter, but not in the AFM filter bed. This result is supported by the lower levels of ammonium from the sand filter in Figure 4.5.

Figure 4.6 Nitrite Nitrogen Levels (Site J)



4.2.3 Nitrate Nitrogen

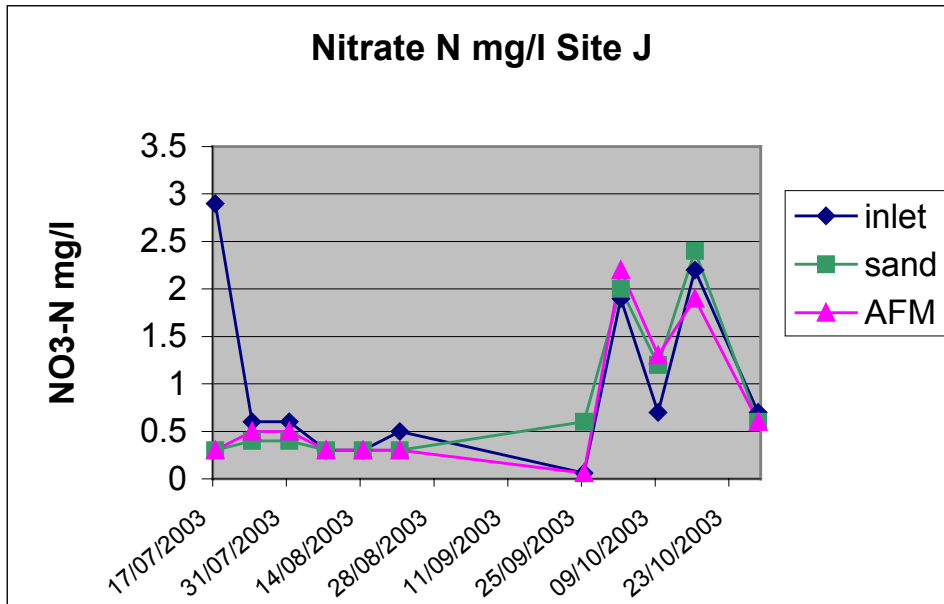
If the nitrate levels increase across the filter bed it is due to autotrophic nitrification by nitrifying bacteria converting the nitrite through to nitrate.

The nitrifying bacteria responsible for converting the nitrite into nitrate (*Nitrobacter spp*) become established after the *Nitrosomonas spp* that convert the ammonium through to nitrite.

The nitrate levels should increase by approximately 0.15mg/l across the filter bed to indicate complete nitrification. If the increase is less than this figure it will be due to heterotrophic bacterial assimilation.

The results presented in Figure 4.7 indicate similar results for AFM and sand.

Figure 4.7 Nitrate Nitrogen Levels (Site J)



4.3 Physical and Chemical

4.3.1 Colour

Colour is a key water quality parameter. It is important that the water has as low a colour component as possible. The colour is probably due to humic acids, so colour is important from a water quality perspective as well as aesthetics.

Results

The results in Figure 4.8 show that the AFM provided equivalent or slightly better water quality. In the un-clarified water (Figure 4.9) the AFM filter gave a substantial reduction in colour without the use of chemicals.

Figure 4.8 Colour Pt / Cp (Site J Clarified Water)

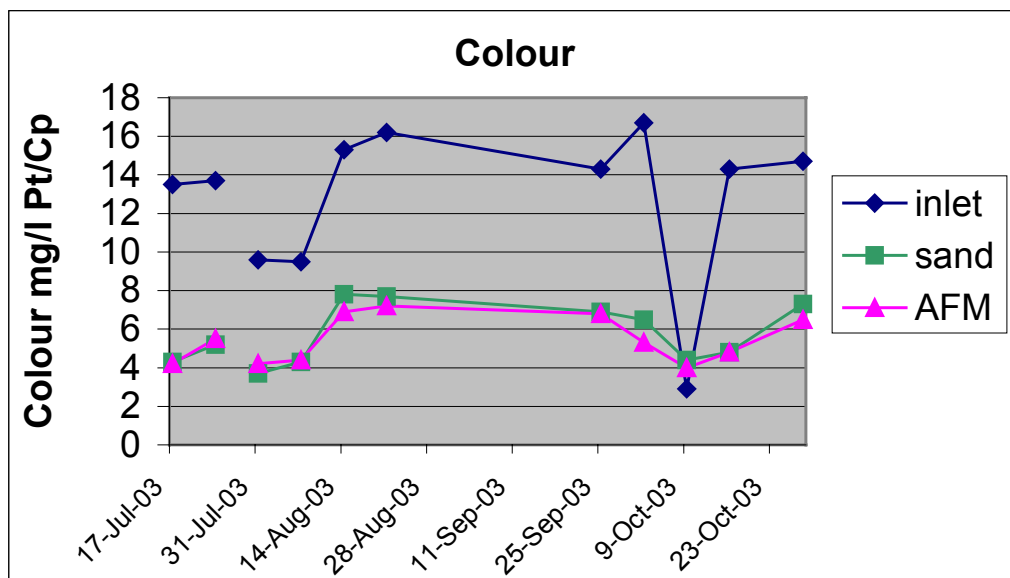
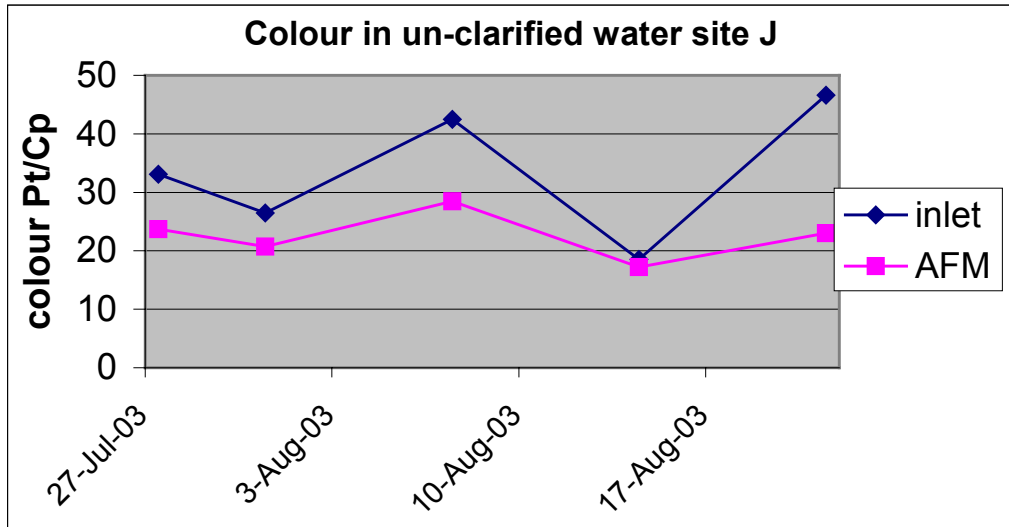


Figure 4.9 Colour Pt/Cp (Un-clarified Water Site J)



4.3.2 Turbidity

Turbidity, measured in Nephelometric Turbidity Units (NTU) is a key water quality parameter which is often monitored on a continuous basis to follow the performance of sand filters. Turbidity levels are used to control chemical dosing as well as back-flush procedures.

Results

The laboratory analysed data in 4.10 shows that the performance of the AFM filter was slightly better than the sand filter. Figure 4.11 shows that we have a substantial reduction in turbidity of the un-clarified water.

Figure 4.10 Turbidity Laboratory Analysis (Site J)

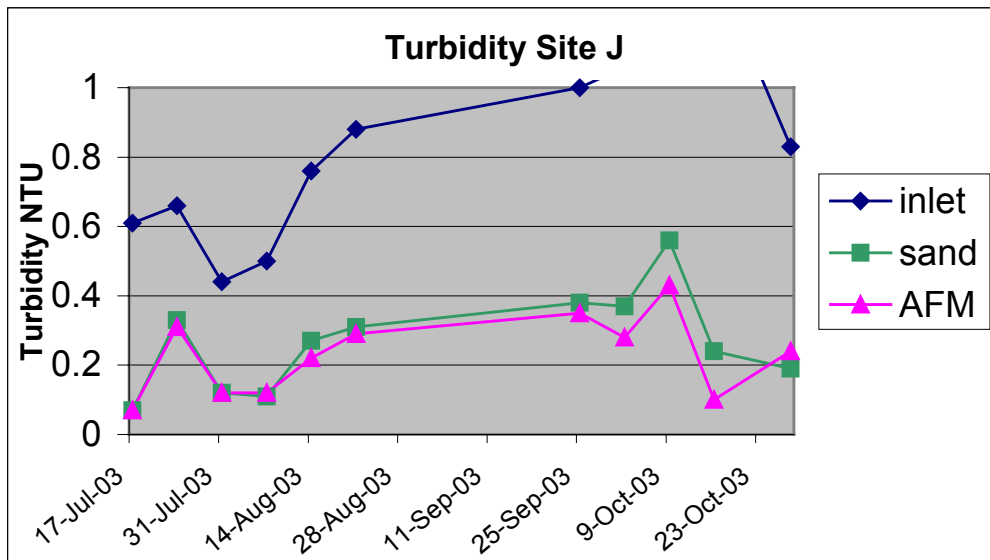


Figure 4.11 Turbidity Levels (Un-clarified Water Site J)

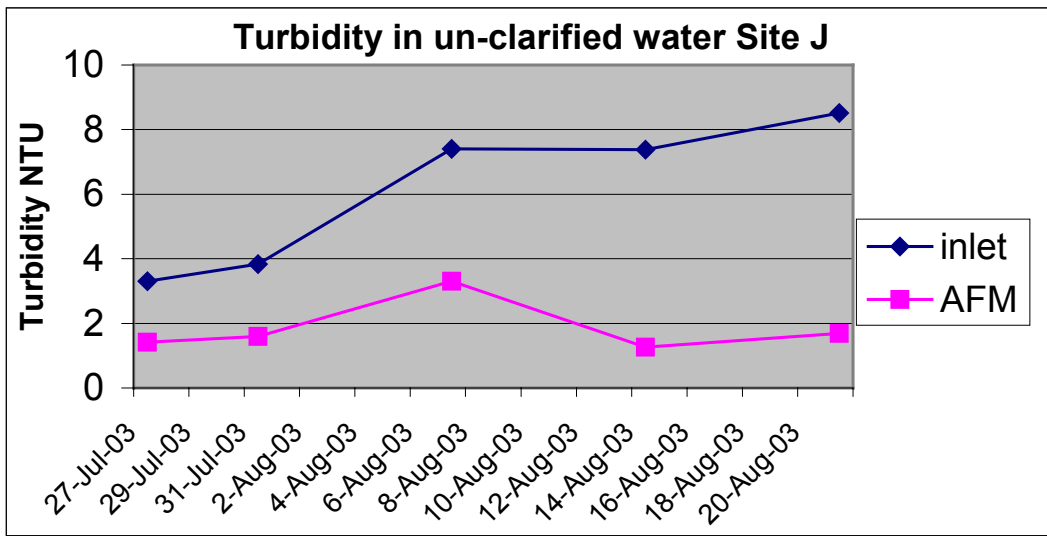
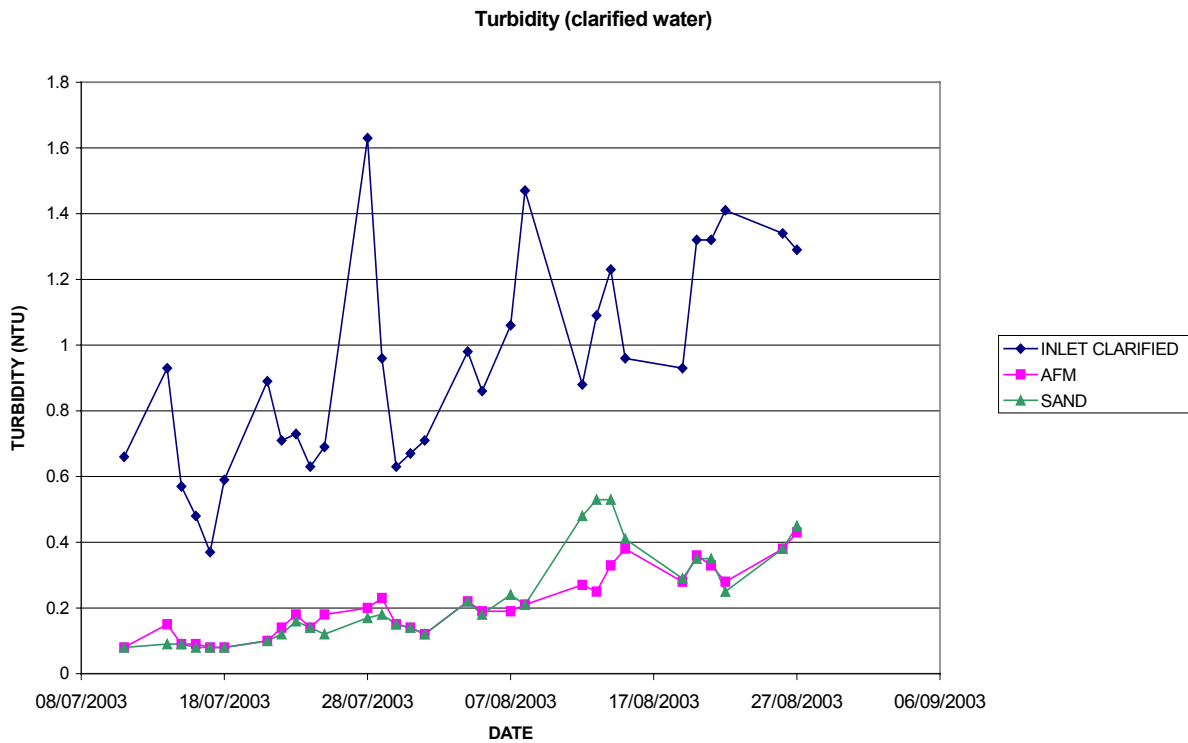


Figure 4.12 presents the results from frequent on-site analysis. The data showed that for a period of a few days, the turbidity level from the sand filter was higher than the AFM filter. This result is confirmed by three data points, and is a sign that the sand filter was dumping into the product water. Transient high discharge concentrations may pass unnoticed and will only be detected with on-line analysis, or frequent analysis. Transient spikes may be attributed to contamination of the water sample, however they appear to be a function of the sand filter and not the AFM filter.

Figure 4.12 Turbidity Levels (Un-clarified Water Site J On-Site Analysis)



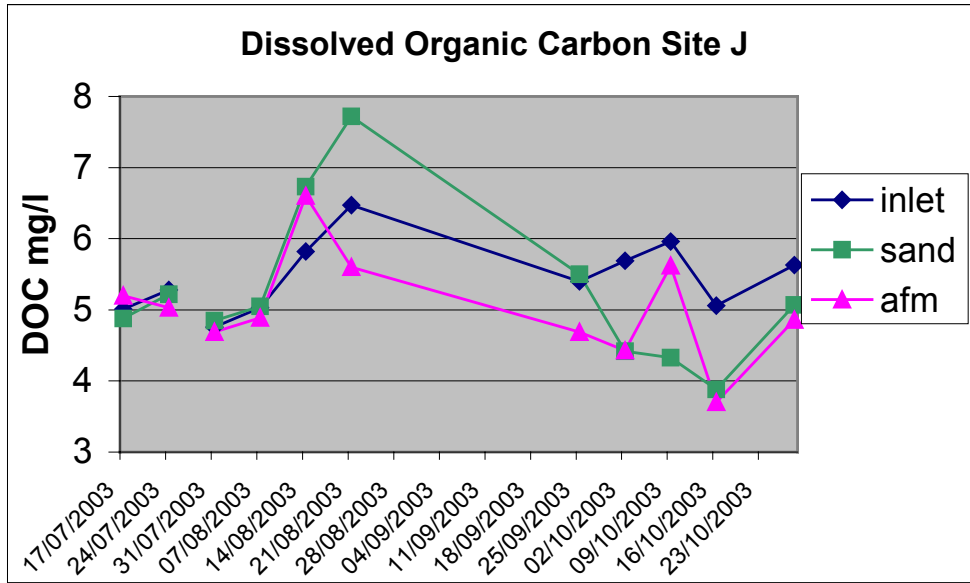
4.4 Organics

The concentration of organic matter in the discharge water from the filter bed is an important water quality parameter in relation to the concentration of combined chlorine and development of THMs.

Results

The data presented in Figure 4.13 shows that the AFM filter produces lower levels of dissolved organics than the sand filter. It would appear that at certain stages in the trial the sand filter is releasing organic matter back into the product water as the levels are higher than those in the inlet water.

Figure 4.13 Dissolved Organic Carbon (Clarified Water Site J)



4.5 Metals

The trials results for Iron and Manganese are presented below.

4.5.1 Iron

Figure 4.14 Iron Level (Site K)

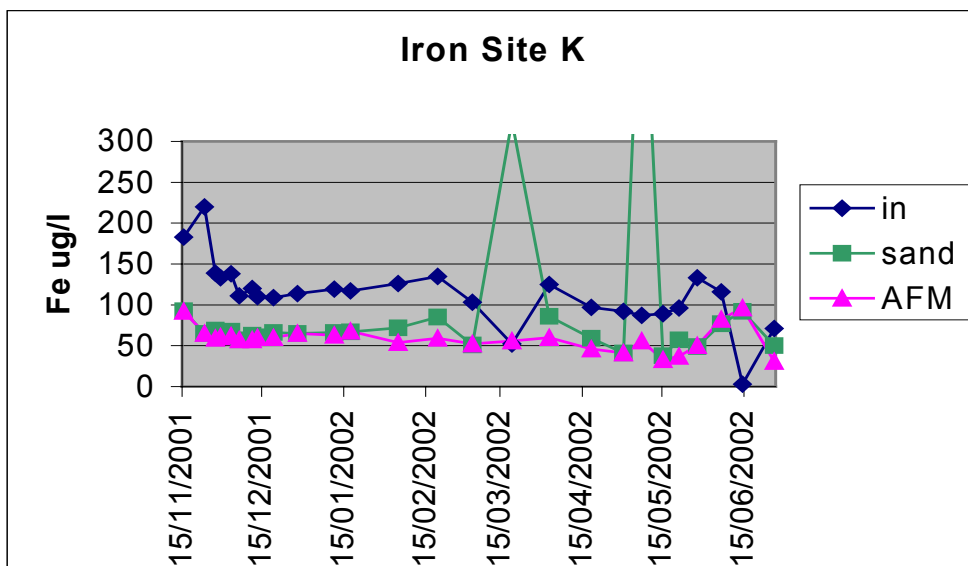


Figure 4.15 Iron Levels (Clarified Water Site J)

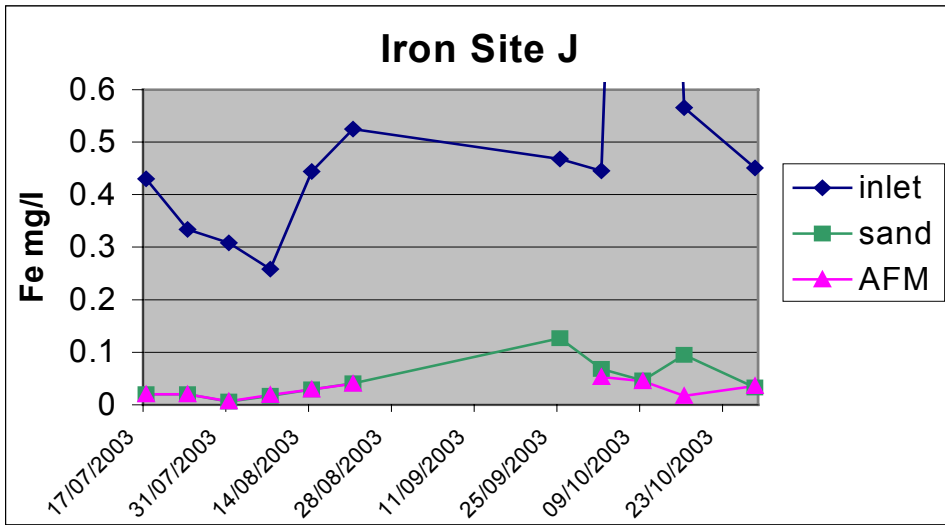
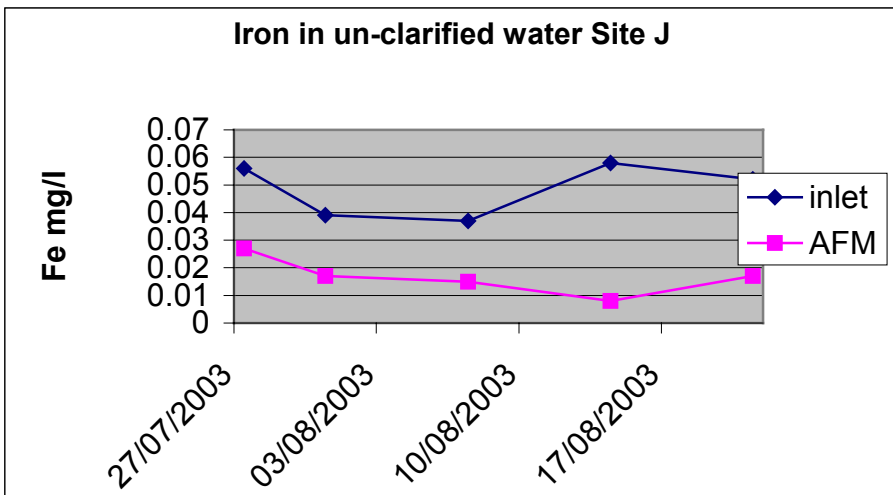


Figure 4.16 Iron Levels (Un-clarified Water Site J)



Discussion

The AFM filter returned lower iron levels and did not discharge high levels of iron back into the product water during two transient spikes.

4.5.2 Manganese

Figure 4.17 Manganese Levels (Site K)

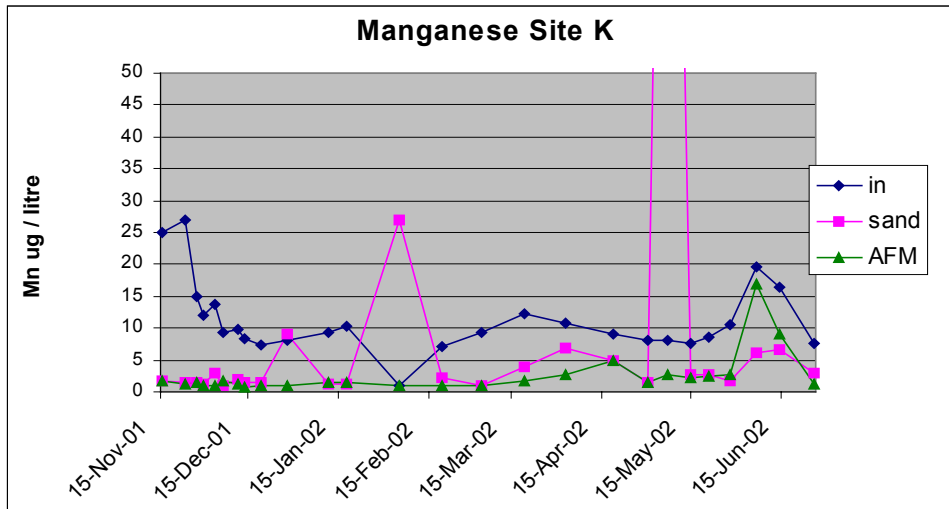


Figure 4.18 Manganese Levels (Clarified Water Site J)

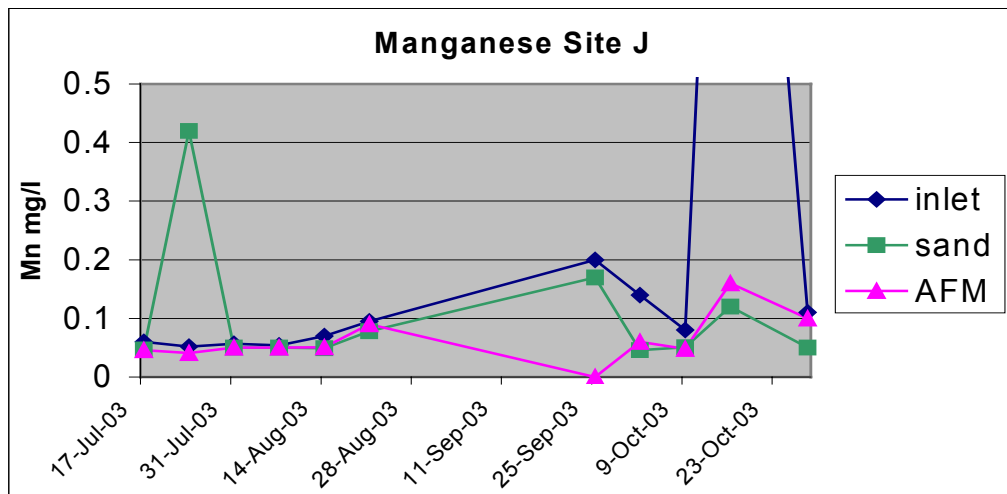
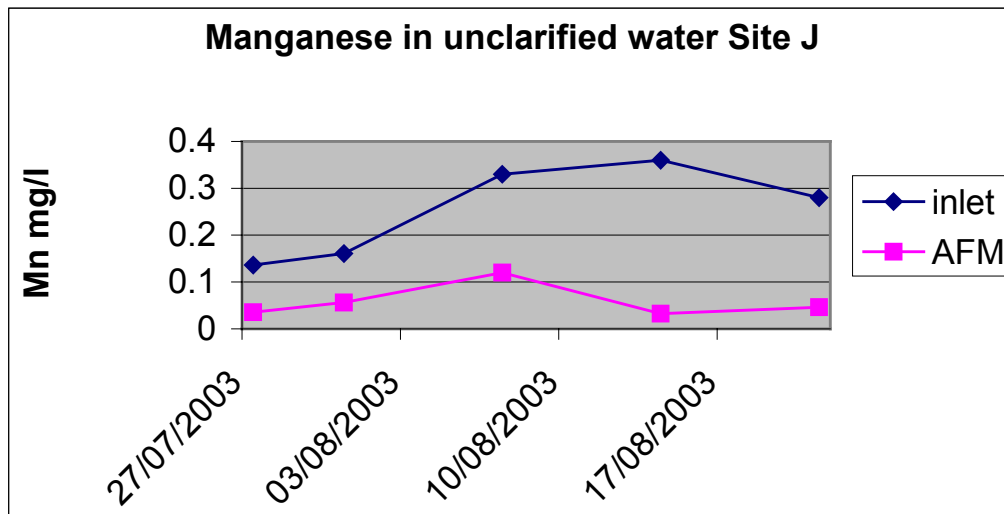


Figure 4.19 Manganese Levels (Un-clarified Water Site J)



Discussion

The manganese results follow a similar pattern to Iron. Overall AFM gives better results than the sand filter although there is some evidence towards the end of the Site K and Site J clarified water trials that the AFM performance deteriorates slightly compared with sand.

The sand filters periodically dump retained solids back into the product water.

4.6 Particulate Matter

Site J trials results for particulate levels are presented below.

4.6.1 2 - 6 Microns

Figure 4.20 2-6 um Particle Size Removal (Clarified Water Site J)

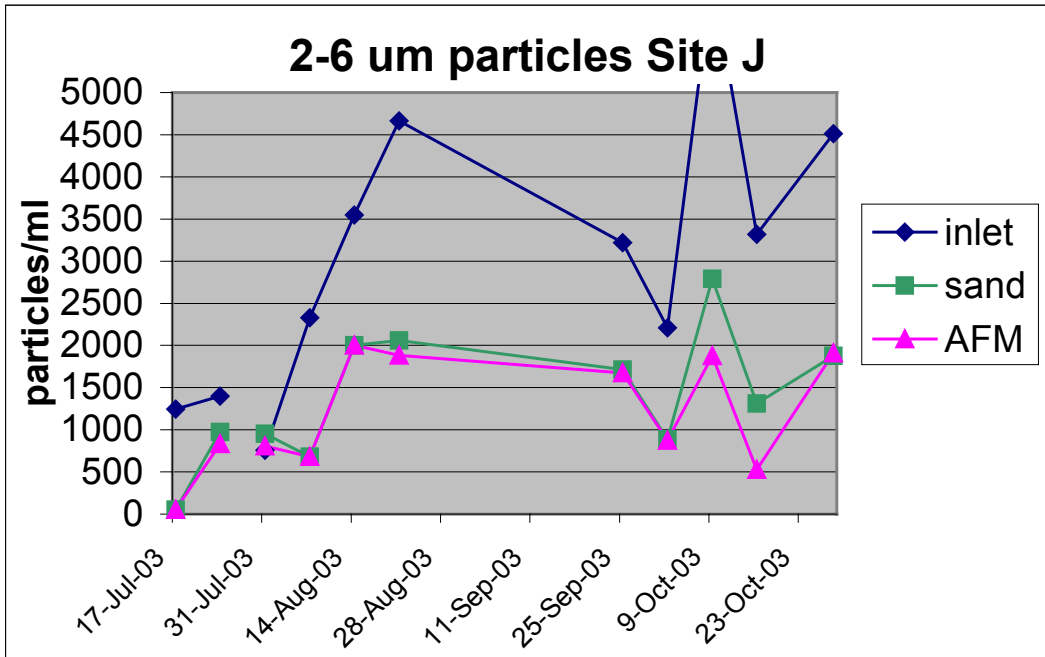
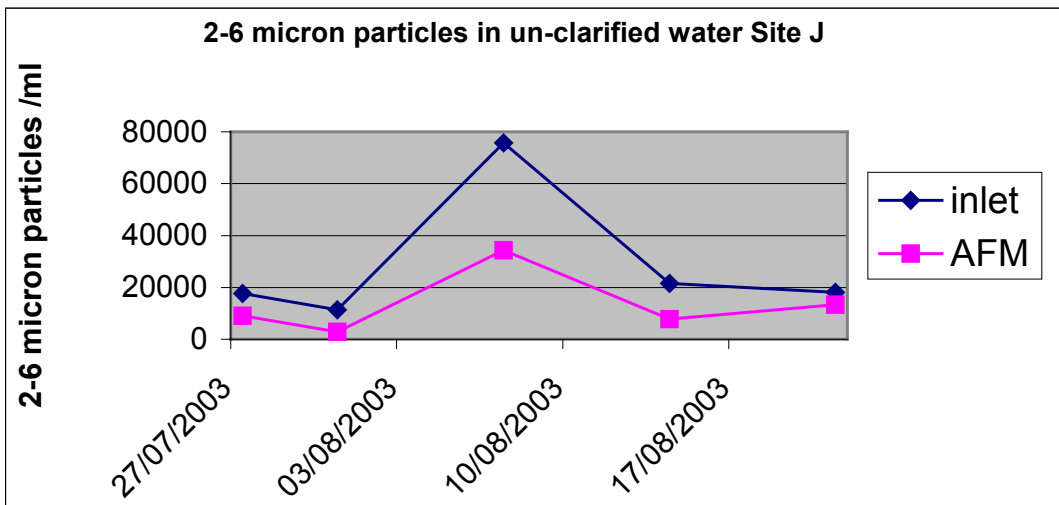


Figure 4.21 2-6 um Particle Size Removal (Un-clarified Water Site J)



4.6.2 7 – 12 Microns

Figure 4.22 7-12 um Particle Size Removal (Clarified Water Site J)

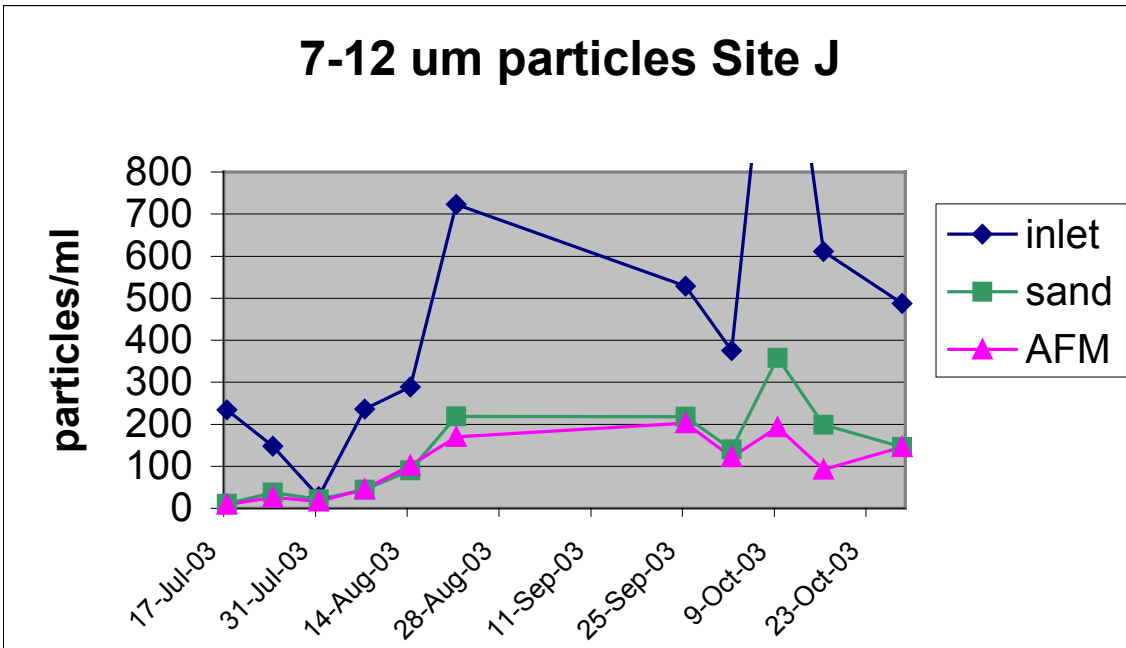
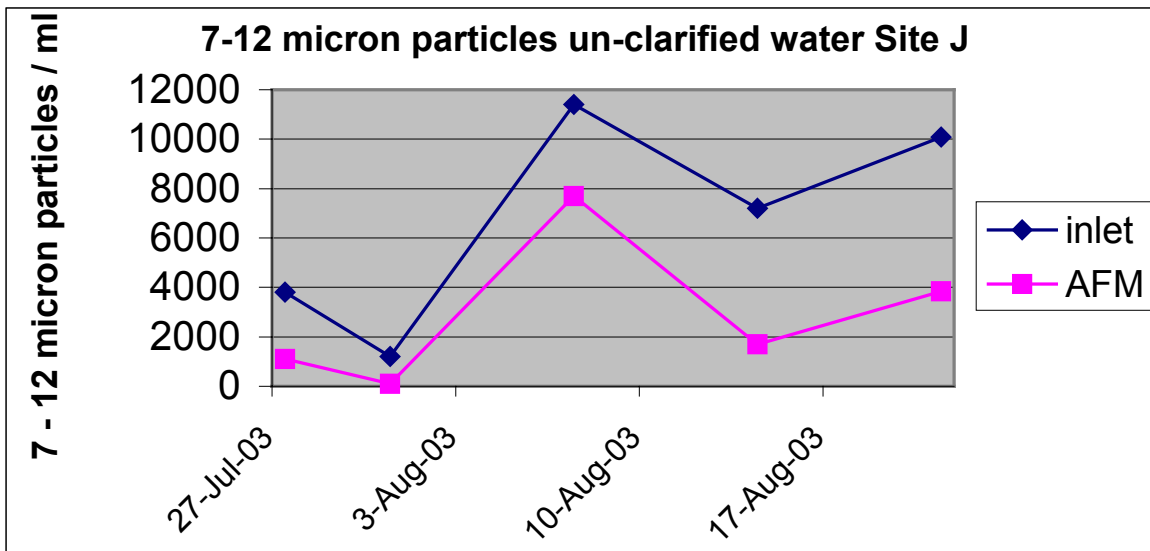


Figure 4.23 7 - 12 um particle size removal (Un-clarified Water Site J)



4.6.3 > 12 Microns

Figure 4.24 > 12 um Particle Size Removal (Clarified Water Site J)

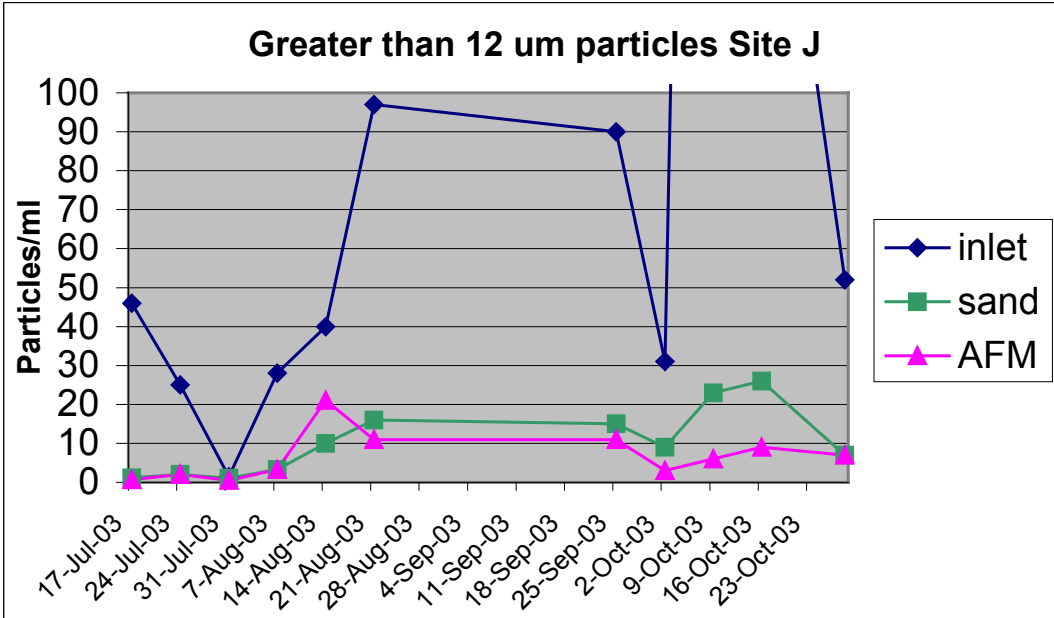
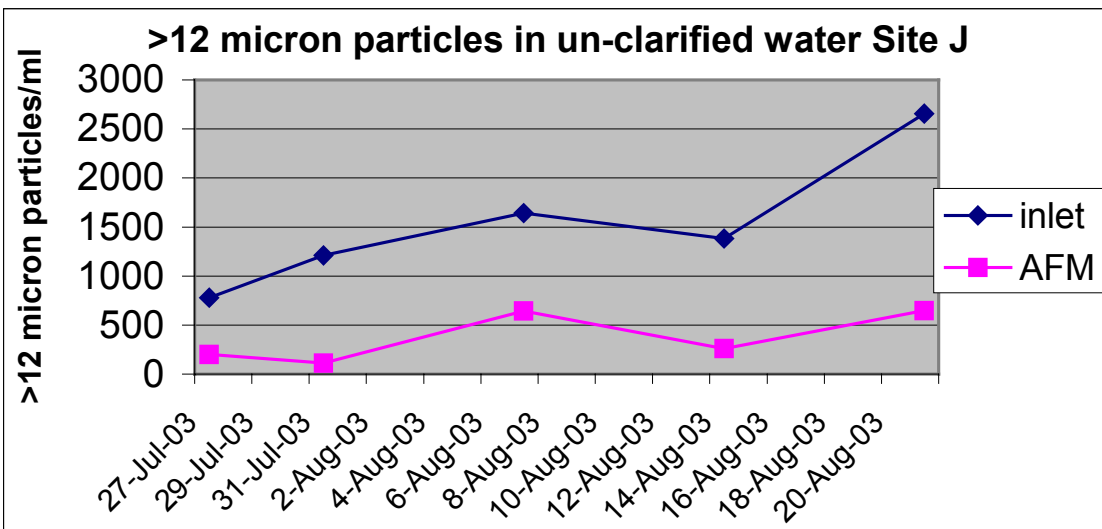


Figure 4.25 > 12 um Particle Size Removal (Un-clarified Water Site J)



4.6.4 > 2 Microns

Figure 4.26 >2 um Particle Size Removal (Clarified Water Site J)

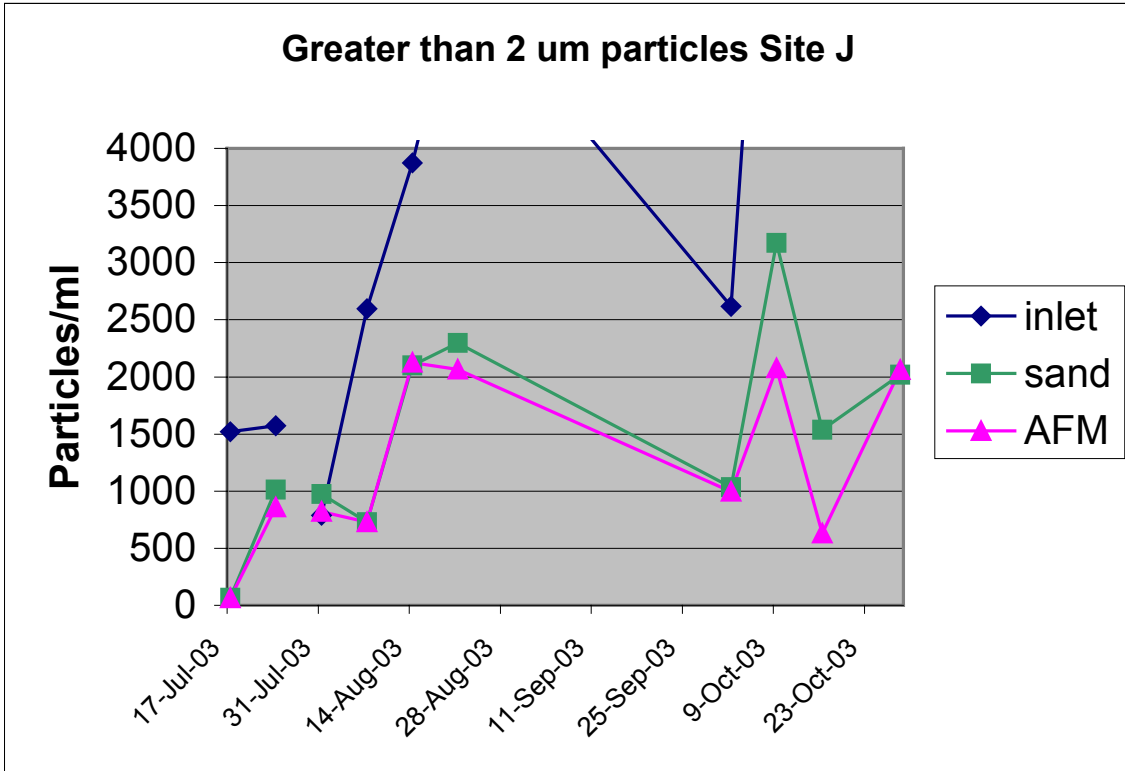
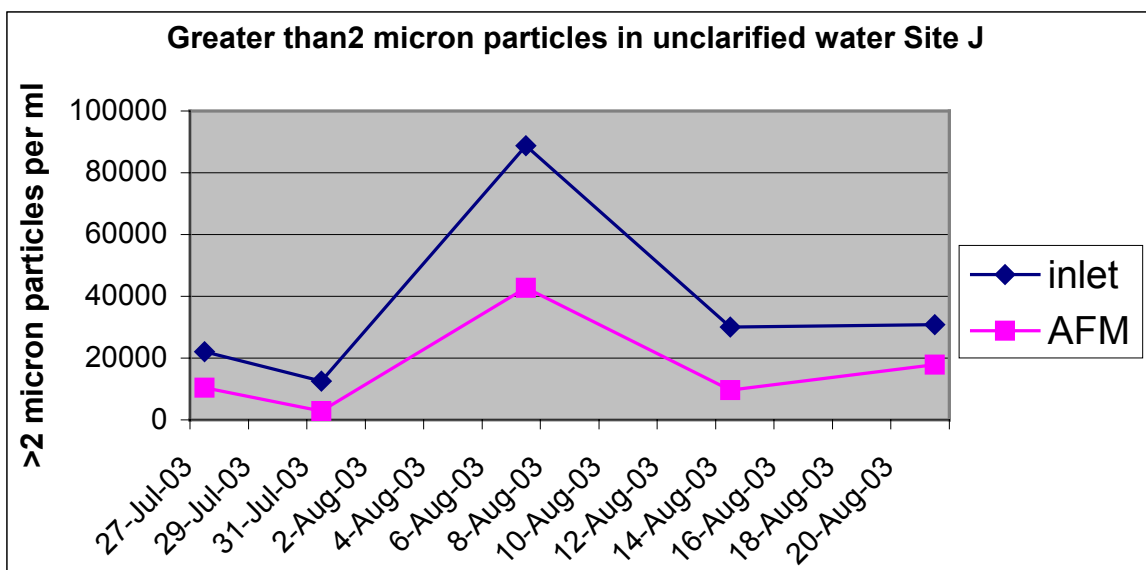


Figure 4.27 >2 um Particle Size Removal (Un-clarified Water Site J)



Discussion

All of the data collected from Site J shows that in terms of solids removal from 2 microns to greater than 12 microns, AFM performed better than sand. The results also indicate that the difference between the sand and AFM media is increasing towards the end of the trial. The observation is likely to be due to biofouling becoming established in the sand filter.

5. Discussion and Conclusions

Two independent parallel trials have been completed by water companies in which AFM was compared directly with high quality silica sand in identical filters. In both systems and for all parameters measured the results can be summarised as follows:

1. Overall AFM performs better than sand with regard to the removal of particles, metals, organics and biological organisms. This will allow operators to more easily comply with water quality directives.
2. AFM, unlike sand, does not build up a reservoir of retained material in the bed and then dump this material back into the product water. This reservoir of material relates to metals, organics, solids and bacteria.
3. AFM does not become a biofilter.
4. In biologically active un-clarified water such as eutrophic lake water, sand will rapidly become blocked by bacterial growth; the time frame may be a few weeks to months. AFM can be used for this water type without any bed blockage issues.
5. AFM performance as indicated by backwash profile is stable and predictable, which will lead to better automation and control.
6. AFM removes at least 30% more solids and material from the water in comparison to sand. The percentage is likely to increase as sand filters age and become more seriously biofouled.

AFM is a direct replacement for filter sand. A simple retrofit is required without any physical changes to the filtration system or the operating procedures.

Full scale trials with AFM in drinking water rapid gravity flow filters are due to commence in 2004. Further research is required to quantify other potential operational benefits linked to the media's use, for example the removal and deactivation of *Cryptosporidium* oocysts. Work is also in progress to obtain certification to use AFM to treat potable water for human consumption.