Creating markets for recycled resources

Full Scale Operational Trials Using Recycled Glass in Two-stage Filters and Reed Beds

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Final Report

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Management Summary

- The correct characterisation of waste water is critical to glass sizing and therefore optimum filter performance
- The glass media size is the key to suspended solids removal. The smaller the glass particle the smaller the void size and consequently the smaller the particle size that can be removed.
- For certain effluents two-stage glass filters can remove up 90% of suspended solids and provide effluent, which remains within environment agency consent to discharge standards removing the risk of process shutdown.
- For certain effluents the two-stage filter process will treat suspended solids shock loadings in excess of 1200mg/l and still recover within 36 hrs
- Two-stage filters are a cost effective method for removing suspended solids and COD before ultrafiltration for water re-use as they do not need an additional chemical treatment phase which is required when single stage sand filters are used.
- Oil and grease entry to the filter will bind the glass particles and render the filter useless. Detergents and / or solvents may be necessary to recover the filter system in the event of a grease entry.
- Glass media 6mm-15mm will make an ideal base material for reed bed filtration systems when processed correctly to remove all fines less than the media band specification. Suspended solids and BOD reduction is equally as good if not better than that experienced with traditional washed gravel media. Root growth and head growth has been extremely good as the root zone has an easier path to expand in glass.
- A small amount of phosphate removal has been experienced through filtration in the glass reed bed. Further investigative works will need to be done to establish the reason for this and also to establish the complete adsorption rates. One theory for the phosphate removal is the amount of brown glass containing iron, which is currently dosed into conventional sewage treatment works to promote biological phosphate removal.

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1 Introduction

Aqua Enviro are an independent consultancy company based at Wakefield whose expertise lies in the treatment of industrial and municipal wastewaters and providing training and seminars for the relevant industry sector. Their client base boasts many of the water plc's and our courses and publications are regulated by CIWEM. (Chartered Institute of Water and Environmental Management)

In April 2005 Aqua Enviro were commissioned to carry out a series of studies to further develop the suitability and marketability of a range of recycled glass filtration media for the wastewater treatment markets. This study has followed on from works previously commissioned by WRAP to carry out, pilot and full-scale studies to assess the performance of recycled glass compared to sand as a filter media for tertiary treatment (Project GLA0036-10).

This phase of study examined the use of glass media in a 2-stage process and specifically the variability of suspended solids removal when applied to differing sizes and combinations of glass media.
The study also determined the suitability of glass media as a support media for reedbeds when applied to food trade type tertiary treatment

This report covers the whole project from 4th April 2005 until 28th November 2005.

1.2 Two-stage filter operation at Hartleys

Hartley's is a family owned and run business processing fresh vegetables, some of which are also grown on the owners land. The site is particularly rural and has very tight discharge consents for solids and COD together with a stringent volumetric control. The plant discharges into a dyke before finding its way to the River Ouse. The treatment system on the site is in the form of a twin basin SBR (Sequencing Batch Reactor) with a pre-treatment balance tank and final settlement tank. The final effluent passes through a sand filter prior to discharge. The plant suffers wide process variations which cause overloading and under-loading at certain times of the year due to seasonal variations in the influent, which can also cause very poor settlement in the SBR. The treatment process can therefore be reliant on the sand filter as a means of maintaining consent. However, the upstream process conditions mean that the filter is prone to blinding which can result in consent failures for the site.

The main aim of the study was to determine the effect of using mixed cullet as a filtration media and for the purposes of the study mixed cullet of PAS 102 grade fine, medium and coarse media was purchased from The Glass Recycling Group and additionally one filter was packed with AFM® supplied by Dryden Aqua. The second stage of the trial involved the scaling up of the previous stage and the use of the best performing media in 10m^3 vessels (Purchased as part of a previous Project GLA36-10, details of which can be found on the WRAP website).

1.2.1 Pilot scale two-stage filters

After the completion of trials undertaken as part of Project GLA36-10 to determine the performance of glass and sand on this particular effluent, the original pilot rigs were reconfigured to allow two-stage filtration to the carried out. It was considered that this would allow the removal of additional solids whilst minimising fouling. The backwash configuration was uprated, allowing the process to be carried out using clean liquor, rather than dirty as was previously the case.

Three filter systems were used on the pilot scale vessels and the media present in these is as follows.

1a = Medium glass, 1b = Fine glass
2a = Coarse glass, 2b = Medium glass
3a = Medium glass, 3b = AFM fine grade

Where,
Fine glass – 0.2-1mm, Medium glass – 0.5 – 1mm, Coarse glass – 1 - 3mm

Figure 1. Set up of pilot two-stage filter rig at Hartleys

The reconfiguration of the pilot scale rigs was carried out during the seasonal closure at Hartley's and the schematic is shown in Figure 2. All three of the filter systems are fed from the same influent tank and discharge to a single effluent tank.

The reconfigured pilot rigs commenced operation at the beginning of July at the start of the 'pea' season. During the first couple of weeks, the influent to the filter systems contained variable levels of suspended solids as the on-site treatment processes recovered from an extended period without influent. Despite these fluctuations, the performance of the filter systems was good and the suspended solids concentrations in the filter effluent were low.

There were two months operation following the reconfiguration and the results for this period were very positive. Towards the end of August there was another switch in production as carrots and other root vegetables were being processed. Traditionally, this is a time when the onsite effluent plant struggles and this allowed the ideal opportunity to observe how a two-stage treatment system can remove solids under more challenging conditions.

The pilot filter systems operated at a downward flow rate of 200l/hr and a upward backwash flow rate of 1200l/hr on each individual filter, the sequence of operation has been mapped form the original trials (under project GLA 36-010) and comprises a 4 hour solids removal cycle (operational mode) before taking all the filters off line by isolating the feed pump and selecting backflush mode. The backflush mode requires the selection through a 3-way valve of a clean water supply to the pump which is preceded by a 2 minute air scour at 2bar and a flow rate of 198l/min, the clean water is then pumped through each individual filter to drain for 5 minutes before re-commencing the cycle.

1.1.1 Results from pilot scale

The results (Figure 3) have shown that the best performing glass media has been coarse glass followed by medium glass. Overall there was a 72% removal of suspended solids through filters 2a and 2b.

Table 1. Average suspended solids concentration before and after the filters.

	Influent	Filter System 1	Filter System 2	Filter System 3
Suspended solids (mg/l)	43	13	12	9

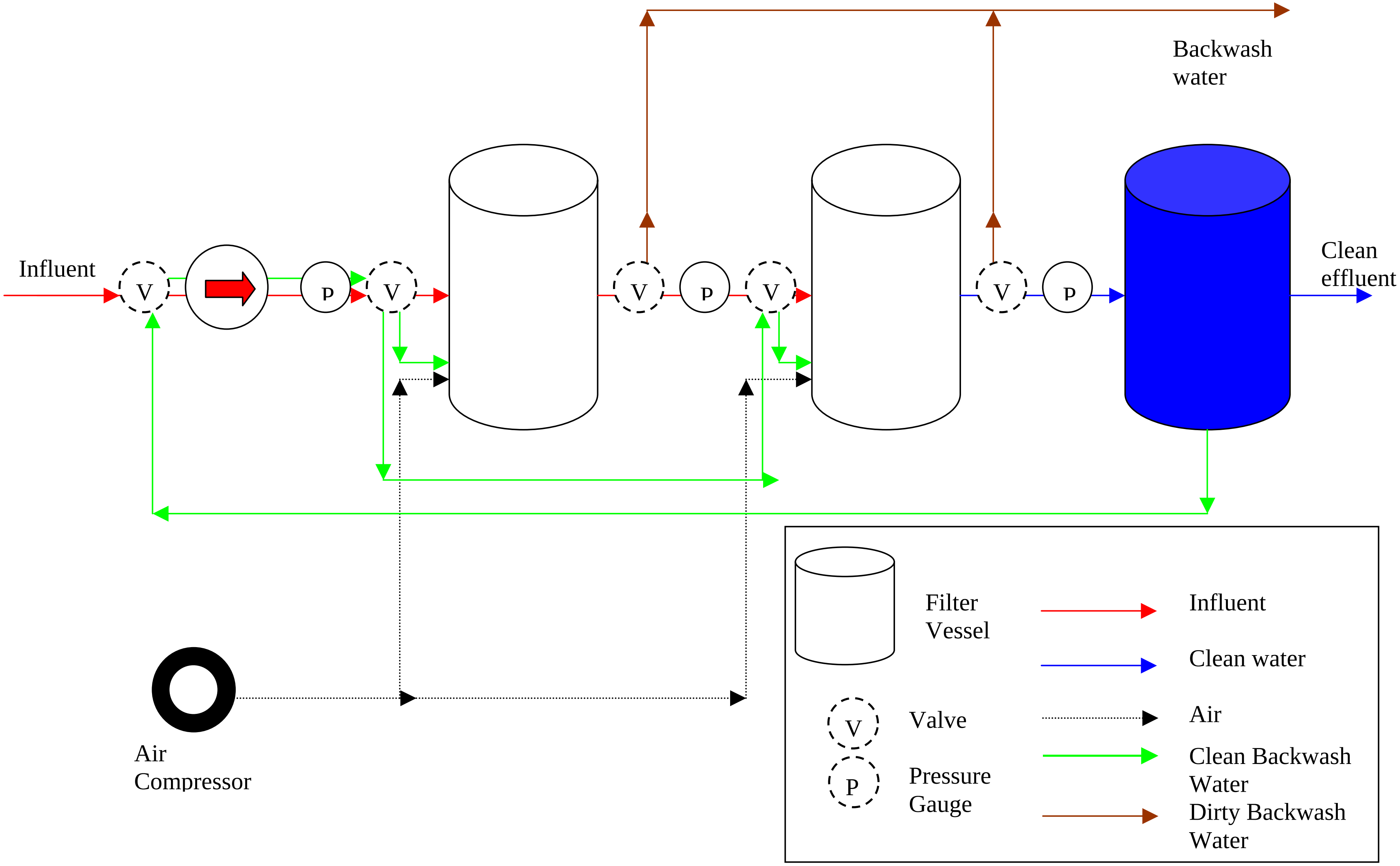

Figure 2. Schematic of a single filter system

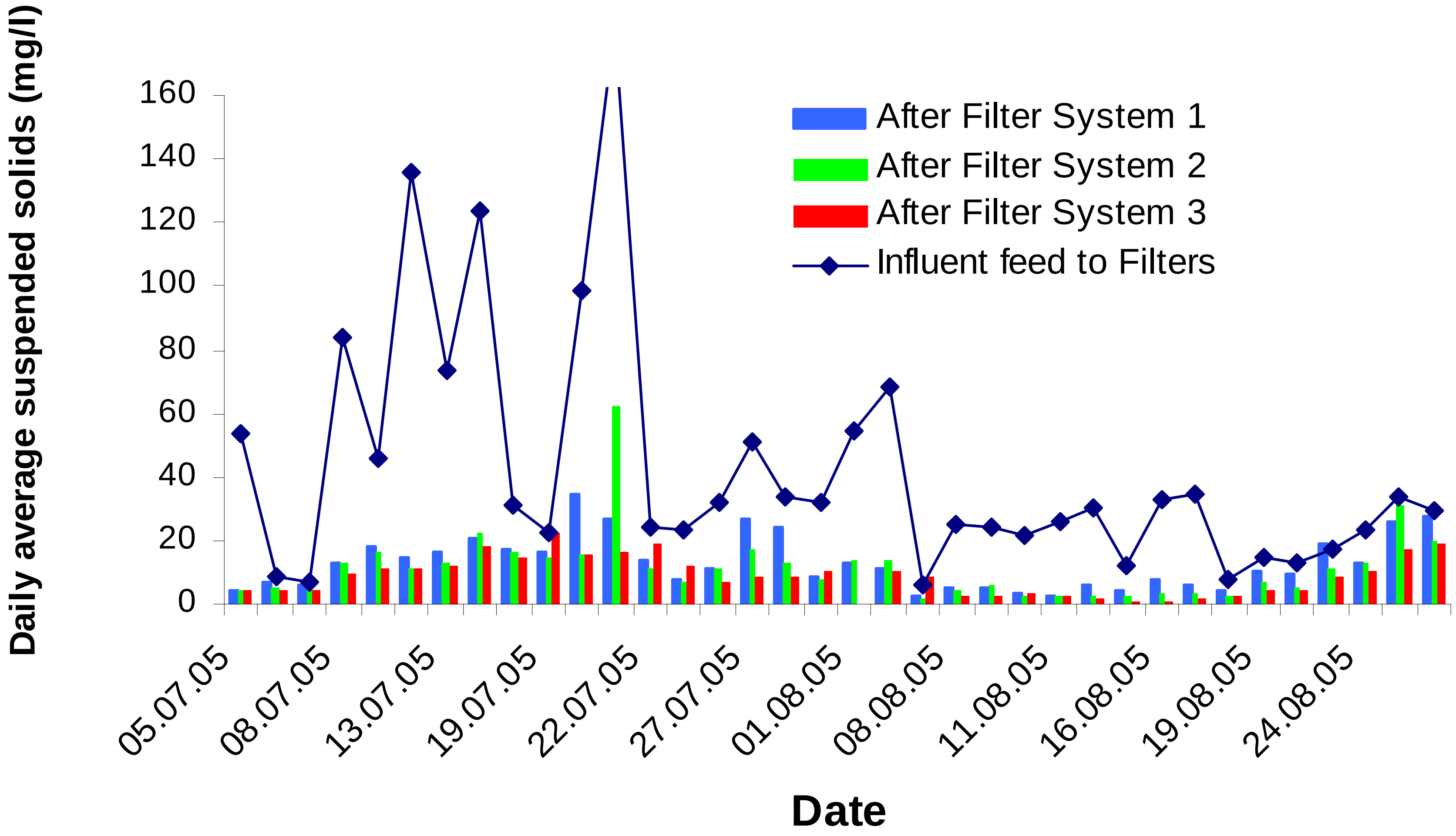

Figure 3. Graph showing the performance of the three filters

1.1.2 Large scale two-stage filtration system

Project GLA036-10 involved the use of two large-scale vessels with a volume of $10m^3$. These large-scale vessels were refitted to allow a two-stage filtration system to be engineered, replicating the operational practice of the pilot scale programme. The larger scale two-stage filters began operation on the 14th October and ran through until the 28th November. The media used in the rigs was the coarse grade glass followed by medium grade as this combination performed the best in the first stage of this project.

Figure 4. Two-stage filtration system

1.1.3 Results from large scale filtration system

The rigs were operated over 6 weeks, on a four-hour operational cycle with backflush following 4 hours of forward flow at an average flow rate of $4.4m^3$/hour for the study. Samples were collected of the influent, at the intermediate stage after the 1st filter and the final effluent following the 2nd filter . Analysis was carried out for suspended solids and overall the removal rates were good and exceeded the removal rates experienced by the full-scale equipment on the Hartleys site.

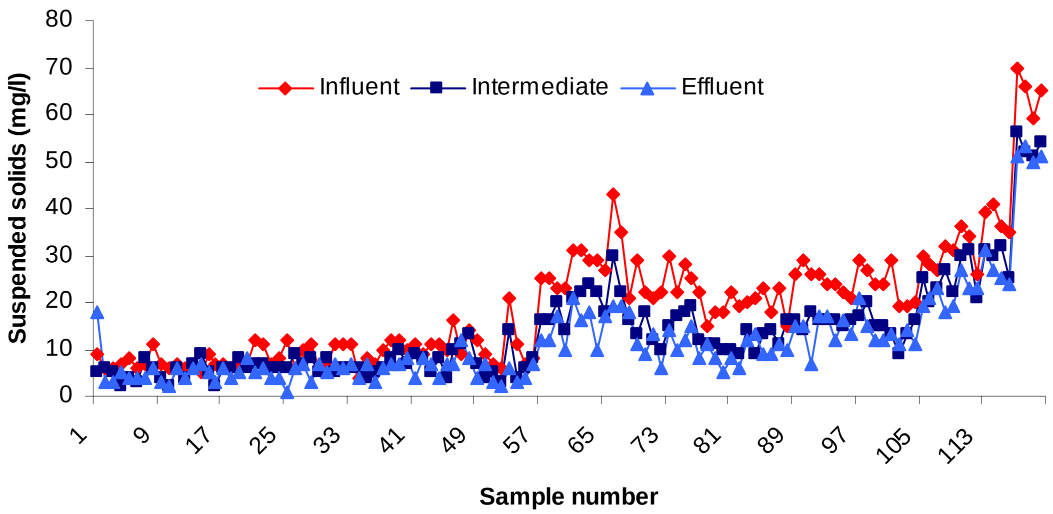

Figure 5. Suspended solids concentrations in the influent and effluent from the filter system

During the first 14 days of the study, the influent to the filters was very good with average suspended solids of 9mg/l, following the filters the suspended solids concentration averaged 6mg/l. At this level of influent suspended solids there is no real need for the removal efficiency to be particularly high as the influent is already within the consent limit for the site. However, it was found that at these low concentrations, there was almost always some removal within the two-stage filtration system with an average removal efficiency of 37%.

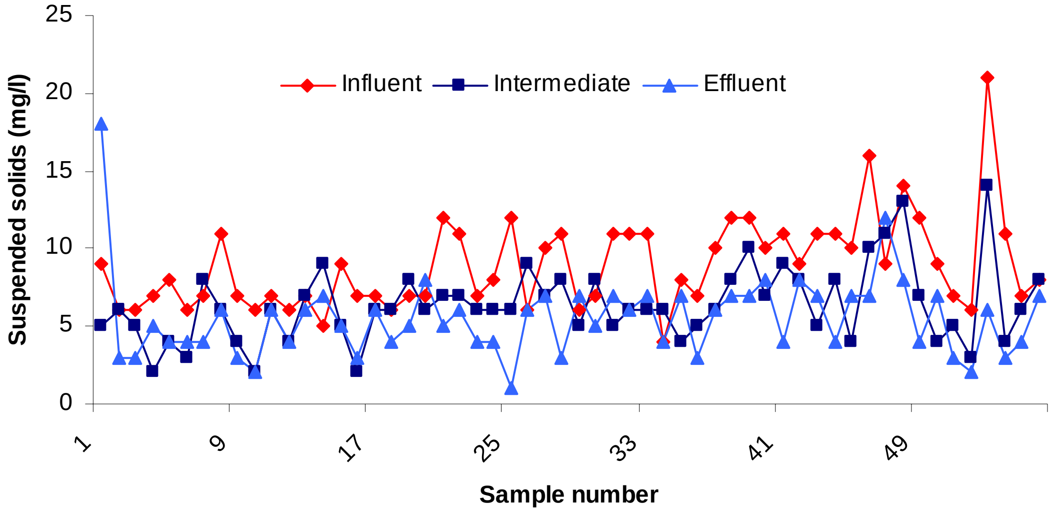

Figure 6 . Suspended solids concentrations 14/10/05 – 3/11/05

In the second period of the trial, there was an increase in the suspended solids concentration within the influent to the filters and this was especially the case in the last day of the trial as can be seen in Figures 5 and 7. The average concentration was 28mg/l with a maximum of 70mg/l. During this time the average suspended solids concentration in the treated effluent was 17mg/l with a maximum of 53mg/l. Removal efficiency was 42% for the latter period 7/11/05 - 28/11/05.

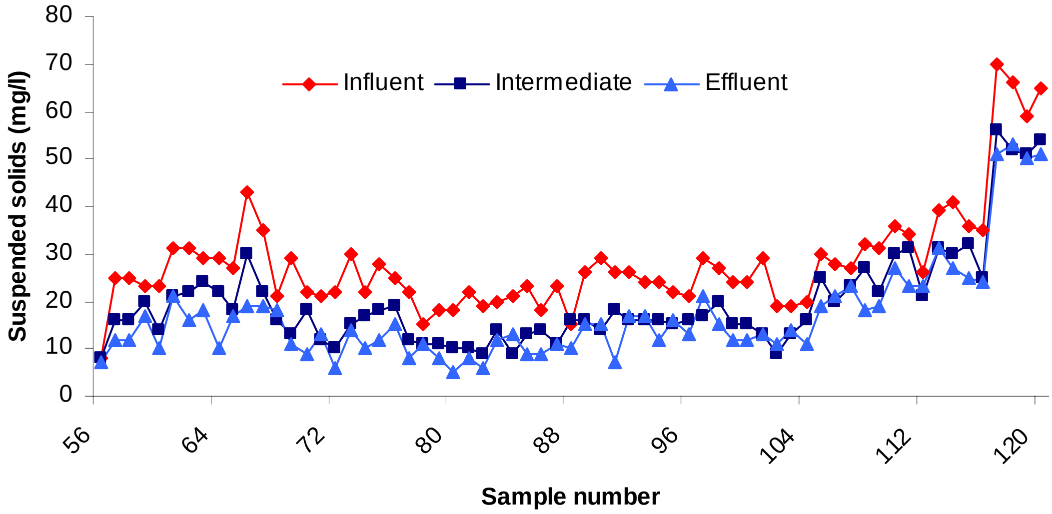

Figure 7. Suspended solids concentrations 7/11/05 – 28/11/05

The solids loading to the plant was also calculated and is shown in Figure 8. The solids loading and percentage removal rates were erratic throughout the trial. It can be seen that towards the end of the trial, the solids loading increased significantly and overloaded the filter, which was unable to process the effluent. It is suggested that a design rate of 0.15kg/m^3/hr is used for this effluent.

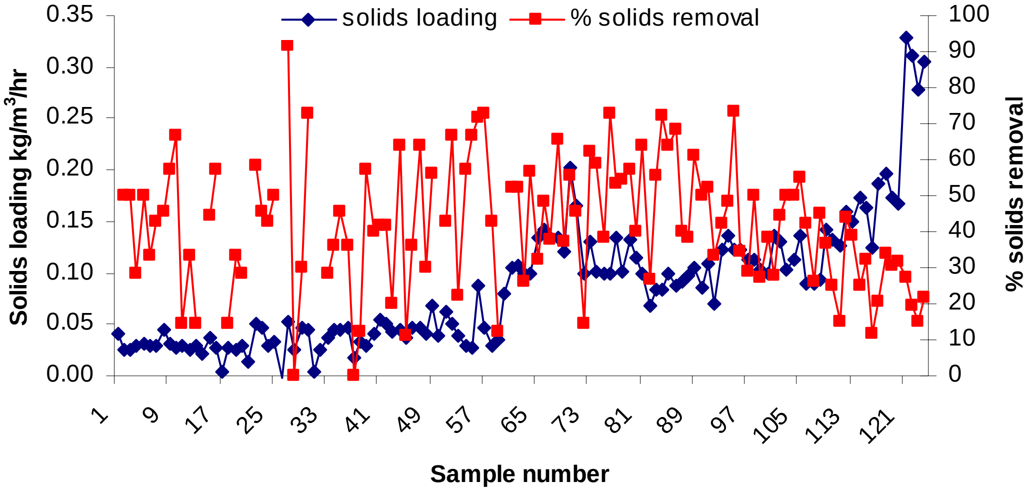

Figure 8. Solids loading and solids removal 14/10/05 – 28/11/05

The average influent suspended solids for this part of the trial was 22mg/l with the average concentration in the final effluent from the 2nd filter being 12mg/l with an average removal efficiency of 45%.

Table 2. Suspended solids before and after the filter system

	Influent	Intermediate	Effluent	% removal
Average	22 mg/l	14 mg/l	12 mg/l	38.5
Minimum	4 mg/l	2 mg/l	1 mg/l	
Maximum	151 mg/l	56 mg/l	53 mg/l	

Table 3. Suspended solids before and after the on site sand filter

	Before sand filter	After sand filter	% removal
Average	29 mg/l	27 mg/l	-5.9
Minimum	9 mg/l	8 mg/l	
Maximum	78 mg/l	60 mg/l	

It can be seen from these two Tables that the two-stage filter system is producing an effluent far in excess of the one that is being achieved by the onsite sand filter where there is very little solids removal being measured and on average there is a 6% increase in the solids present.

Hartleys are now considering changing their filtration system due to the success of this trial. They are aware that the sand filter on site is having a negligible affect on the suspended solids that are discharged and it is not helping them meet their consent.

1.2 Full Scale operation of two-stage filter at Croda

Croda Chemicals Europe Ltd is situated at Rawcliffe Bridge and is a manufacturer of speciality chemicals from natural raw materials. These products are surface-active compounds that are used in personal care, home care and industrial products. The site was built in 1925 and has a current capacity of 50,000M tonnes pa. The site employs approximately 400 workers most of whom are shift workers. The site has an effluent treatment system in place but has a requirement to reduce its final suspended solids by an average of 200mg/l in line with its application to the EA for IPPC (Integrated Pollution Prevention and Control)

Figure 9. Aerial view of Croda Chemicals site at Rawcliffe Bridge

1.2.1 Pilot scale two-stage filtration systems

Aqua Enviro have been commissioned by Croda chemicals to establish a tertiary treatment option to reduce the solids levels in their final effluent to an imposed standard of 50mg/l. The current average solids level in the effluent is 250 mg/l. Results from a previous trial at Georgia Pacific (Project GLA36-10) have proven that solids reduction in excess of 200 mg/l are possible with correct equipment and operation using glass as the filter medium. Other options to be considered would be membrane technology or flocculation; both of these technologies have high capital expenditure and can require extensive operational and maintenance costs. Additionally, membrane filtration commonly employs a pre-filtration stage to protect the membranes.

As with Hartleys it was decided that a 2-stage filter system would give the most efficient removal of solids with the first stage removing the larger solids particles and the second stage "polishing" the effluent by removing the smaller particles that passed through the first filter. This should give the filters a higher capacity for solids removal before fouling, compared to a single filter. As with Hartleys, the pilot scale rigs were re-configured to be operated as a two-stage system with a backwash tank (Figure 10).

Table 3. Configuration of the three filters

	Filter system 1	Filter system 2	Filter system 3
Filter media A	Medium grade	Coarse grade	Medium grade
Filter media B	Fine grade	Medium grade	Fine AFM

Fine grade – 0.2-1mm, Medium grade – 0.5 – 1mm, Coarse grade – 1 - 3mm

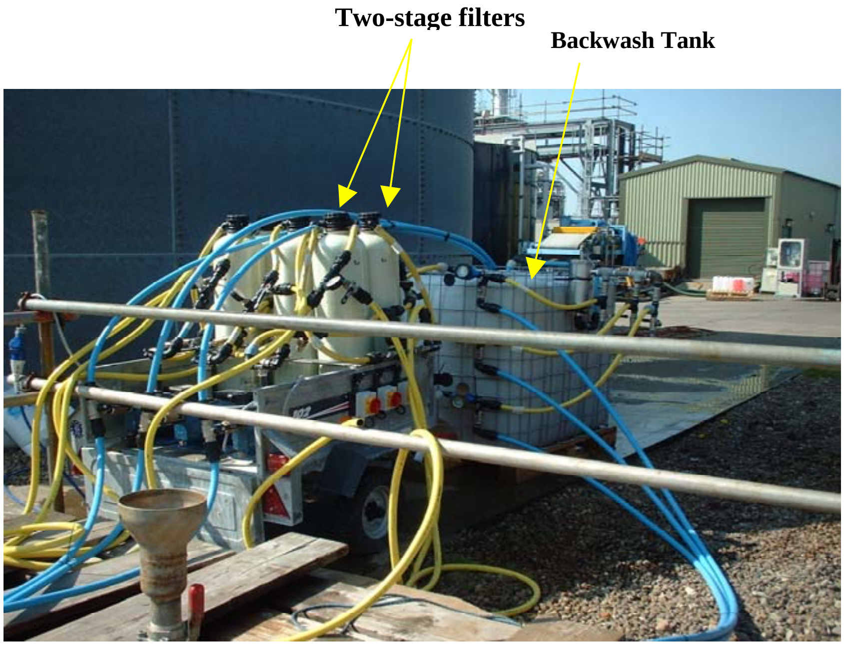

Figure 10. Pilot scale trial rig at Croda

1.2.2 Results for pilot scale

Initial problems were experienced with the influent pipes entraining sludge from the sides of the effluent sump, which caused fouling of the filters. Additionally the filters were set up to operate at a high flow rate (0.6 m3/d) giving an upflow rate (UFR) of 16 – 30 m/h. This is significantly higher than the usual operating range of 6 – 8 m/h and initially the solids removal was poor. This data does however show that when the influent solids increased to 200-300 mg/l there was no change in the effluent with this remaining ~100 mg/l. A second increase in influent solids was observed with a peak of 545 mg/l and initially the effluent quality was good but this rapidly deteriorated as the filters fouled.

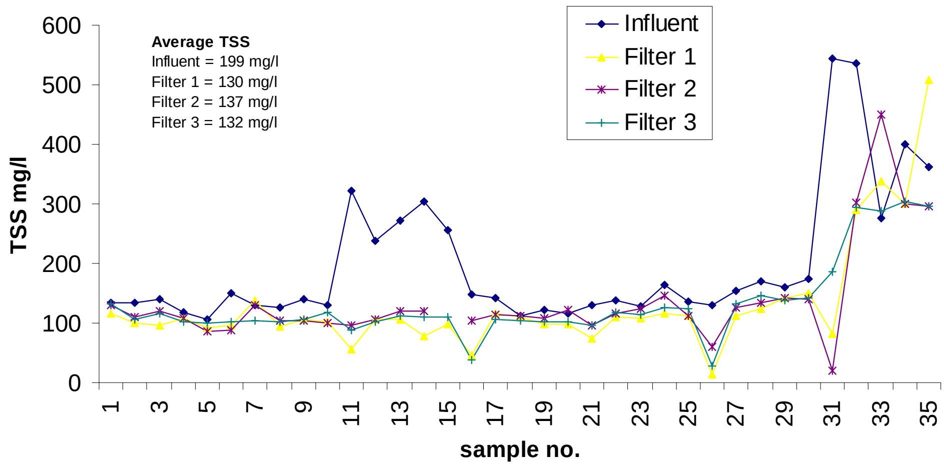

Figure 11. Suspended solids removal of the filters at high flow rates (28.04.05 to 09.05.05)

The flow rates were reduced to 0.15 to 0.2 m3/h giving a UFR of around 6 m/h. The results showed a good removal of solids with filter 1 performing best with 68.6 % TSS removal compared to 59.9 % in filter 2 and 65.6 % in filter 3 (Figure 12). The lowest level of solids recorded was 36 mg/l from filter 1.

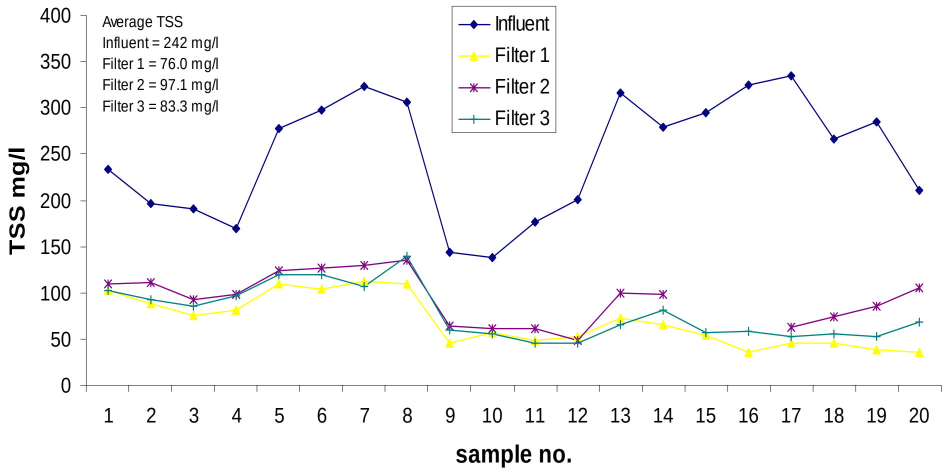

Figure 12. Suspended solids removal at ~0.2 m^3/h (11.05.05 to 16.05.05)

1.2.3 Automated 10m^3 vessels

As with the Hartley's study the project was scaled up to use the 10m^3 volume vessels used as part of project GLA036-10. These were reconfigured to give a two-stage process and automation was fitted to allow the plant to be able to operate automatically 24 hours a day (Figure 13). Based upon the pilot data the best configuration of media was determined to be medium grade glass in the first filter followed by fine grade glass in the second filter (Figure 14). The filters were operated with the following cycle: 4 hours service flow, 5 minutes drain down, 8 minutes air scour and 10 minutes backwash.

Figure 13. Large scale trial rig at Croda

The filters were initially operated with a forward flow rate of approximately 6m^3/hr; the backwash was carried out at a higher rate of 10m^3/hr. The filters were operated with the following cycle: 4 hours service flow, 5 minutes drain down, 8 minutes air scour and 10 minutes backwash and samples were taken hourly during the service flow to give a detailed profile of the filters response to changes in the influent composition.

1.2.4 Results from automated vessels

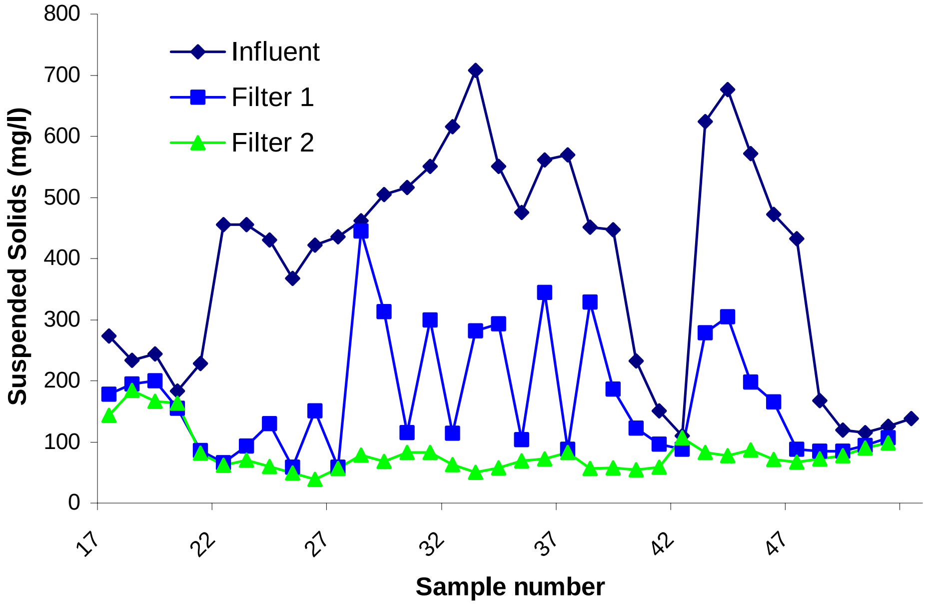

Figure 14. Performance of large scale filters during a week of operation (hourly spot samples)

This graph shows the suspended solids removal during the first week of operation. The levels of solids following the second filter were below 100mg/l for most of this time. The two-stage filter can be seen to be working well, solids that are not removed in the first filter are removed during the second stage. Suspended solids following the two filters have shown as much as a 90% reduction. There has also been a removal of COD during the filtration process with a maximum of 70% removal being recorded due to much of the COD being related to suspended solids.

The rig was operated for 33 manual 4-hour cycles with both filters being backwashed after each cycle. The results (Figure 15) show that after a sustained period of high influent solids (>400 mg/l) the effluent quality deteriorated from ~100 mg/l to ~300 mg/l. A further increase in influent solids to >1000 mg/l occurred and the effluent solids increases accordingly. Once the level of solids decreased, the filters took a further 7 cycles until the performance improved. This indicated that after periods of high loading the backwash was not sufficient to remove the solids from the filter media.

Investigation of the backwash showed that the backwash flow rate was slower than required to fluidise the bed due to sections of the backwash pipe work restricting flow. Sections of the pipe were replaced to optimise the backwash rate and the drain down times were checked to ensure the level of water covered all the media bed during the air scour.

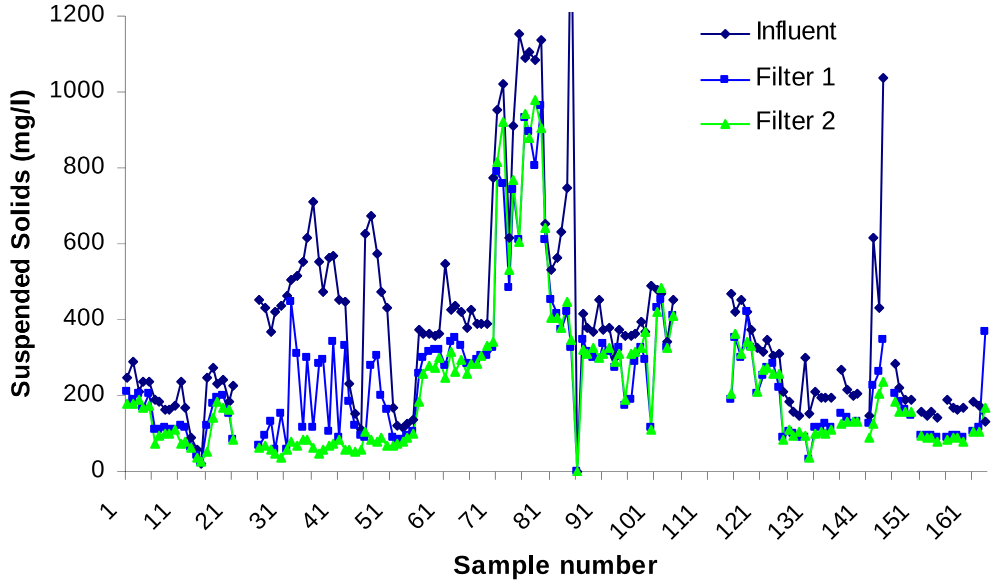

Figure 15. Performance of filters over the longer term with the reduction in the quality of the influent being observable with a similar reduction in performance of the filter system (hourly spot samples).

The plant was then operated 24 hours a day on a 4-hour service flow cycle. Auto samplers were placed on the influent and on the final effluent from the rig. These took samples every 15 minutes to give 24 x 1 hour composite samples. These samples were combined to give 4 x 6 hour composite samples representing the flow to and from the plant for 10:00 to 16:00, 16:00 to 22:00, 22:00 to 04:00 and 04:00 to 10:00.

The rig was operated at 3 different flow rates to investigate whether lower UFR's would improve the effluent quality. The results show that the plant consistently removed between 45 to 55 % suspended solids and the best performance was achieved at the lower flow rate of 3 m^3/d prior to a shock being received to the plant.

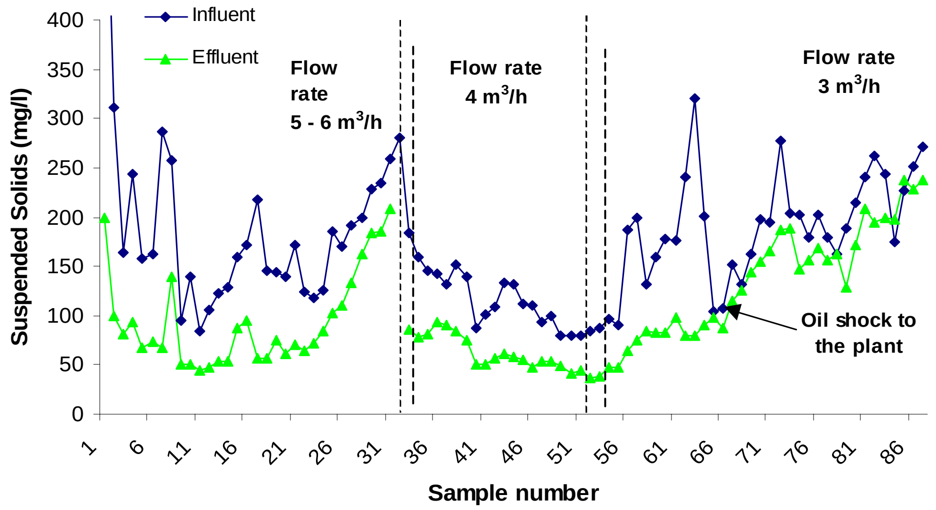

Figure 16. Performance of large scale fully automated rig operating 24 hours a day at different flow rates (6 hour composite samples).

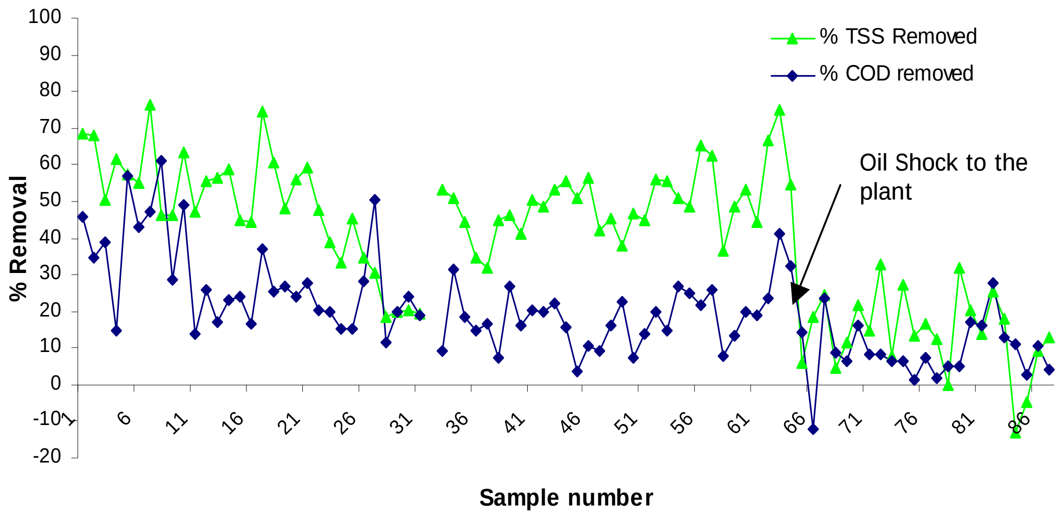

Figure 17. Performance of large scale fully automated rig operating 24 hours a day at different flow rates (6 hour composite samples).

The upstream biotowers, part of the existing wastewater treatment system, had been out of service for around 6 weeks and when these were brought back into service, a lot of material was washed forward and oily residues were observed on the inside of the flow meter on the rig. After this event the rig performed very poorly. The likelihood of an event such as this is very low, however it has been decided that the full-scale plant should have the facilities to add cleaning chemicals to the backwash (bleach or detergents) as a way of recovering the process if oils reach the filters.

The results are summarised in Table 5: and these show that at 3 m^3/h the average removal of suspended solids was 55% and this removed 22% of the COD. The maximum TSS removal was 76%.

Table 4. Performance of the large-scale rig operating 24 hours a day.

	Influent		Effluent		Removal	
	TSS mg/l	COD mg/l	TSS mg/l	COD mg/l	TSS %	COD %
Total Average	174	488	104	391	40	20
Average @ 5.5 m^3/h	192	449	94	316	49	29
Average @ 4 m^3/h	119	389	64	326	46	16
Average @ 3 m^3/h (until 17 Nov)	163	701	68	549	55	22
Maximum	631	1244	238	803	76	61

These trials have shown that the effluent from Croda's treatment process is highly variable with regards to levels of TSS and COD and a filter system would not be able to guarantee <50 mg/l in the final effluent. However these trials have shown that the filters are capable of reducing the level of solids to a level where the wastewater can be treated by a membrane system.

Croda had been considering installing a membrane system to re-use a proportion of the wastewater to meet their requirements for IPPC. The installation of a full scale plant will therefore be followed by further work to assess the most suitable system to reduce the level of solids further, thus meeting any future discharge consent and giving the option for water re-use.

Using this two-stage glass filtration system has the advantage of being able to cope with the very high level of solids without fouling of the filters. Using a sand filter as a pre-treatment to membranes would usually require <100 mg/l total suspended solids and so a further treatment stage before a sand filter would probably be required. This would typically comprise a form of chemical treatment to settle a proportion of the solids and such a system would cost in the region of £100 – 150k depending on the volume of water to be treated and have ongoing chemical costs associated with it. The two-stage glass filtration system would not require this additional step and therefore the associated costs.

1.3 Glass as a base material for a reed bed

Following a contact from a glass supplier, in-house research into this application was carried out. Potentially there is a large market for using glass as a base media in reed beds and other filtration systems such as those in swimming ponds. Another important factor is the increase in popularity of reed beds as they can be used as part of sustainable urban drainage systems (SUDS).

In a reed bed there is a need for a base material that acts as a both a means of supporting the reeds as well as helping to filter out suspended solids from the influent. There are a number of different reed bed designs that can be used for different purposes. They include vertical (downflow) and horizontal flow, the latter of these can be either surface or sub-surface flow. While horizontal reed beds have been traditionally used for tertiary treatment systems and BOD and suspended solids removal, vertical reed beds are becoming more popular in this application as they can also remove ammonia.

Bernard Matthews Ltd employs over 3400 people in the UK, principally at their Great Witchingham and Holton sites. The site at Great Witchingham has a long history of producing a compliant effluent and employs both activated sludge and filtration technologies. Filter beds with plastic or stone media polish a proportion of the effluent. There is the potential for reed bed technology to replace these aspects of the effluent treatment process and to therefore improve the final effluent discharge quality. The reed bed at Bernard Matthews uses glass in place of washed gravel (5-10mm).

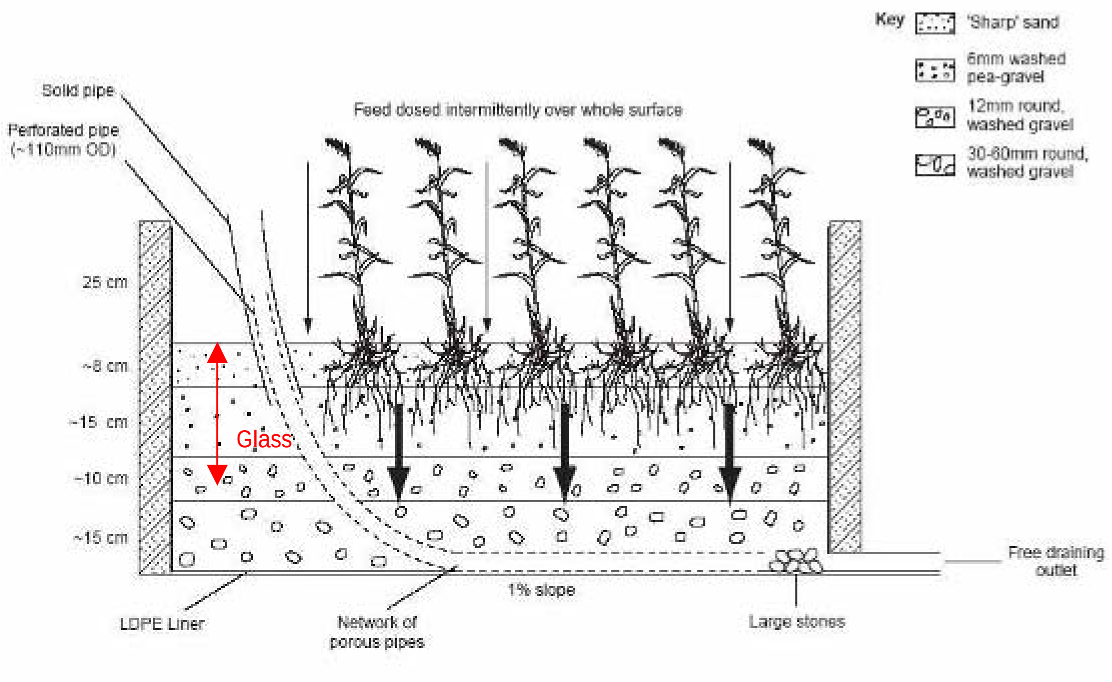

Figure 18 . Diagram of a typical vertical flow reed bed (The Building Regulations 2000, Drainage and Waste Disposal, Approved Document H, 2002 edition, DETR).

A vertical reed bed was designed using typical effluent data from the existing secondary treatment system and installed earlier in the summer by a leading reed bed manufacturer (ARM Ltd) and this has been treating the waste since the 11th July 2005. *Phragmites australis* reeds (common reed) are deemed the most suitable type of plant for reedbed development and are used in most reed bed applications in the UK as they are a quick growing, hardy species.

Typically for tertiary treatment, reed beds have a sub surface flow, however, initially the water depths were kept near the surface of the bed to encourage the growth of the reeds. Over time the level has been reduced by approximately 150 mm as the roots extend further into the glass bed. The design characteristics of the reed bed are given in Table 6. The retention time of 7 days means that there is a large buffering capability within the reed bed allowing for degree of variation in the influent quality.

Table 5. Design of the vertical flow reedbed.

Design parameter	Value
Area	49 m^2
Mass of glass	32 tonnes
Volume of glass	12.8m^3
Daily flow	5 m^3
Retention time	7 days
Influent loading (BOD)	14mg/l
Influent loading suspended solids	6 mg/l
Influent loading ammonia - N	13 mg/l

The reeds are growing well and the picture below shows the condition of the reeds in August, September and November of 2005.

Figure 19. Reed beds on 10/08/05

Figure 20. Reed beds on 10/09/05

Figure 21. Root structure of a reed (*Phragmites australis*) 24/11/05

1.3.1 Selecting an Appropriate Media

A 300mm long length of 110mm diameter PVC pipe is placed in a bed of pea gravel and filled with 200mm of the media to be tested as in Figure 22. A small square of pan scourer is placed on the surface to reduce disturbance by the water. Next, 500ml of tap water is poured into the tube quickly, but without disturbing the media surface too quickly, and the time for it to drain completely is measured. As soon as it has passed through another 500ml of water is added and again timed. This is repeated until the time taken levels off and plotted as in Figure 23.

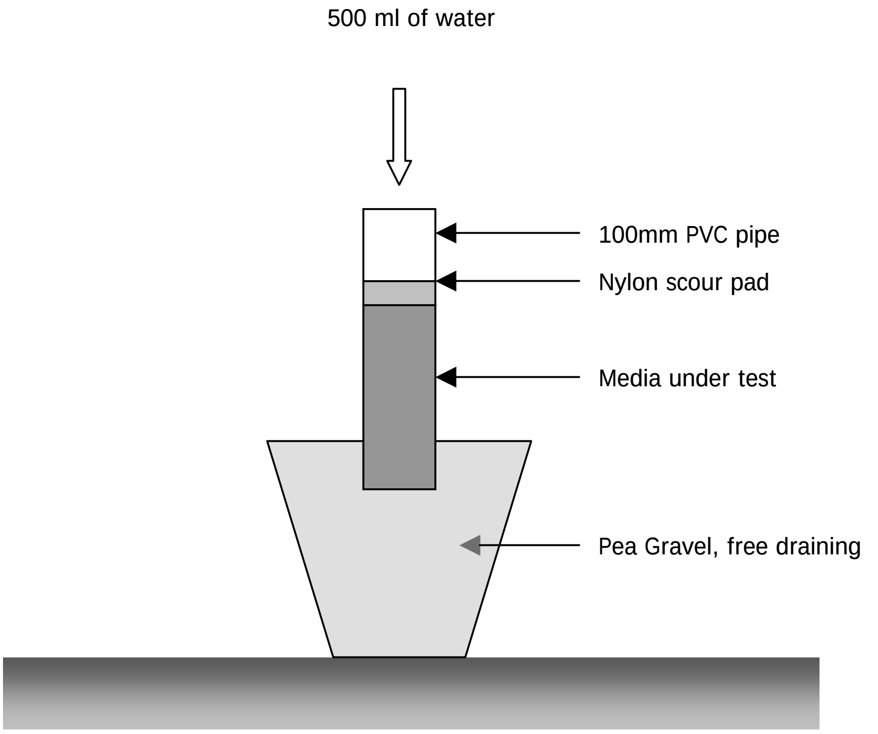

Figure 22. Media Suitability Test (Adapted from Grant, 1985).

Table 6. Particle size distribution of potential glass media for reed bed application.

Size (mm)	% Particles		
	Krysteline	GRG	AllGlass
>5.6	44	72	52
5.00	22	15	14
4.00	17	7	5
2.80	15	5	10
2.50	1		2
2.00	1	1	3
1.70			1
1.40			2
0.50			5
0.355			2
0.180			3

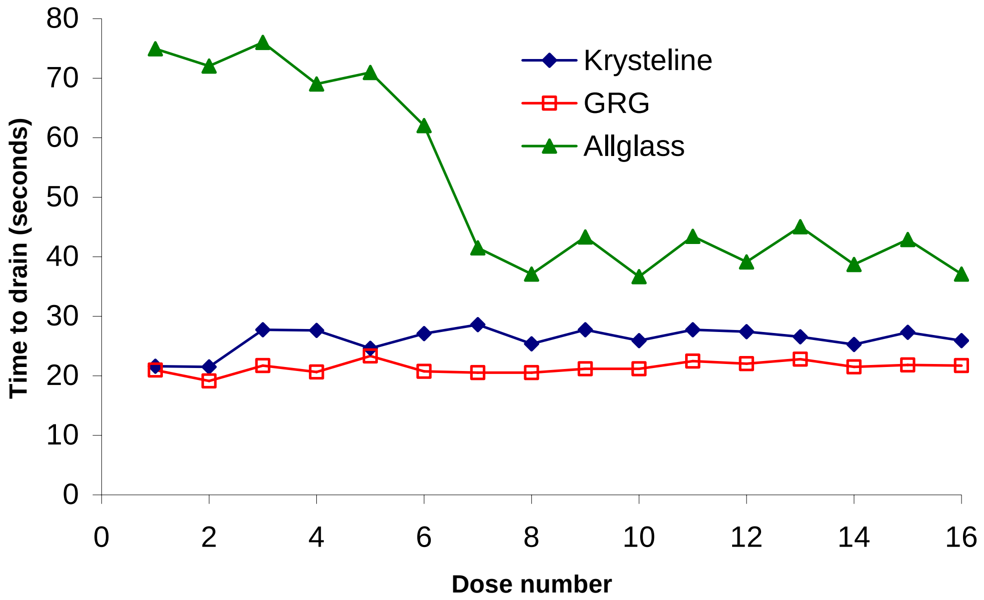

Figure 23. Graph: Percolation tests

The test was repeated 16 times for each of the 3-different media. The performances of the Glass Recycling Group and Krysteline media were similar and constant throughout the trial and this is likely to reflect that neither of these samples contained fine particles. The AllGlass sourced media impeded the flow of water for the first six tests, this is thought to be due to the presence of fine material which is then washed through the system. For the purpose of the full-scale trial both the Krystelline and Glass Recycling Group medias were deemed suitable as fine material could lead to blinding of the reed bed on a full-scale application.

1.3.2 The Economics of Recycled Glass as a Material for Reedbed

The percolation tests demonstrated that particle size distribution of the media is important. There should be little or no fines present in the media as these impede the flow of liquid through the bed. In this instance material sourced from Krysteline and GRG were suitable substitute media for reedbed applications. In the market for reedbeds recycled glass is in direct competition with 5-10 mm and 6-12mm washed gravel (Table 8).

Table 7. The cost of recycled glass versus gravel

Supplier	Price (£ -ex-works)
Krysteline recycled glass	36
Cardigan sand and gravel (North Wales)	13
Franks Lyons Group (Essex)	10.25
Online Gravel	106.48
Buckbricks (Colchester)	17.50
Cas Filtration (Leeds)	100

Table 8 demonstrates that there is a large amount of variability in the price of suitable media depending upon both the supplier and the location. Under current market conditions the Krysteline media is not competitive at the lower price end of the market, but is significantly cheaper than the products available from Online Gravel and Cas Filtration. The choice of media used in any given reedbed application is determined by the reedbed manufacturer and there is no one recommended supplier for the industry. The choice of media is crucial as proportionally it is the single largest cost in construction. It is also important to note that the media was originally chosen as it was manufactured as a by-product of processing recycled glass to a PAS 102 specification grade. The price for recycled glass can be regarded as fluid and will be largely dependent on the volumes of sale and the requirement for storage and delivery. It would be reasonable to suggest that the cost price of the media could be *significantly* reduced if the material could be supplied in bulk i.e. >100tonnes.

1.3.3 Results

Table 9 details the average results for the entire trial. A mature, fully performing reedbed can take up to 12-months to develop depending upon the rate at which root/rhizome structure develops.

Table 8. Average performance of the reed beds (11.7.2005-28.11.05)

Parameter	Influent (mg/l)	Effluent following Reed Bed (mg/l)
BOD	16.3	6.0
Suspended solids	12.3	5.3
COD	100.8	102.2
Ammonia	11.4	10.8
Phosphate	2.1	1.7

The reedbed removed an average of 57% of suspended solids and 63% BOD over the course of the trial. Removal rates for other parameters were negligible and any future work considering different process applications for this specific site (e.g. nitrification and denitrification) should include an assessment of the wastewater treatability.

Figures 24, 25 and 26 show in more detail the results for suspended solids, BOD and phosphate with a 7-day moving average.

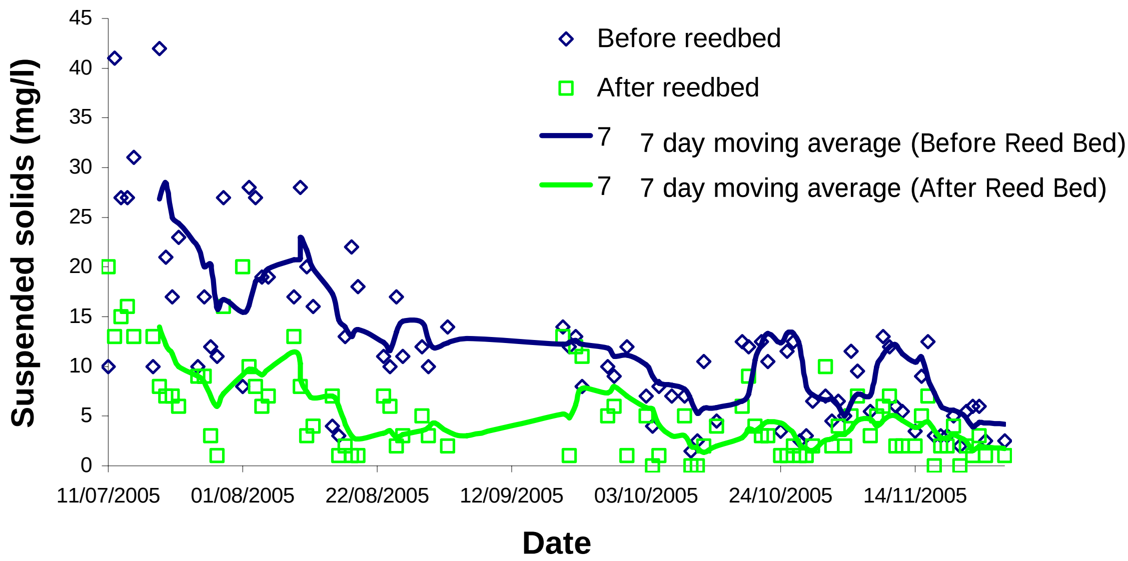

Figure 24. Suspended solids performance

The minimum effluent suspended solids was 0 mg/l, the maximum 17 mg/l and the average 5.3 mg/l. The reedbed was effective at buffering out relatively high levels of suspended solids at the beginning of the trial (up to 45 mg/l) and produced a consistently polished effluent during October and November when influent wastewater was more consistent.

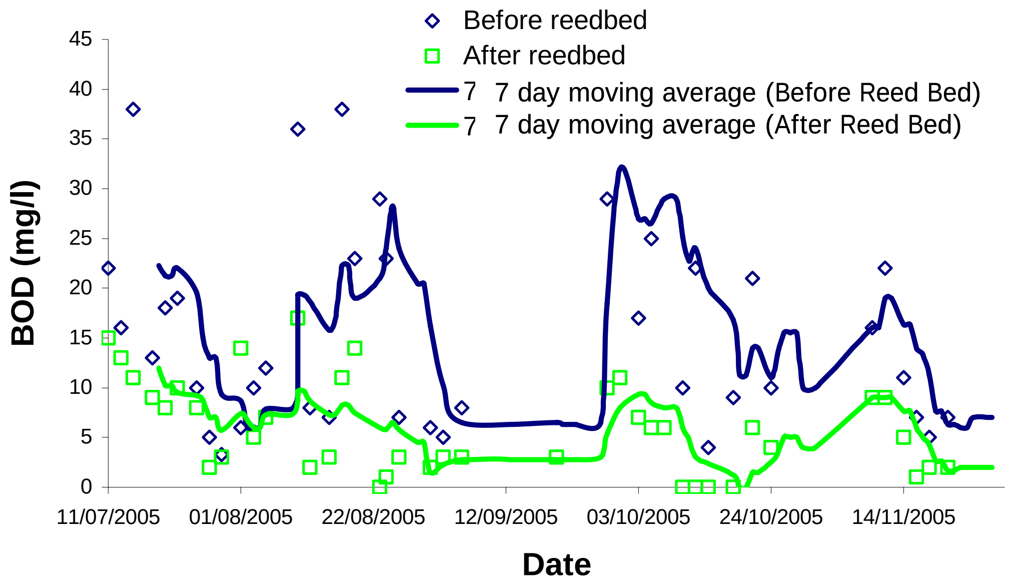

Figure 25. BOD performance

The minimum effluent BOD was 0 mg/l, the maximum 20 mg/l and the average 6.0 mg/l. The performance was similar to suspended solids in that relatively high strength influent BOD levels were effectively buffered.

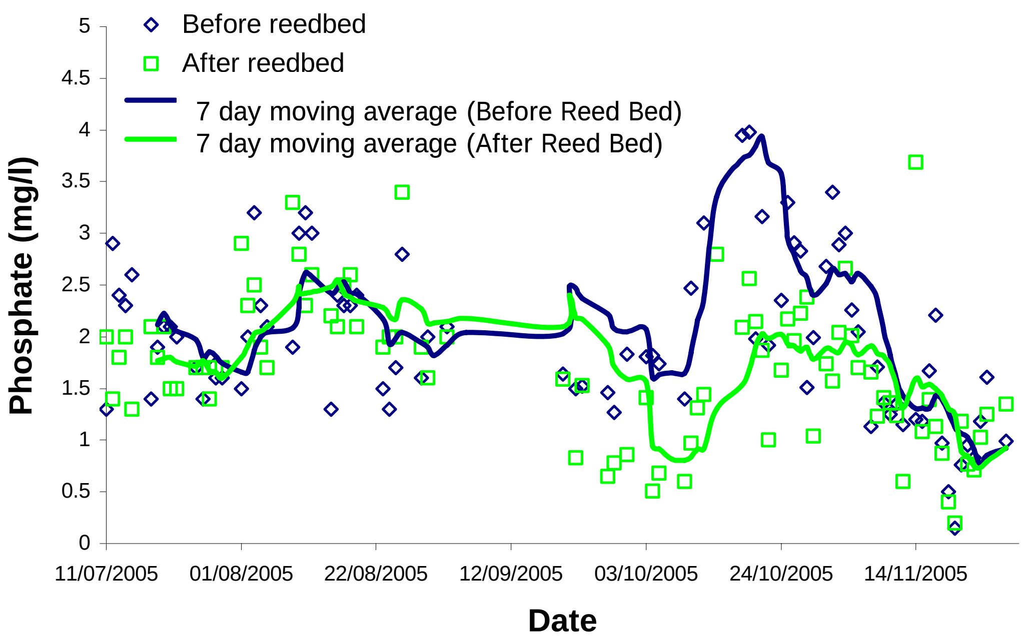

Figure 26. Phosphate performance

Phosphate removal via gravel media has not been reported in the literature. During October and November of 2005, however, effluent reedbed levels were consistently 20-50% less than influent levels. An explanation for this trend has not yet been found and further investigation should focus in part on this finding.

1.4 Conclusions and further work

Over the whole project the two-stage glass media filters at Hartleys have proved to be effective at removing solids on the larger scale, when the on site sand filter was removing only negligible amounts of solids. Hartleys are considering upgrading their processes to include a two-stage glass filter inline with the site trial, although this is in the early stages at present.

Results from Croda Chemicals have been very good and they are in discussions for the installation of a full scale filter system based on the data generated in this trial. An order will be placed by the end of the year, which will allow commissioning to take place in Spring 2006. Monitoring of the full scale filter system will carried out which should allow a stronger business case for the use of glass to be developed. Croda are also extremely proud to be able to use a recycled material as a means of cost reduction and meeting discharge consents. They are planning to publicise results with a view to enhancing their environmental image.

The results from the relatively immature reed bed trial are very promising. Typically at least 1 year of operating is required for the root \ rhizome structure to fully develop and for the performance to be satisfactorily assessed. The single, vertical flow reedbed trialled here has proven that recycled glass can be used as a media to remove BOD and suspended solids. Many different configurations, resulting in hybrid systems, to achieve nitrification, denitrification and balancing of flows are also possible and it would be worthwhile exploring further the process capabilities of recycled glass media to achieve these targets. Analysis of phosphate concentrations through the bed has indicated that removal has been occurring during October and November of the trial. Phosphate removal via gravel media has not been reported in the literature and further investigation of this trend could result in a significant competitive advantage in the market place for recycled glass. Further testing of flow rates, nature of the wastewater, and solids loadings through the Bernard Matthews reedbed would also yield more detailed design criteria.