Creating markets for recycled resources

Full Scale Operational Trials Involving The Use of Recycled Glass in Selected Markets

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Contents

Executive Summary 3

1 Introduction 4

2 Technical and Competing Technology Review 4
2.1 Background 4
2.2 Scope of Review 5
2.3 Conventional Filtration Technology 5
2.4 Granular Filter Media for Pressure and Gravity Flow Filters 6
2.5 Membrane Filtration 8
2.6 Recycled Glass Filter Media (RGM) 9
2.7 Summary 11

3 Environmental Legislation & Life Cycle Analysis 12
3.1 Environmental Legislation 12
3.2 Life Cycle Analysis 14
3.3 Discussion and Conclusions 1

4 The Trials 16
4.1 The Sites 16
4.2 Plant 22
4.3 Operational Parameters 25

5 Results and Discussion 31

6 Conclusions 39

7 References 42

Appendices

APPENDIX 1 **Process & Instrumentation Diagram**
APPENDIX 2 **Outline Process Flow Diagram**
APPENDIX 3 **Data for Slimbridge**
APPENDIX 4 **Data for SCA Histon**
APPENDIX 5 **Data for Premier Food**
APPENDIX 6 **Glass Analysis**
APPENDIX 7 **Control Screens (Examples)**

Executive Summary

This project was initiated by WRAP to expand on the findings of several pilot studies into the use of recycled glass filtration media (RGM) by carrying out full-scale operational trials. Water Development Services were awarded a contract in October 2004 to undertake works in the sector of industrial water treatment, food processing, paper and pulp and canal water extraction.

Other areas of work identified by WRAP for investigation under the contract included the RGM supply chain, technical development in this field of water and waste water treatment, anticipated life cycle for RGM, a review of existing legislation, an analysis of competitor systems and an appraisal of the marketplace for the use of RGM.

The three sites selected for filter testing were:

- Slimbridge Wetland and Wildfowl Centre Trust, Gloucestershire
- SCA Packaging in Histon, near Cambridge, who produce cardboard and paper
- Premier Foods at Long Sutton, Lincolnshire

Bespoke water treatment plants with two filters in each plant were designed and constructed and strategically sited to allow testing to proceed for the duration of the contract with the minimum of disruption to the normal operations at each site. Although the treatment systems were fully automatic with data downloaded by telephone links, assistance was provided by personnel from each 'Client' as some manual sampling was needed.

The length of the contract, which has been nine months, is somewhat short for a thorough comparison to be carried out of the use of RGM and sand for filtration. It is well established that sand filters become "bio-fouled" (blinded) with time, but this does not generally take place within six months as it depends upon a variety of factors not least being air temperature which controls bacterial growth. RGM on the other hand does not bio-foul as it is non organic.

Nonetheless the data gathered during the project does indicate a decrease in the performance of the sand over that of RGM used in identical pressure filters.

The overall findings from this project were: -

- Both sand and RGM filters generally performed well on all three sites, in that they reduced the contaminants significantly in all the key parameters of SS and COD.

- The performance of the RGM from all four suppliers was very similar – no one product stood out as significantly better than the others.

- The physical analysis of the glass, carried out by an approved independent laboratory, identified that all the RGM, with two exceptions, generally complied with PAS 102 Section 7.

- The trial results demonstrated that the use of RGM filtration greatly improved the influent quality and apart from mild "discolouration", the resulting effluent was clear and generally contained an effluent within discharge consent levels for each site.

- The trials also demonstrated that the RGM filters performed equally well or better than the sand filters which began to deteriorate as the trials progressed.

1 Introduction

This project was awarded by WRAP to investigate the treatment of water and wastewater by comparing the performance of recycled glass filtration media (RGM) against sand. Pilot scale trials have been carried out during the last 8 years, culminating in two main trials during 2004[8, 9]. The results from those trials concluded that the use of recycled glass filtration media as a direct replacement for sand in gravity and pressure sand filters has not only been successful but the performance has been significantly better than that of traditional sand in all the tested applications.

Where recycled glass filtration media has been used in place of filter sand in the treatment of sewage and industrial effluent, it has not been as susceptible to biological fouling as sand. Sand suffers badly in this respect, resulting in the filters becoming blocked and failing.

Not only has recycled glass filtration media been shown to resist bio fouling, it also needs less water for back flushing.

This project concerns the full-scale operational trials on waste liquor at three different sites, to confirm the findings of earlier pilot test results and to show that the use of recycled glass filtration media may be recommended across the water industry.

The project also investigated environmental legislation issues, to establish how it might impact on these trials and ensure that it was taken into consideration when evaluating the effluent discharge levels from the trial plant. The life cycle of recycled glass was also thoroughly investigated.

The team also carried out a technical review to ascertain the benefits of using this filtration media. An analysis of the technical requirements has been made and compared to the available materials used with all available test results. Special attention was given to their effectiveness in reducing suspended solids, chemical oxygen demand (COD) and ammonia levels. This review also refers to all available published data.

In order to assess the commercial viability and determine the market potential of this new product, a diagnostic review has been made of recycled glass filtration media compared with existing available competitor systems. Product availability with costs, supply chain restraints and material quality has also been addressed. The likely demand for this material has been evaluated together with its potential for further exploitation in the marketplace.

The information gained from these full scale operational trials will be used to prepare a plan for the dissemination in collaboration with WRAP or its appointed contractor, which may include the production of case studies, other similar publications and publicity events.

2 Technical and Competing Technology Review

2.1 Background

Many wastewater and industrial effluent treatment works have difficulty meeting and/or maintaining their Consent to Discharge standards issued by the Environment Agency (EA). The reasons are many and varied; erratic loading, overloading and lack of maintenance are just a few of the causes. In many cases, the EA may have increased the consent standard and treatment plant improvements are yet to be implemented.

It is EA policy to impose tighter standards for effluent discharge, in order to improve environmental quality[1]. Particular emphasis is being placed on reducing the levels of ammonia, which is harmful to fish and other river wild life. Ammonia is, however, the most difficult of the three main Consent to Discharge parameters, the others two being Bio-chemical Oxygen Demand (BOD) and Suspended Solids (SS), to achieve because the nitrifying bacteria needed to reduce ammonia levels are slow growing and affected by low liquor temperatures.

To exacerbate the problem, Environmental legislation in the UK and Europe is marching towards an ever-stricter discharge quality for Phosphates and Nitrates. Furthermore, these contaminants are very difficult to remove from waste effluent using conventional processes. The forthcoming water quality treatment framework proposed by OFWAT (Asset Management Planning Round 4), (AMP4)[2], will be raising discharge effluent quality for sewage treatment plants throughout the UK.

To meet this tighter Consent to Discharge standards, almost every wastewater and industrial waste treatment plant in the UK will either have to be renewed or provide additional treatment processing plant. Tertiary treatment of existing effluent by filtration is the most cost effective and simplest method of meeting many of the new discharge requirements

Granular media filtration using predominantly silica sand is traditionally used in the final treatment of effluent. However, sand is a tenacious media and prone to bio-fouling that drastically reduces filtration performance, resulting in poor and fluctuating effluent quality.

The use of innovative filter media, which mitigates bio-fouling issues, such as, recycled crushed glass, for tertiary effluent treatment has considerable potential. Filtration using recycled crushed glass therefore represents a potential solution to stricter discharge consents and more reliable long-term operational performance.

Although published evidence suggests that filters using crushed recycled glass are capable of improving effluent discharge quality, available data and knowledge on the usage, performance and operational characteristics of the material is limited.

2.2 Scope of Review

This section of the report reviews the technical benefits of treating water and wastewater from the food and drink industry, the pulp and paper sector and abstracted canal water using recycled crushed glass filtration systems. The project deliverables aim to:

- Ascertain the technical feasibility and practical advantages of using recycled filtration media for the enhanced treatment of effluent, in comparison with technology currently available in the UK.

- Review filtration media properties and analyse test results.

The main technical work presented herein reviews data published on various filter media materials and process properties, primarily concentrating on their effectiveness in reducing suspended solids, BOD, chemical oxygen demand (COD) and ammonia levels. Data concerning their performance in lowering nitrogen and phosphate concentrations is also investigated. Target discharge performance levels from current and proposed environmental legislative requirements are also reviewed.

This review encapsulates a broad spectrum of available published data, including professional and learned journals, related wastewater industrial and commercial literature, technical indices and on-line technical sources.

The status and application of competing filtration technology with recycled glass media is also reviewed. The competing technologies studied include conventional sand and membrane technology, and the introduction of recycled plastic media.

2.3 Conventional Filtration Technology

Wastewater and industrial effluent requires numerous different treatment processes prior to safe discharge into the environment [3,4]. Treatment varies according to the quality, quantity and nature of the effluent and the ability of the local environment to safely accept the treated effluent. These factors impact on the overall cost of effluent management and treatment strategy.

Treatment processes typically fall into three broad categories:

1. Primary treatment such as coarse screening, settlement tanks and clarifiers.
2. Secondary treatment such as biological air filtration, anaerobic digestion, sequenced batch reactors and activated sludge.
3. Tertiary treatment such as continuous sand filters, rapid gravity flow and filtration, pressure and membrane filters.

Filtration is becoming a more acceptable process in wastewater and water treatment, facilitating the reduction of suspended matter and associated contaminants in the influent stream. Filtration technology is now being extended into the tertiary treatment of sewage and industrial effluent. [4, 5, 6] A variety of filtration technologies are available with their selection being dictated by the degree of filtration required, which is usually based on particle size (see Fig 2.1). The range of particle sizes removed by traditional filtration media is in the micro and macro particle range and towards the upper particle size range for membrane filtration.

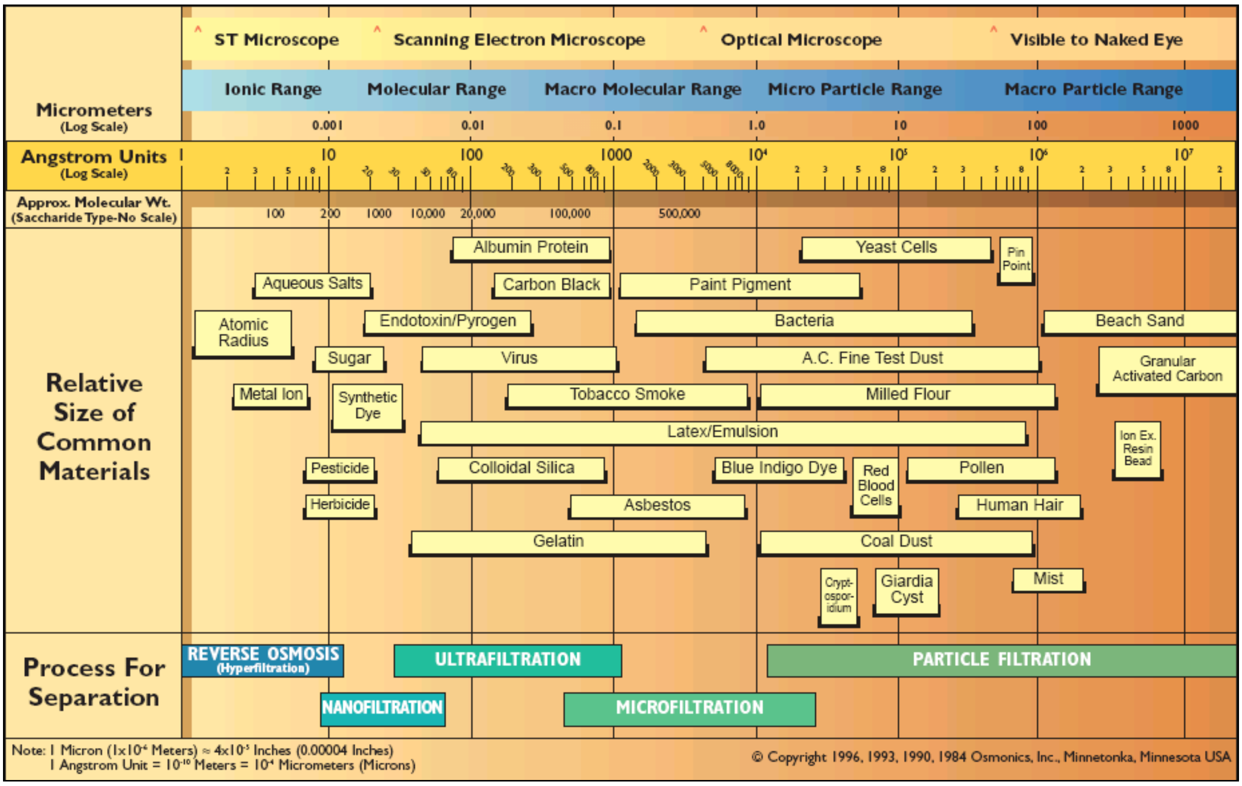


Fig 2.1 Filtration Spectrum

The primary function of filtration is to remove contaminants efficiently and consistently to stipulated levels, without undue maintenance or frequent renewal. Filtration can be undertaken using a range of filter types and combinations of media material. The choice of filter and media is dependent upon numerous parameters, such as the type and quality of the influent, required effluent standards, footprint dimensions and cost [3].

2.4 Granular filter media for pressure and gravity flow filters

The most common application of filtration in wastewater treatment concerns tertiary treatment, where granular filter media is used to clarify effluent prior to discharge into the environment. Filtration typically targets particulate matter in the influent stream, with solid components down to 1 micron being removed. The performance of the filter media depends on its particle size, shape, degree of uniformity and density. The filter media should also be chemically inert and not produce fines when agitated (low friability). Standard friability test procedures have been developed for these parameters by the water industry[7]. Traditional granular media filters include anthracite and garnet, but silica sand is the most common.

Silica sand is a well-processed and specified product, providing a very effective low cost filtration media. Uniform grain size and grading standards ensure optimum filtration performance. The effective size of sand required for slow and rapid gravity filters are 0.35mm, and between 0.6 – 1.2mm respectively. However, sand is a tenacious material and supports a relatively high biomass of bacteria, resulting in bio fouling almost immediately under biological loading, binding the sand grains together[8,9]. Sand filters, therefore, require regular back-flushing to clean the filter media and to maintain filtration efficiency.

However, it is extremely difficult to clean sand efficiently and maintain filtration performance. Chemical cleaning strategies and extensive back-washing regimes do alleviate the problem, but further reduce filtration efficiency and increase operating costs. Sand is regularly replaced in filters to optimise performance, but has to be disposed to landfill due to its contamination. Typical life cycles for sand are between 5 and 10 years[10,11].

The degree of bacterial biomass attachment to the filter media is an interaction between the physical-chemical parameters of the bacterial cell wall and the filter media. The filter media parameters, which affect bacterial adhesion, are surface roughness, surface charge, the degree of hydrophobicity and the metal oxide content of the filter media[12]. In some applications the prevention of biomass growth and adhesion may not be universally beneficial, for example the removal of ammonia in conventional sand filters may be due to the presence of a nitrifying bio-film on the sand material.

Filtration is also used for supplemental removal of suspended solids (including particulate BOD) from wastewater effluents of biological and chemical treatment processes. Filtration is also used to remove chemically precipitated phosphorous. In reuse applications, filtration of treated wastewater is required for applications to food crops, park and playground irrigation, and swimming pools.

During filtration, the rate of flow can be constant or variable depending on the flow control method. Filtration performance fails when suspended solids in the effluent increase beyond an acceptable level, or when a limiting head loss occurs across the filter bed. At this stage, the filter is backwashed by reversing the direction of the flow. Air is often used in conjunction with water to enhance the backwash operation, with chemical cleaning utilised if necessary.

Gravity filters are the most commonly used for treating effluent at large plants, while pressure filters are normally used in smaller plants. Pressure filtration is carried out in a closed vessel under pressurised conditions achieved by pumping the effluent, and normally operated at higher head losses, which results in longer filter runs and reduced backwash requirements. Pressure systems are able to operate at a constant or variable flow-rate, where either the influent or the effluent is controlled. Important influent characteristics include SS concentration, particle size and distribution, and floc strength. Typically, the suspended-solids concentration in effluent from water treatment plants[13] varies between 6 and 30mg/L. Particles normally fall into two distinct sizes, namely between 1µm to 15µm and between 50µm to 150µm (equivalent circular diameter). The weight fraction of the smaller particles is estimated to be approximately 40 to 60 % of the total, but this depends on the operation and efficiency of the biological processes. This bimodal distribution size is important because it influences the removal mechanisms that may be operative during the filtration process. The removal mechanism for 1µm would be different from that for 80µm particles. Floc strength will also vary with the type of process and the mode of operation.

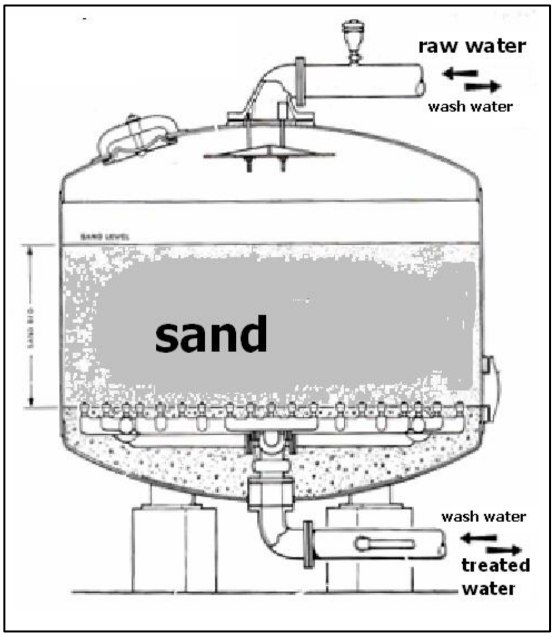


Fig 2.2: Pressure filter principle

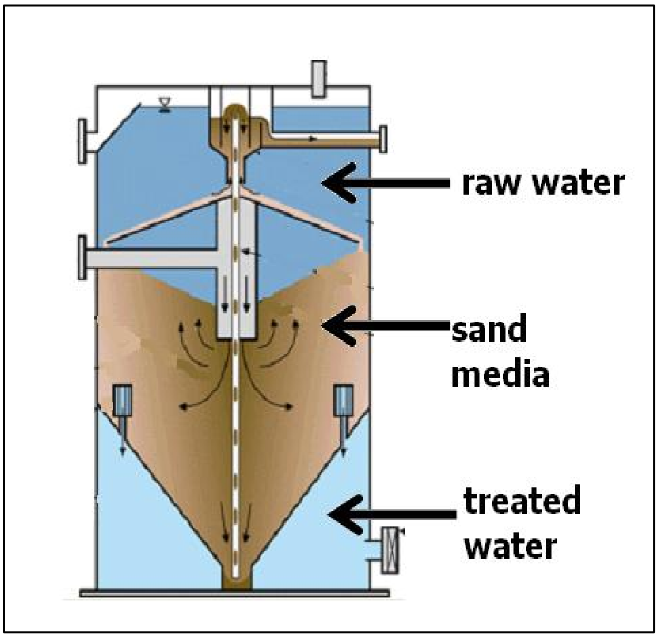


Fig 2.3: Gravity filter principle

Filter media grain size is the principal characteristic that affects the filtration operation. Grain size affects both the clear-water head loss and the build-up of head loss during the filter run. If too fine a filtering media is selected, much of the energy used to drive the effluent flow will be used to overcome the frictional resistance of the filter bed. However, if the grain size is too large, many of the small particles in the influent will pass directly through the bed.

Effluent flow-rate influences the size of the filters that will be required, and is dependent on floc strength and filter media grain size. If floc strength is weak, high filtration flow rates will tend to shear the floc particles and transport fine particles through the filter. For example, it has been observed that filtration rates in the range of 80L/m2/min to 320L/m2/min will not affect effluent quality because biological floc is strong[13].

Optimising silica sand deep bed filtration parameters has been investigated[14] for a filtration column 1m high, 0.15m in diameter, with a bed depth of 0.8m. Media grain size and filtration velocities were varied to optimise the system. The filter media tested was between 0.8 – 1.2mm, and 2 – 3mm, while the filtration rate varied between 5 – 13.4m^3/hr/m^2 over a 6-hour period. The filter performance varied considerably when the filtration velocity and particle size distribution changed. However, the suspended solids influent concentration remained constant. Optimum SS removal was achieved for particle sizes between 0.8mm to 1.2mm and an inflow rate of 5m^3/hr/m^2. For influent having SS of 20.9mg/L, SS removal was up to 92.7%[4].

Plastic media has also been used in the biological filtration of sewage effluent[15, 16]. A recent investigation into the use of recycled plastic as a possible alternative to sand in high flow rate filters has been undertaken[17]. In this instance, recycled plastic is utilised in permanently fluidised filters, whereby bacteria adhere to the surface of small-recycled plastic beads, which in turn remove pollutants from the wastewater. This system is not suitable for tertiary treatment, where bio fouling due to the surface roughness of the media is to be discouraged.

2.5 Membrane filtration

Membrane technology has been considered to be an attractive alternative to conventional water treatment since it can provide better water quality with high reliability. Membrane filtration involves the use of a semi-permeable plate membranes or screens capable of separating substances in-suspension when pressurised [3, 4], as shown in Fig 2.1.

Membrane filtration is applicable to a wide range of industrial effluents and potable water treatment, where it is being increasingly employed for the removal of bacteria and other micro-organisms, particulate matter and natural organic materials. When operating at peak efficiency, membranes can provide excellent water quality.

Fig2.4 Ultrafiltration module

Fig 2.5: Micro filtration module and vessel

Fig 2.6: Nano filtration unit

However, concern exists on the efficacy of membranes when influent streams have high suspended solids content. Due to fouling, membranes need to be backwashed regularly, and undergo chemical cleaning as necessary. Fouling is a major bottleneck that hinders the wide application of membrane process. The target application for traditional filtration media is for particle filtration above 1µm (micro and macro particle range), but a lower range can also be processed using micro-filtration membranes, with numerous applications being suitable for ultra-filtration (UF), nano-filtration (NF) and reverse osmosis (RO) membrane systems.

Ultra-filtration processes are increasingly popular in drinking water treatment because they produce better quality water and meet more stringent effluent regulations, particularly concerning removal of pathogens and turbidity. However, the widespread use of UF membranes in drinking water treatment is still limited due to two major drawbacks, namely membrane fouling and insufficient removal of disinfection by-products.

Ultra-filtration systems are pressure-driven membrane processes that use porous membranes for the removal of dissolved and colloidal material. These systems differ from reverse osmosis systems by the relatively low driving flow pressure, usually under 1034kN/m2. Ultra-filtration is normally used to remove colloidal material and large molecules with molecular weights in excess of 5000. Applications for UF include removal of oil from aqueous streams and the removal of turbidity from colour colloids. Effluent from ultra-filtration is suitable as a feed source for RO.

Membrane filtration systems are more complex and less robust than traditional sand-based processes, whilst having a higher capital cost and increased operating charges. Membrane life cycles are typically short, having an average life of approximately 7 years2.

2.6 Recycled Glass Filter Media

2.6.1 Introduction

Research over the past 15 years both in the UK and abroad has shown that granulated recycled glass has strong potential as a replacement for traditional silica sand. A great deal of work has been undertaken on the filtration of numerous effluent streams, such as industrial waste, swimming pools and provision of drinking water [6, 18, 19]. Extensive work around the world [8, 20, 21, 22] has shown that processed recycled glass can be utilised in the tertiary treatment of wastewater and industrial effluent as a direct replacement for silica sand.

Processed glass grains have angular, flat surfaces but retain a high degree of sphericity, which results in improved permeability. Glass is amorphous and has no internal crystal structure, making each particle homogeneous with no internal grain boundaries.

Glass is therefore more resistant to breakdown and disintegration (friability) through heavy filtration and back-washing cycles. Furthermore, effectively smooth grain surfaces prevent the adherence of pollutants and bacteria, thus reducing bio-fouling and promoting effective long-term filtration performance. Glass particles have a weak negative surface charge, which further attract fine particles during the filtration cycle. Upon rigorous back-washing, these particles detach and are flushed away thereby maintaining optimum filtration action. However, differences in biomass adhesion were found for glasses made under different manufacturing techniques[12].Two highly processed recycled glass media in the UK[23] and USA[24], are based on green and brown glass cullet. The recycled glass is carefully processed, sterilised and cleaned to provide a media conforming to PAS 102 specifications[25] in the UK and AWWA standards[26] in the USA.

Recycled glass filtration media has been used as a direct replacement for silica sand for use in gravity or pressure sand filters for the following applications: potable water treatment, advanced sewage treatment, industrial effluent treatment, grey water recirculation, boiler feed water, aquaculture, swimming pools, river, pond and lake treatment, aquariums and cooling towers.[27]

Results from field trials using both sand and highly processed recycled glass[23] are generally encouraging. Recycled glass in general produced a slightly improved standard of treated sewage effluent when compared with sand[8]. However, the performance benefits also included revenue cost savings due to reduced back-washing requirements and less maintenance.

Recycled glass typically removed between 25% and 80% of contaminants[23, 24] in the influent stream, whilst in general removing finer particles than equivalent grade silica sand. Furthermore, recycled glass was less likely to block or channel during filtration and required 30% less back-washing, when compared with sand. Its self-cleansing properties allow long-service life, with lower operating costs, whilst providing stable and consistent long-term effluent discharge levels.

However, only limited data exists on optimising the efficiency of recycled glass filtration media by varying critical performance parameters, such as particle size, effluent flow rates, back-wash regime, air scouring and combined filters having specific filtration tasks.

Filtration using less well specified crushed glass is reported as being less effective than sand but does have the additional benefit of reduced bio-fouling [28, 29]. Evidence also suggests that recycled glass filtration media can be used for high levels of suspended solids, up to 2000 mg/L.

Recycled glass can also remove Cryptosporidium oocysts and Giardia from water, using rapid gravity and pressure filters. Evidence suggests that recycled glass performs better than sand in terms of its removal of small particles from water, and therefore in terms of oocysts removal.[30]

In summary, the advantages of using processed recycled crushed glass in comparison to sand filters when applied to wastewater treatment filtration, are as follows:

- Reduce suspended solid load in discharge by up to 80%
- Minimise the discharge of chemical toxins
- Revenue costs savings due to the high performance and long term reliability
- No need for humus/clarifier sedimentation tank in tertiary wastewater treatment
- Surface permanent negative charge removes small particles, organic modules and positive ions such as iron and manganese
- The small amounts of chromium and other metals present in coloured glass have a catalytic effect on the treatment
- Smooth micro surface, which makes it less prone to contamination by fats, lipids and biological growth and also consequently ~50% less water is needed for back-flushing
- Recycled crushed glass does not contain free silica, therefore decreased potential of respiratory disease
- Improved treatment efficiency (by up to 30%, compared with sand)

The unique properties of recycled glass do, therefore, allow filtration systems to perform tasks that cannot be considered using sand, such as the primary filtration of sewage effluent[7]. Again, this new market offers great potential, but little detail concerning operating parameters and filtration performance is available at present for future exploitation.

2.6.2 Operational Parameters

Provisional design operating parameters for Grade 1[25] recycled glass filtration media for a variety of pressure filter applications[28] have been investigated[23]. Proposed effluent flow rates and back-wash regimes for sewage and industrial effluent, are as follows.

Performance	Effluent flow rate ($m^3/hr/m^2$)	Back-flush flow rate ($m^3/hr/m^2$)[(1)]	Back-flush duration (minutes)
Optimum	1 – 5	30 – 45	2 – 4
Maximum	5 – 10	40 – 45	4 – 8

1. Back-flushing every 4 to 6 hours.

Table 2.1 Typical operating parameters for processed recycled crushed glass.

These figures have not been fully qualified and are based on limited test results[4, 8, 9, 20] and unknown influent quality. However, this data provides a benchmark for developing the prototype system operating parameters. When using recycled glass, a 2 – 6mm gravel or Grade 2 (1 – 2mm) recycled glass bed should be used at the base of the filter.

A comparison between recycled glass (bed depth 30 cm and water flow rate 6 $m^3/hr/m^2$) and a moving bed sand filter (bed depth 2.5m and water flow rate 2$m^3/hr/m^2$) was undertaken on sewage effluent.[20, 21] Results indicated similar removal efficiencies for SS, BOD and COD. However, the sand filter was better in removing ammonium due probably to bio-fouling within the sand filters. Similar tests on brewery effluent using recycled glass showed that 6µm to 8µm particles were removed and COD levels were reduced by 70%.

Numerous operating protocols have been published[16, 23, 24], which indicate that SS, BOD and COD influent levels within standard constraints reduced to relatively uniform values, regardless of the influent levels. SS is reduced to between 2 – 12mg/L for influent values ranging from 14 – 70mg/L. Similarly, BOD is reduced to between 2 – 12mg/L for influent values from 14 – 70mg/L, and COD to 10 – 50mg/L from 50mg/L to 225mg/L.

For aquaculture applications[23], Grade 1 recycled glass within a filtration system having a flow rate between 5$m^3/hr/m^2$ and 15 $m^3/hr/m^2$removed particles down to 5µm. Furthermore, Grade 0 recycled glass removed particles down to 1µm at a flow rate less than 5 $m^3/hr/m^2$. Back flushing was performed twice daily.

Tiehm *et al* [32] demonstrated that a significant part of the waste water COD and phosphorous removal is related to the suspended solids and concluded that efficient removal of suspended solids is necessary to protect highly sensitive water courses.

There is no generalised approach to the design of full-scale filters, because of the inherent variability in the characteristics of the influent suspended solids to be filtered. The most effective method to ensure that the filter configuration selected for a given application will function properly is to conduct pilot plant studies. Due to the many variables that can be analysed, care must be taken not to change more than one variable at a time so as to confound the results. Testing should be carried out at several intervals, ideally throughout a full year, to assess seasonal variations in the characteristics of the effluent to be filtered.

Results from municipal potable water treatment[33] indicate that the filtration performance of glass was similar to that of sand having similar effective size and uniformity under all conditions tested with the benefit of taking 10-15% longer than the sand to reach particle breakthrough. It also found that glass expanded more than the sand under the same backwash water rates, which was seen as a potential benefit to installations that have low backwash water flow. Pre-treatment of the water with coagulant dosing was performed before the pilot-plant (gravity filter). Filtered water turbidity of less than 0.2 NTU were produced in all runs when filtration was stable.

2.7 Summary

Filtration is one of the processes used in tertiary treatment to improve the quality of wastewater and industrial effluent discharge to the natural environment, as it facilitates the removal of suspended matter and associated contaminants. Silica sand is the media normally used for this filtration but as sand is a naturally tenacious product, it suffers from bio fouling, which causes the filter to become quickly blocked with bacteria and particles. Filter performance then deteriorates and the treated effluent quality will not meet the required Consent to Discharge standards set by the Environment Agency (EA).

Even with extensive air scour and intensive backwashing regimes, the performance of silica sand remains poor over a continuous period. Owners of effluent treatment works that under-perform and fail the Consent to Discharge requirements have to either invest in new larger works or seek alternatives such as expensive main sewer connections or off-site treatment. A very large number of effluent treatment plants in the UK under-perform for a variety of reasons and cannot meet either the existing or future legislation requirements being implemented by the EA and European Union.

Research indicates that around a 30% improvement in filter performance can be achieved by simply changing from sand to recycled crushed glass filter media. Benefits include improved contaminant removal with no bio-fouling, reduced back-washing requirements and media longevity. Evidence suggests that environmental health, water quality and potential life cycle cost benefits through the use of recycled crushed glass as a filtration media are significant.

Further opportunities exist in primary sewage treatment, where filtration of effluent containing high levels of suspended solids is normally processed in large humus sedimentation tanks. If proven, capital cost savings could be substantial as pressure filtration systems are far less costly than alternatives, such as clarifiers and humus tanks.

Although published work has shown that recycled crushed glass can be utilised for effluent treatment, current published data, albeit limited, indicates that treated effluent performance levels can be increased to meet existing legislation. However, extensive development is required to reach future discharge standards, with proposed work being targeted on operational performance parameters, particle size and distribution, effluent flow rates, back-wash regime, air scouring and combined filters, for which there is limited published data.

3 Environmental Legislation & Life Cycle Analysis Review

3.1 Environmental Legislation

Environmental legislation relating to sewage and trade effluent discharge imposes a timescale and quality objective for treatment performance[7], in order to reduce the impact on the receiving environment.

As with most wastewater applications the performance criteria is set by the Urban Waste Water Treatment Directive (98/15/EC)[34] amending Directive (91/271/EEC)[34]. The Directive has requirements and sets standards for sewage treatment (see Table 3.1 and Table 3.2).

Parameters	Concentration	Min % of reduction (1)	Reference method of measurement
Biochemical oxygen demand (BOD at 20 °C) without nitrification (2)	25 mg/L O_2	70-90 40 under Article 4 (2)	Homogenized, unfiltered, un-decanted sample. Determination of dissolved oxygen before and after five-day incubation at 20 °C ± 1 °C, in complete darkness. Addition of a nitrification inhibitor
Chemical oxygen demand (COD)	125 mg/L O_2	75	Homogenized, unfiltered, un-decanted sample Potassium dichromate
Total suspended solids	35 mg/L 35 under Article 4 (2) (> 10 000 p.e.) 60 under Article 4 (2) (2 000-10 000 p.e.)	90 (3) 90 under Article 4 (2) (> 10 000 p.e.) 70 under Article 4 (2) (2 000-10 000 p.e.)	Filtering of a representative sample through a 0.45 µm filter membrane. Drying at 105 °C and weighing Centrifuging of a representative sample (for at least 5 mins with mean acceleration of 2 800 to 3 200 g), drying at 105 °C and weighing

1. Reduction in relation to the load of the influent
2. The parameter can be replaced by another parameter: total organic carbon (TOC) or total oxygen demand (TOD) if a relationship can be established between BOD5 and the substitute parameter.
3. This requirement is optional. Analyses concerning discharges from lagooning shall be carried out on filtered samples; however, the concentration of total suspended solids in unfiltered water samples shall not exceed 150 mg/L.

Table 3.1 Requirements for discharge from urban waste water treatment plants subject to Articles 4 and 5 of the Directive 98/15/EC.

However, it should be noted that these levels are baseline values and national environmental agencies are beginning to set tighter standards than stipulated under these directives.

The revised Directive of the European Parliament and of the Council concerning the Quality of Bathing Water COM(2002)581 concerns the quality of bathing water, with the exception of water intended for therapeutic purposes and water used in swimming pools.

Parameters	Concentration	Minimum % of reduction(1)	Reference method of measurement
Total phosphorus	2 mg/L (10 000-100 000 p.e.) 1 mg/L (> 100 000 p.e.)	80	Molecular absorption spectrophotometry
Total nitrogen(2)	15 mg/L (10 000-100 000 p.e.) (3) 10 mg/L (> 100 000 p.e.) (3)	70-80	Molecular absorption spectrophotometry

1. Reduction in relation to the load of the influent.
2. Total nitrogen means the sum of total Kjeldahl nitrogen (organic and ammoniacal nitrogen), nitrate-nitrogen and nitrite-nitrogen.
3. These values for concentration are annual means as referred to in Annex I, paragraph D.4I (Directive 98/15/EC). However, the requirements for nitrogen may be checked using daily averages when it is proved, in accordance with Annex I, paragraph D.1 that the same level of protection is obtained. In this case, the daily average must not exceed 20 mg/L of total nitrogen for all the samples when the temperature from the effluent in the biological reactor is superior or equal to 12°C. The conditions concerning temperature could be replaced by a limitation on the time of operation to take account of regional climatic conditions.

Table 3.2 Requirements for discharge from urban waste water treatment plants to sensitive areas which are subject to eutrophication as identified in Annex II.A(a) Directive 98/15/EC.

The quality requirements for bathing water include:

- Microbiological parameters (total and faecal coliforms, faecal streptococci, salmonella and enteroviruses PFU);
- Physico-chemical parameters (pH, colour, mineral oils, surface-active substances reacting with methylene blue e.g. lauryl sulphate, phenols, transparency, dissolved oxygen, ammonia and Kjeldahl nitrogen;
- Other substances regarded as indications of pollution (pesticides, cyanides, nitrates, phosphates and heavy metals i.e. arsenic, cadmium, chrome, lead and mercury).

Furthermore, the Dangerous Substances Directive (76/464/EEC)[34] and Daughter Directives now under the new Water Framework Directive (2000/60/EC)[34] for river basin management eliminate the discharge of List 1 substances and minimises the discharge of List 2 substances to the aquatic environment. List 1 substances are categorised by their toxicity and potential for bio-accumulation, while 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 standards (EQS). The Freshwater Fish Directive (78/659/EEC)[34] now also under the Water Framework Directive regulates designated stretches of water (rivers, lakes and reservoirs) to achieve a minimum standard for the protection of salmon, trout and coarse fish. Fourteen parameters were selected for control under this Directive, including BOD, dissolved oxygen, temperature, ammonia, chlorine, suspended solids, copper and zinc.

Impending legislative compliance[2] requires water companies to upgrade their sewage treatment works under the forthcoming AMP4 (see Section 2.1) water infrastructure and environmental improvements for the period 2005 to 2010. All water companies in the UK have received their final AMP4 determinations[2] from OFWAT, which stipulates discharge consent levels for each sewage treatment works targeted for improvement.

In Wales[35] and across the rest of UK, specific discharge consent levels for a number of the treatment works are very onerous, having typical values as follows:

BOD 4mg/L; SS 6mg/L; Phosphorous 1mg/L; Nitrates 15mg/L and Ammonia 3mg/L.

Future discharge consent levels will undoubtedly become stricter[34,36,37], with a 10, 5 and 2 mg/L specification for suspended solids, BOD and ammonia is becoming commonplace.

3.2 Life-Cycle Analysis Review

Life Cycle Analysis (Assessment) is a powerful tool used to inform decision making concerning policy and strategy, investment decisions, use of alternative materials/products, evaluation of alternative designs and marketing claim.

Life Cycle Analysis (LCA) is typically data intensive and involves a rigorous examination of all aspects involved in the manufacture, use and end of life of a product system. The LCA comprises an inventory of material and energy use ('inputs') as well as associated releases to air, water and land ('outputs') for each of the activities included in the 'life cycle'. The inventory data is then used to calculate impacts (actually 'impact potentials') to environmental concerns through the use of conversion factors, e.g. calculation of global warming impact arising from emissions of carbon dioxide, methane, nitrous oxides, etc.

In terms of glass recycling, the specific fuel usage per kg for recycled material decreases with increasing material recovery rate[35]. Recycling glass produces a reduction of over 30% in environmental loads. However, the extra loads due to collection reduce these savings by 3-5%. The energy saved by recycling glass reaches a maximum of 4 MJ per kg of produced glass at a recovery rate of 83%, with the optimum energy saving being achieved[39] at a UK glass recovery rate of approximately 83%.

During 2003, Enviros[40] completed a LCA of glass recycling on behalf of the British Glass Manufacturers Confederation. The aim of the study was to examine the various options for glass recycling and to compare these in terms of energy use and associated carbon dioxide emissions. The baseline scenario for this work assumed that all glass containers are used once and then land-filled. For each end use application, the life cycle carbon dioxide emissions were calculated for both virgin raw materials and recycled glass. CO_2 is the principal greenhouse gas and is the major contributor to global warming.

All sources of carbon dioxide were considered, including quarrying, raw material preparation, transport, product manufacture, recycled glass collection and recycled glass processing. Enviros[40] stated that closed-loop recycling of bottles and jars within the container sector deliver the best environmental benefit. Even when glass is exported to European containers manufacturers, closed-loop recycling delivers the greatest reduction in CO_2 emissions.

Based upon current glass recycling levels it is calculated that the use of recycled glass is currently saving approximately 186,000 tonnes of carbon dioxide emissions, of which 172,000 tonnes results from using the recycled glass to manufacture new glass. Carbon dioxide emissions are reduced by 314 kg/tonne of containers if recycled glass is used as a feedstock compared to the use of virgin raw materials, i.e. a reduction in emissions of 37%. This is because it requires less energy to melt recycled glass than it does to melt the constituent raw materials, and the breakdown of the raw materials in the melting process releases 'chemically bound' carbon dioxide. Furthermore, soda ash, one of the raw materials in glass manufacture, is a very energy intensive material to manufacture, but its use as a raw material is avoided when recycled glass is used.

Although the greatest environmental benefits would result if recovered glass were used as a feed stock in new glass manufacture, this is not possible in the UK due to the colour imbalance between recycled glass (which is mainly green) and the UK container manufacturers (which produce mainly clear glass). Thus other outlets for the remaining recovered glass are necessary.

There are two environmental benefits common to all glass recycling applications[40]:

- Glass recycling removes a significant quantity of material from the waste stream that would otherwise go to landfill. If all UK container glass was recycled then this would avoid the disposal of some 2.2 million tonnes of waste glass.

- In most cases recycled glass substitutes a virgin quarried material. There are the benefits associated with avoiding the environmental impacts of quarrying and processing the raw material.

Source materials	Virgin sand	Recycled glass	Assumptions
Extraction of sand	2	-	Sand is extracted with very little processing
Reprocessing	-	10	Recycled glass for this application is highly processed requiring crushing, classification and washing
Transport to reprocessor	-	16	Identical collection, bulking and transport to glass container manufacturing
Transport to end user	18	21	Sand delivered directly on site.
Collection and transport to bulking site	-	3	Assumed kerbside collection with a 5 tonne load moved 15 miles i.e. journey of 7.5 miles no return load.
Transport from bulking station to glass re-processor	-	13	Recycled glass per tonne based on average haulage distance of 150 km 25 t loads.
Transport to final disposal	2	2	Assume that filtration media is disposed to landfill at the end of life
CO_2 equiv. for life cycle	22	65	
Net effect of substituting recycled materials for virgin		43	

Table 3.3 Carbon Dioxide LCA Emissions for Filtration Media (kg CO_2 / tonne of media)

Evidence shows that there is a net increase in CO_2 emissions from using recycled glass filtration media instead of sand resulting from the higher processing requirements for glass and the transport energy use associated with collection[37] However, this analysis does not take into account any potential life cycle benefits associated with the wider health benefits provided by a possible superior performance of glass, and the reduced pumping energy and reduced flocculent use. At this stage there is no information available on these possible benefits but they could be considerable.

Membrane filters are generally expensive[3] and a standard membrane system for tertiary treatment can cost upwards of £10,000 to £30,000 for small sewage treatment works. Competitors in the packaged sewage treatment plant market have already identified the market potential and are marketing products based on expensive filter membrane technology. Initial quantifiable cost analyses[41] show that utilisation of recycled glass filter media is approximately half the cost of membrane equivalents.

3.3 Discussion and Conclusions

Environmental Legislation is continuing to tighten up on the requirements for discharge consent of sewage and trade effluent. This requires water companies and manufacturing industries to rethink their strategies over the next five years to respond to these demands.

There is a massive programme underway within the water industry to improve most of its sewage treatment works, paying attention to the new requirement for reducing phosphorous and nitrates.

The manufacturing industries, focused in this project, i.e. food and paper, are becoming more and more aware of these stricter requirements as the bills increase for discharging their waste into the sewers. Although there is reluctance for installing treatment works on site, this is a golden opportunity to tell this industry about the benefits of treating their effluent, using RGM, to either reduce or totally eliminate their high discharge charges.

Environmental legislation continues to dictate maximum effluent discharge levels, and promotes stringent guidelines to industries. Industry is becoming increasingly aware of the need to reduce waste discharge levels as charges impose large financial penalties. Responsible action requires improved waste regeneration by industry, to reduce environmental impact.

4 The Trials

4.1 Sites

4.1.1 Slimbridge Wildfowl & Wetlands Centre, Gloucestershire

The first trial unit was installed at the Slimbridge Wildfowl & Wetlands Centre, in Gloucestershire. The centre was founded in 1946 by Sir Peter Scott and is now part of the Wildfowl & Wetlands Trust, which has some 10 centres across the UK. The Slimbridge centre has a multitude of ponds for all manner of water birds, from geese to flamingos, and is famous for its numerous swans.

The water for these ponds is abstracted mainly from the nearby Gloucester and Sharpness Canal. The Centre Manager was concerned with the quality of the water flowing through the site, in particular in the swan and flamingo ponds, where there is very little flow and a large quantity of detritus from the birds.

Fig 4.1: Chilean flamingos in their pond

Fig 4.2: Gloucester and Sharpness Canal

The water from the ponds is currently discharged via extensive reed beds into the River Severn. The Environmental Agency test this discharged water regularly and the pollution levels are within the allowed limits.

It is the Centre Manager's aim to:

- clean the water sufficiently so that it may be returned to the canal from whence it came,
- to locally improve the water quality in the individual ponds. There is a 10 year-plan to clean up and reconfigure all the ponds so that flow through the site is improved and stagnant areas reduced, if not completely removed.

The trial unit was installed on 22nd February adjacent to the Chilean flamingo house (see Fig 4.3), and the operational phase began on the 17th March 2005.

Fig 4.3: Front view of the trial unit on site, adjacent to the Chilean flamingos house.

Fig 4.4: Back view of the trial unit.

During the course of the trial, the liquor from the ponds varied in quality, partly due to the seasonal activity of the flamingos and whether they were kept in their house or allowed to move freely around their extensive ponds. Also, members of staff clean out the ponds by hand on a regular basis. This causes significant variations in the quality of the water.

The "liquor" is pumped from the pool adjacent to the flamingo house into a balance tank (See Fig 4.5, shown in green) and then into the unit for treatment.

The treated liquor is then pumped back into another part of the same pool (Fig 4.5). At prescribed times, the treated liquor is used to backwash the filters before being discharged into the same pool. The treated water and backwash liquor return to the same pond because there was no facility for sending the flow further; and, as the trial time was short, the client preferred not to have pipes crossing thoroughfares into another pond.

Fig 4.5: View and Description of the unit on site

4.1.2 SCA Packaging at Histon, Nr Cambridge

SCA Packaging is part of SCA, a worldwide company (based in Sweden), providing packing solutions for industry.

The factory at Histon manufactures various grades of corrugated cardboard, which involves the gluing of continuous cardboard strip. The main application for these products is in the food and drinks industry.

Fig 4.6: Paper rolls for the corrugating process

Fig 4.7: Corrugating process

The effluent being treated comes from the liquor, which is washed down when the cardboard manufacturing plant is stopped for maintenance, at least once a day, and every Friday, when there is a major wash-down.

This liquor is discharged to a collection chamber, which is approximately $10m^3$ in size, the pH is adjusted and the liquor is then released into the sewer. The quantity of effluent, which flows into the sewer, is about 1900 m^3 per year.

The existing liquor treatment provides for settlement of solids in a chamber, with flocculent aids, prior to overflowing into the drain.

Fig 4.8: Gluing process on the corrugated cardboard

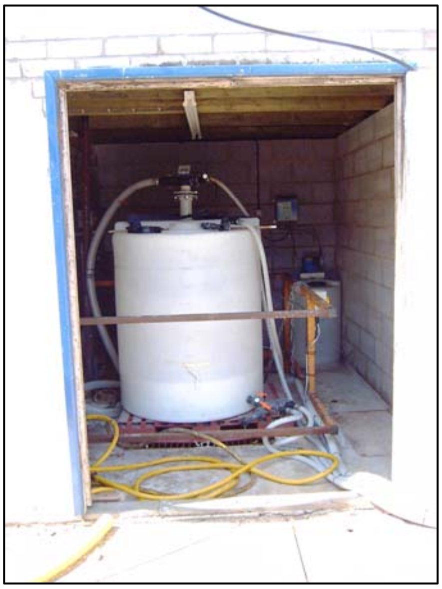


Fig 4.9: WDS balance tank on the top of the Collection Chamber

Fig 4.10: Sample of SCA white effluent

The effluent has a very high suspended solids concentration, which includes cardboard particulates and solidified starch based glue (see the white liquor sample in Fig 4.10); this creates a waste discharge problem for the site, particularly during the summer months. The Environment Agency has frequently tested the outflow and found solids in suspension, which exceed the discharge consent limits.

The purpose of the filtration trials was to:

- reduce the charges for discharging effluent with high solid contents;
- to establish whether discharge consents could be met more reliably.

The trial unit was delivered to Histon and installed on 24th March, commissioned on 29th and the operational phase commenced on 30th March.

Fig 4.11: The WDS plant on the SCA site

4.1.3 Premier Foods at Long Sutton, Lincolnshire

The Premier Foods plant at Long Sutton processes many different food products such as baked beans, preserved fruits in syrup, sauces, etc. This site is the head office of the Premier Foods Company, which has 8 other food process plants across the UK.

Fig 4.12 & 4.13: Processed food assembly line.

Fig 4.14: Water sample from the Premier water plant (pink colour due to rhubarb).

The factory currently discharges very large quantities (some 150 m^3/hr) of treated effluent through some 2 miles of pipes into the local river. The factory has its own extensive treatment works on site, which improves the quality of the effluent considerably.

Fig 4.15: Balance tank

The effluent is first cleared of remaining solids through a static run down Solids Screen, and is collected in a Balance Tank before being passed on for further treatment (the raw effluent is aerated at this stage). From these storage tanks, the effluent is forwarded to two Primary Clarifiers, to remove particulate and colloidal solids, and flocculent suspensions. Primary sludge from this process is transferred to the centrifuge plant where it is thickened prior to disposal. This is used as a soil enhancer in a similar way to peat.

After the Primary Clarifiers, the effluent enters the Conditioning Tank, where the pH is automatically adjusted for the next stage, namely the Anaerobic Digester, Up-Flow Anaerobic Sludge Blanket (UASB) reactor. The wastewater passes through a blanket of naturally formed bacterial granules. The bacteria metabolise the pollutants and natural convections lifts a mixture of gas, treated effluent and sludge granules to the top of the reactor. The three phases of gas, sludge and treated effluent are separated.

The biogas generated is used in a boiler that is connected to the reactor to maintain the operational temperature between 35-37ºC. The sludge remains in the tank until it has reached a certain level at which time it is bled off to the centrifuge for thickening prior to disposal.

After the digester, the treated effluent passes with the sludge granules into a series of tanks for aeration treatment to break down the remaining BOD and to increase the oxygen content in the water. This is a two-step system of flash aeration followed by standard aeration in open top tanks.

Fig 4.16: Anaerobic digesters in the water treatment plant on Long Sutton site

Any remaining solids are settled out in a secondary clarifier after the addition of flocculants. Solids from the secondary clarifier stage are reused to re-seed the digester plant. Any sludge surplus to requirements is transferred to the centrifuge for thickening. The treated effluent is then transported to a final holding tank prior to its final discharge.

All of the treated water is currently piped to the river.

Fig 4.17: Secondary Clarifiers to settle remaining solids

The WDS trial unit treated a small part of the effluent discharged to river, to investigate whether the unit could improve the quality of the effluent sufficiently to be able to pass it through the Reverse Osmosis plant for processing in place of the currently processed mains water for onward use in the boilers.

Fig 4.18: The trial plant on site.

Fig 4.19: The trial plant and the raw water collection point.

4.2 Plant

4.2.1 Design

The Generic Trials Filter Package (GTFP) was designed to provide the basic effluent treatment facility to enable a range of trials conditions to be implemented and for respective results to be established and recorded for filtration performance of recycled glass primarily as a replacement for sand.

The completed detailed design is shown in two documents, which are referred to in this section:

- Process & Instrument Diagram **Appendix 1**
- Outline Process Flow Diagram **Appendix 2**

Fig 4.20: Exterior view of the trial plant

Fig 4.21: Interior view of the trial plant.

A benchmark was established using the GTFP with filter F2 (see **Appendix 2**) charged with traditional filtration sand. Filter F1 was to be charged with a selection of available filtration grades of recycled glass (RGM) for trials & comparison.

Three GTFP units were constructed for use on the trial sites where there was a known filtration requirement and/or "challenge". The performance of each media was measured and recorded from pressure, flow and turbidity analysers. The measured values were stored in the control system data acquisition tool from where it was down loaded remotely for analysis and trend line monitoring.

The control and monitoring system was accessible remotely for responding to alarms, regular monitoring, and to assist client or WDS engineers during on site repairs and maintenance.

Samples of the control screens, which were used for these tasks, are provided in **Appendix 7**. These show a real time "snapshot" of the control settings for the Premier Foods unit at 9.00am on Wednesday, 6th July, 2005.

4.2.2 Equipment

- The equipment comprises:
- Balance Tank
- Raw liquor pumps
- Filter vessels & multiport control valves
- Ultra violet sterilizers
- Treated water collection tank
- Backwash water (treated water) pump

Fig 4.22 : white balance tank (in Premier & SCA), green tank in Slimbridge

Fig 4.23: Raw liquor pumps, UV sterilisers; filters 1&2

Fig 4.24: UV sterilizer

Fig 4.25: Control Panel & Treated water tank

The balance tank provided storage of the untreated influent liquor to ensure a representative nominal quality and also to maintain a constant head to the raw liquor pumps. The raw liquor pumps were configured to provide specific flow to each filter vessel. A variable speed device to produce a constant flow to the filter, from which the filter performance was derived, controlled the pump motors.

The filter vessels were selected to provide a known cross section area (CSA). This known area enabled the optimum and resultant flows to be regulated. The selected vessels had a CSA of $0.1m^2$. Therefore optimum flows of 1 to $10m^3/m^2/hr$ (m/h) were achieved by controlling the pump flow to between 0.1 and 1.0 m^3/hr.

The multi-port valves are mounted on the filter vessels for the purpose of achieving the three functions required:

- Online flow
- Back wash (reverse flow) to drain
- Rinse flow (in online direction) to drain

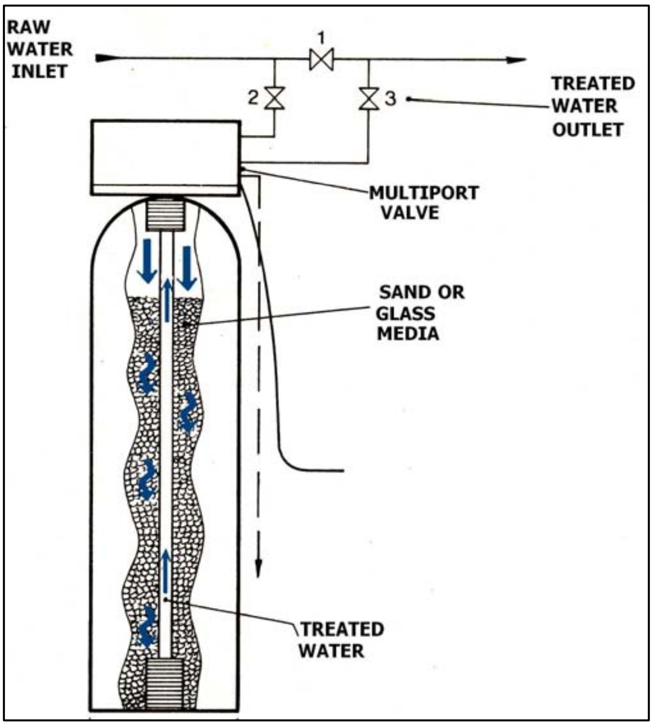


Fig 4.26: Filter vessel principle

The Ultra Violet sterilizers (UV) were located in the treated water flow from the filter vessels. The purpose of the sterilizers was to control the potential for bacteriological build up in the treated water storage. This provided water for backwashing, which would not introduce bacteria into the filter media.

The treated water collection tank was selected to store sufficient volume of treated water for use as the back wash water. The tank was equipped with an overflow above the required volume. The overflow discharge was the recovered water or water of improved quality for discharge to drain.

The backwash water (treated water) pump provided clean water to backwash each filter vessel in turn. A variable speed device provided an optimised flow rate to control the pump motor. This was also a function of the cross section area of the filter vessels, i.e. 30 to 45 m/h = 3 to 4.5 m^3/hr.

4.2.3 Control System

The control of the whole package is achieved from a single control panel, which includes:

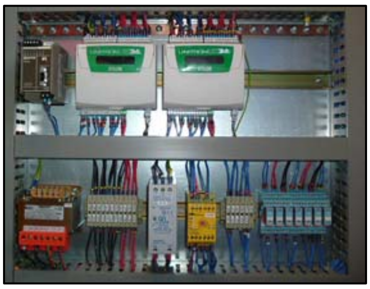
- Power protection devices
- Programmable logic controller (PLC)
- Data acquisition system
- Remote access / telemetry module
- GSM modem for dial out & dial in services.
- Analysers displays & control inputs
- Control outputs
- Start / stop controls
- Emergency stop circuit

The PLC is an integrated system, which comprises all of the elements of logic control, data acquisition and telemetry. The GSM modem facilitates installation in a location where a landline facility cannot be provided.

The analyser displays in the panel are those, which were not located on the analysers themselves. All analyser and instrument control loops were brought into the control panel to provide inputs to the PLC in order to condition control outputs.

Fig 4.27: Control Panel front

Fig 4.28: WDS engineer working on the Control Panel



Figs 4.29 & 30: views of interior details

The control outputs provided the conditioned outputs to control:

- Raw liquor tank level control (operating a transfer pump or valve from the source)
- Raw liquor pump speed
- Filter vessel backwash control frequency & duration
- Backwash pump speed control
- Treated water sample manifold changeover flow control

4.2.4 Instrumentation

The control & monitoring instrumentation comprised:

- Raw liquor tank level control (Ultrasonic – giving an analogue signal to the control)
- Two Raw liquor flow instruments (Magflow flow – giving an analogue signal to the control)
- Four Pressure instruments (Transducer – giving an analogue signal to the control), positioned in the inlet and outlet stream of each filter.
- Two Sample stream flow switches (Variable area visual flow indicators – magnetic float / reed switch giving a digital open/closed signal to the control)
- Two Turbidity analysers (Optical sensor – giving an analogue signal to the control)
- Treated water tank level control (Ultrasonic – giving an analogue signal to the control).

4.3 Operational Parameters

4.3.1 Filtration Media

4.3.1.1 General

An investigation was carried out into the “supply chain” for the recycled glass in terms of quantity and quality, including any difficulties related to supply.

During the course of the contract, various glass suppliers were contacted, requesting them to provide relatively small quantities of glass, i.e.125 kg, for use in the trials. Several supplies indicated that this should present little difficulty. However, it became more difficult to acquire glass as the contract proceeded.

Some of the suppliers would only supply their glass in 1 tonne loads, whilst others promised to and later could or would not supply the required glass. There was a general reluctance to provide small quantities of glass and most suppliers stated that they considered it unlikely that there would be a demand for their glass to be used as filtration media.
Most of the suppliers contacted were providing recycled glass for other industrial applications, e.g. the abrasives industry and decorative paving, i.e. the higher cost end of the market.

Eventually, glass was acquired from 4 suppliers in various grades. Since the properties of AFM from Dryden-Aqua have been well documented over the last few years, it was agreed with WRAP that these trials would concentrate on the other supplied recycled glass.

With that in mind, AFM was used in the first month of the trial at Slimbridge, but at the other two sites and all subsequent media changes, the other three suppliers of RGM were used.

The three suppliers used were Allglass, Recycled Glass Group and Krysteline Glass.

Glass Technology Ltd, who was nominated by WRAP, tested samples of all the various grades of RGM used during the trial. The results of these tests, which were based on the requirements of PAS 102, Clause 7 (Processed container glass as water filtration media), are provided in **Appendix 6**. The photographs of the various RGM samples on the following pages include the sample references numbers for those tests. Table 4.1 below provides details of the reference numbers of the samples tested:

SAMPLE No	SUPPLIER	SIZE
1	All Glass	1.0 – 2.0 mm
2	All Glass	0.5 – 1.0 mm
3	Krysteline	0.75 – 1.5 mm
4	Krysteline	0.25 – 0.75 mm
5	AFM	0.5 – 1.0 mm
6	GRG	0.2 – 0.5 mm
7	GRG	1.0 – 2.0 mm
8	GRG	0.5 – 1.0 mm

Table 4.1: List of Glass Samples Tested by Glass Technology ltd

The overall conclusions from this independent evaluation by Glass Technology Ltd were that:

- None of the samples fully complied with PAS 102:2004 section 7
- All the samples were of relatively good quality except for samples 4 & 7
- Only two of the samples complied with the requirements for particle size
- Only two samples (different to the above two samples) complied with the requirements for colour.

4.3.1.2 AFM (Dryden-Aqua)

This material has been the recognised market leader in the field of filtration media for some time and it is therefore considered unnecessary in this report to comment further on its properties.

Grade 1 (0.5 – 1.0mm) AFM was used in the first filter vessel at Slimbridge as the benchmark used alongside sand in the second filter.

Fig 4.31: AFM (0.5 – 1.0 mm) sample 5. Green. (The pencil serves as a scale).

4.3.1.2 Allglass Reprocessors Ltd

Allglass Reprocessors (UK) Ltd operate a glass grains plant at their headquarters in Linwood producing specifically sized glass grains, dried and bagged to order. They handle both container glass and clean plate glass ensuring that these different sources of material are used in the most appropriate end markets.

This company supplies a variety of products related to the recycling of glass, including industrial and decorative products for use in the building, manufacturing and services industries. Among these are abrasives, flooring and building products, as well as a range of landscaping materials such as decorative aggregates, and resin bound surfacing.

Glass from this company was used exclusively in the WRAP operational trials carried out recently by Aqua Enviro. However, within this contract, just two grades of their glass were used, both at the SCA Histon site. Their glass is normally specified by size rather than PAS 102 grade and the two sizes used were 0.5 – 0.75 mm, which is nearly equivalent to Grade 1 and 0.75 – 1.25 mm, which is equivalent to Grade 2.

Fig 4.32: AllGlass (0.5 – 1.0 mm) sample 2. Brown.

Fig 4.33: AllGlass (1.0 – 2.0 mm) sample 1. White.

4.3. 1.4

This company provides glass for a wide selection of applications, including grit blasting, resin bonded surfaces, filtration, decorative , horticultural , paint fillers, concrete, fluxing agents, fibre glass insulation, reflective paint, cementation and anti-fouling treatments.

Their filtration media is available in several sizes and three were used during this trial, 0.25 – 0.75 mm (fine – Grade 1), 0.75 – 1.5 mm (medium – Grade 2) at the Premier Foods site and 3.0 – 8.0 mm (gravel) at Slimbridge.

Fig 4.34: Krysteline (0.75 – 1.5 mm) sample 3. Grey.

Fig 4.35 : Krysteline (0.25 – 0.75 mm) sample 4. Grey/Brown.

4.3.1.5 Glass Recycling Group Ltd

This company produces a wide range of reprocessed glass products for the industrial and leisure industries, including brick making, ceramics (sanitary ware), grit blasting, sports turf, golf bunker sand, fibreglass and filtration media.

The filtration media is available in three different sizes, 0.20 – 0.70mm (Grade 0), 0.70 – 1.50mm (Grade 1) and 1.50 – 3.00mm (Grade 2), all of which were used at some stage during the trials at Slimbridge.

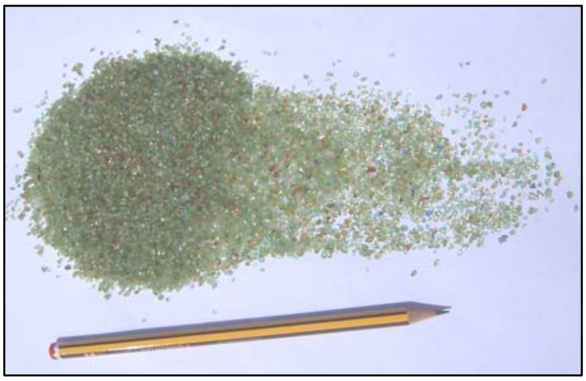


Fig 4.36: GRG (1.0 – 2.0 mm) sample 7. Green.

Fig 4.37: GRG (0.2 – 0.5 mm) sample 6. Green.

Fig 4.38: GRG (0.5 – 1.0 mm) sample 8. Green.

4.3.1.6 Cost Analysis

The quantities of RGM used in these operational trials were very small, i.e. each filter required some 125 kgs of glass. This meant that only small amounts were purchased and the benefits of buying in bulk were not available.

However, the suppliers' prices for supplying a minimum of one tonne of RGM, excluding the cost of transportation, varied widely from £120 to £550 per tonne.

4.3.1.7 Sand Filter Media

Both the sand grain size and depth of bed are important factors when using sand as a filter media, each having an effect on the bacteriological and physical water quality. The recommended effective size of sand used for sand filters should be in the range of 0.15 – 0.35mm, and the uniformity coefficient should be in the range of 1.5 – 3; although a coefficient of less than 2 is desirable.

In sand filtration, the vertical height of the sand bed that the water has to pass through is another important factor in terms of filtration efficiency. The reason for this is the existence of biological activity in a sand filter, which is known to occur at depths of up to 0.5m within a sand bed.

The depth of the sand bed in a sand filter must therefore reflect this zone of biological activity. In coarser sands, an increased sand bed depth may also contribute to better filtration. Greater surface area provides a more intimate contact between the constituents of the raw water, thus speeding up chemical reactions (surface catalysis), and normally using a smaller-grained sand increases the surface area. However, the surface area could equally well be increased by increasing the depth of the filter bed but, when it is noted that a depth of 0.6 m of sand comprising grains of 0.15 mm effective diameter presents the same surface area as a depth of 1.4 m of sand of 0.35 mm grains, it is obvious that the application of finer sand is economically a better method.

The sand used in the filters for all three trial sites was 0.5 – 1.0 mm in the top section, 1.0 – 2.0 mm in the central section and 2.0 – 6.0 mm gravel in the bottom section as a support layer. The flow through the filter is downwards as shown in Fig 4.26.

Fig 4.39: Sand (1.0 – 2.0 mm) sample.

Fig 4.40: Sand (0.5 – 1.0 mm) sample.

4.3.2 Operational Regime

In this section, the operational parameters of the trial unit, i.e. the filtration media in each filter, the flow going into each filter, and the backwash regime are presented.

Media

The filtration media utilised during the trials is outlined below.

Filter 1	Filter 2	Start Date	Comments
AFM (0.5 – 1.0 mm)	Sand	17 March	The sand is tested as a benchmark
GRG (0.5 – 1.0 mm)	Sand	3 May	This was carried out on date shown
GRG (1.0 – 2.0 mm) (2/3) + GRG (0.2 – 0.5 mm) (1/3) + Krysteline glass (3.0 – 8.0 mm)	Sand	2 June	(1.0 – 2.0 mm) size in bottom two thirds with (0.2 – 0.5 mm) size in top one third of vessel

NOTE 1 – the sand media always consisted of a mix, from the top to the bottom:
(0.50 – 1.00 mm) sand, (1.00 – 2.00 mm) sand & (2 - 6 mm) gravel, which is the standard configuration for a sand filter.
NOTE 2 – if not specified, the bottom of the filter always consisted of (2 - 6 mm) gravel.

Table 4.3: Schedule of media at Slimbridge

Filter 1	Filter 2	Start Date	Comments
Allglass (1.0 – 2.0 mm)	Sand	5 April	The sand is tested as a benchmark
Allglass (0.5 – 1.0 mm)	Sand	6 June	This was carried out on date shown

Table 4.4: Schedule of media at SCA

Filter 1	Filter 2	Start Date	Comments
Krysteline (0.75 – 1.5 mm)	Sand	15 April	The sand is tested as a benchmark
Krysteline (0.25 – 0.75 mm)	Sand	19 May	This was carried out on date shown

Table 4.5: Schedule of media at Premier Foods

Flow

The trial units have been designed for a nominal flow of 1 m^3/hr going into the filters. However, the flow coming through them was not constant at the set up value: when the filters were operating efficiently, they became blinded because of the accumulating suspended particles retained in the media, which in turn reduced the flow rate. After the backwash, the solid particles were removed and the filters became clear again and the full flow could run through the filter.

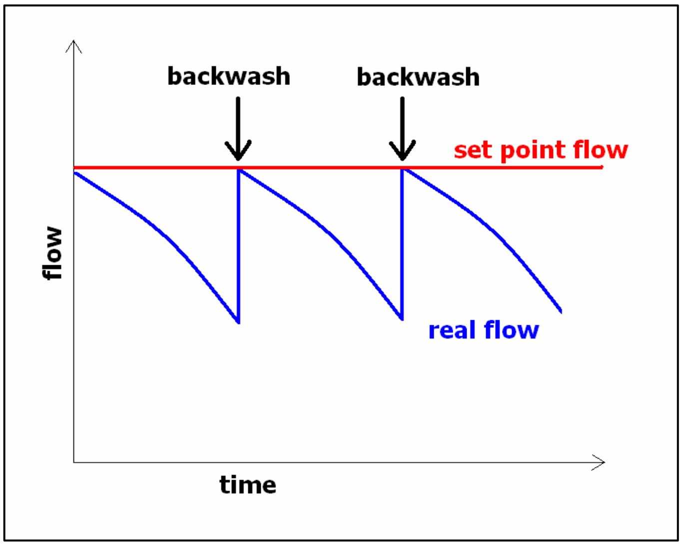


Fig 4.41: Flow variables principle

The effective flows running through the filters were measured remotely and are presented with the results in section 5.

Backwash

The backwash regime was chosen to suit the water quality entering the units (Suspended Solids concentration and COD), as it was different on each site. The direction of the backwash is upwards, i.e. in opposite direction to normal flow, as shown in Fig 4.26.

Backwash rates were changed during the trial periods to test the influence of the backwash frequency on filter efficiency. Indeed, too low a backwash frequency did not clean the media properly and it became blinded more quickly; whereas with too high a frequency energy was wasted. So the optimum backwash frequency had to be found for a maximum efficiency of the filters with minimum energy consumption.

Slimbridge		
date	**backwash frequency**	
	F1	**F2**
14/3	12 hrs	1hr
23/3	4 hrs	4 hrs
3/5	4 hrs	3 hrs
14/5	4 hrs	12 hrs
10/6	6 hrs	6 hrs

SCA		
date	**backwash frequency**	
	F1	**F2**
1/4	6 hrs	6 hrs
15/4	10 hrs	10 hrs
29/4	10 hrs	10 hrs
10/6	10 hrs	10 hrs
16/6	10 hrs	10 hrs

Premier Foods		
date	**backwash frequency**	
	F1	**F2**
22/4	6 hrs	6 hrs
9/5	4 hrs	4 hrs
20/5	6 hrs	6 hrs
7/6	4 hrs	4 hrs

Table 4.6: Schedule of backwash regime.

Testing

To measure the efficiency of the media (glass and sand), water samples were taken from the inlet and outlet of each filter during the trial period. The sample points are shown on the "Process & Instrumentation Diagram" in **Appendix 1.** The inlet sample point is noted SP1, the outlet is SP2

There was only one sample point for the outlet, but it was used for both filters, because the filter being tested could be chosen manually. When taking water samples, the operator switched the control panel to "Filter 1", waited several minutes, and then took the sample; switched it to "Filter 2", let it run for several minutes, and took the second sample.

As described in the following section, there was also a remote control system that analysed the plant running continuously.

4.3.3 Sampling and Testing Regime

The remote control system enabled the flow and the pressure in each filter, together with their running time between backwashing, to be adjusted (in real time). The data was usually collected once a week for analysis. Data for some weeks is missing because of site operational difficulties, e.g. pump blockages.

The remote control system also measured the suspended solids concentration (in ppm) at the inlet and outlet of the unit

The water samples (taken as described above in section 4.3.2.4) were sent to a NAMAS approved laboratory, which measured the suspended solids, the COD, the pH and the ammoniacal nitrogen in the water.

The laboratory, which carried out theses analyses, was at the Staffordshire County Council Scientific Services department. All samples were tested there, except for those from the Premier Foods plant in Long Sutton, which has its own modern laboratory on site. It was agreed with WRAP that all samples on this site would be tested in that laboratory.

5 Results and Discussion

Introduction

The laboratory analysis measured the following parameters: Suspended Solids and COD. The remote controlled data enabled the actual flow going through the filters to be identified for the days the water samples were taken.
To compare the different media (glass or sand), the same experimentation procedure was used for both filters for the trial periods.

During the course of the project, it became apparent that at both Slimbridge and SCA Histon, the quality of the influent varying widely. This was particularly demonstrated when the RGM was changed from AFM to GRG in Filter 1 at Slimbridge after the first month, when the level of suspended solids within the liquor being treated increased some threefold and the COD by nearly the same. It would therefore not be a true comparison of RGM filtration performance if the measurement had been just in terms of solids removed, i.e. in mg/L.

It was therefore determined that the fairest method of comparing the performance was to measure the efficiency of removing both SS and COD, i.e. the percentage of SS or COD removed, using the influent level as 100%.

5.1 Slimbridge

Filter 1 was initially charged with AFM grade 1 (0.5-1.0mm) glass, which was supported by a normal gravel bed. After six weeks, this was taken out and recharged with another grade 1 glass, this time from GRG. After a further four weeks, this was changed again, this time with a “mix” of RGM (see Section 4.3.2.1)

The laboratory data is presented in **Appendix 3**.

5.1.1 Suspended Solids

The average removal efficiency rates for suspended solids were:

	Filter 1	Filter 2
Period 1	AFM grade 1	sand
SS efficiency removal rate (%)	95.6%	94.3%
Period 2	GRG grade 1	sand
SS efficiency removal rate (%)	98.0%	68.7%
Period 3	GRG mix	sand
SS efficiency removal rate (%)	76.8%	49.2%

Table 5.1: SS average removal at Slimbridge

The performance for SS in the first period for both filters was very high, i.e. >94%, which was expected because both filters were new.

In the second period, the efficiency of the GRG grade 1 glass improved to 98% even though the influent SS levels were some five times higher whilst the sand deteriorated by 25%

In the third period of the trial, when the influent concentration was similar to the first period, the performance in filter1 , where a mix of graded RGM was used, was reduced by nearly 20%, whereas the sand in Filter 2 was 45% worse than during the first period.

The conclusion from this part of the trial was that the glass media from the two different suppliers was working with more or less the same efficiency, but the sand filter was deteriorating.

Fig 5.1 shows the variation of the suspended solids removal rate, for the three periods of the trial.

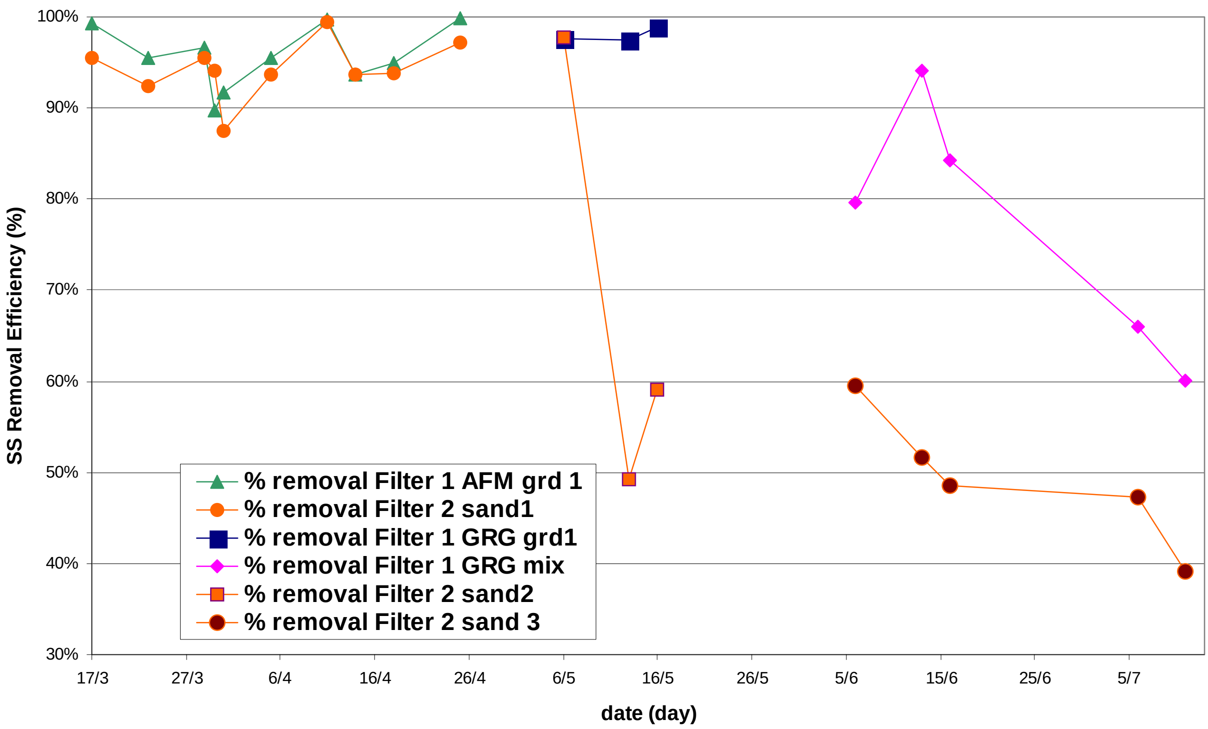


Fig 5.1: Suspended solids Removal efficiency at Slimbridge

5.1.2 COD

The results for the average removal efficiency rates for COD are shown in the following **Table 5.2**.

	Filter 1	Filter 2
Period 1	AFM grade 1	sand
COD efficiency removal rate (%)	56.7%	57.3%
Period 2	GRG grade 1	sand
COD efficiency removal rate (%)	91.0%	63.2%
Period 3	GRG mix	sand
COD efficiency removal rate (%)	56.0%	34.2%

Table 5.2: COD average removal at Slimbridge

The performance improved considerably when the RGM was changed for the second period of the trial: from about 50% to about 90% for COD removal. However, the COD in the inlet increased as well: from a 78 mg O2/L on average for the first test period to 700 mg O2/L for the second period.

However, the performance of the sand filter for removal of COD remained about the same. As the sand is the same for the two periods, it can be seen that the filtration efficiency increased with the inlet COD concentration. Indeed, the media performed better with a higher COD inlet.

Comparing the RGM and the sand, there was no significant difference for the first period, i.e. the sand removed 1% COD more than the AFM glass but for the second period, the GRG glass performed far better than the sand.

In the third period of the trial, when a mix of glass was used in Filter 1, the performance in COD removal was similar to that in the first period when the influent quality was comparable, whereas the sand in Filter 2 was over 20% worse than during the first period.

It is likely that COD removal rates were directly related to the removal of SS, in that the COD was probably contained or attached to the SS.

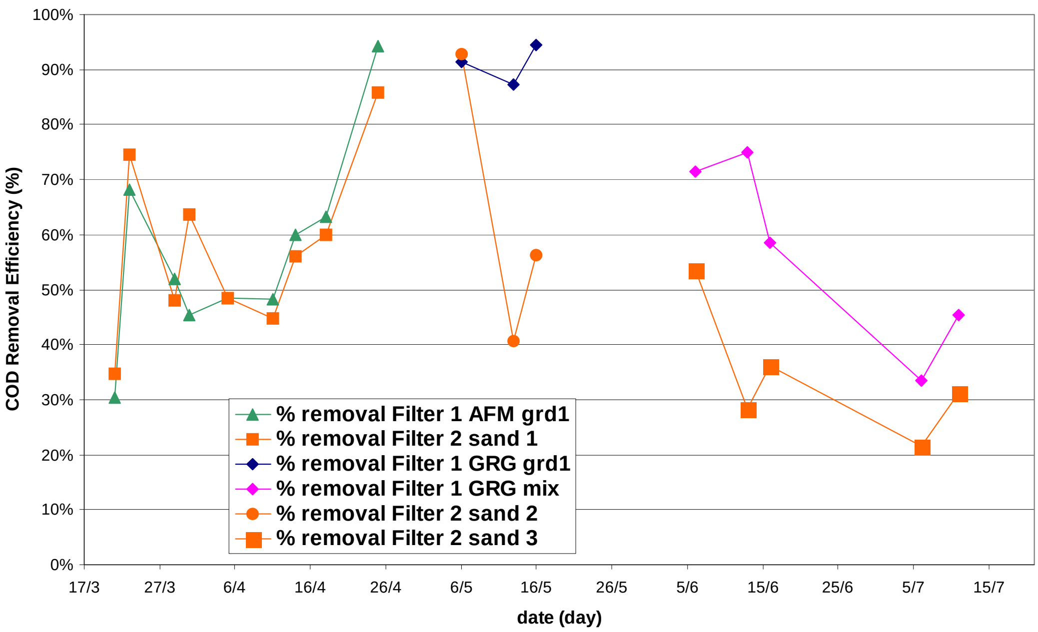


Fig 5.2: COD Removal efficiency at Slimbridge

5.1.3 Discussion

The SS and COD levels of the influent were significantly affected by the inclusion of a "balancing tank" prior to its being pumped into the trial unit for treatment. (see Section 4.1.1, Fig 4.5) This tank was used to ensure that there was a steady flow of liquor into the unit during the trial.

However, in the warm weather, particularly, the bacterial growth within that tank was enhanced and both the SS and COD values were increased some three to four times. (see Table 5.3) However, the levels of the treated liquor still remained low despite this phenomenon, which emphasised the performance of the RGM even further.(see **Appendix 3**)

Suspended solids (mg/L)		
DATE	**pond**	**S1 inlet**
Average	**162**	**836**
21/3	44	80
23/3	54	66
24/3	34	45
29/3	47	90
30/3	38	68
31/3	52	48
4/4	59	30
5/4	410	110
11/4	400	2000
13/4	130	240
18/4	160	80
20/4	170	130
25/4	220	770
26/4	360	210
27/4	450	74
11/5	140	8100
16/5	110	3300
17/5	110	110
27/5	85	340

COD (mg O2/L)		
DATE	**pond**	**S1 inlet**
Average	**76**	**222**
21/3	40	46
23/3	38	94
24/3	66	46
29/3	38	50
30/3	40	18
31/3	64	44
4/4	46	34
5/4	126	66
11/4	110	58
13/4	62	66
18/4	80	60
20/4	76	54
25/4	82	240
26/4	118	106
27/4	140	54
11/5	98	2000
16/5	70	900
17/5	94	88
27/5	50	188

Table 5.3 Comparison between Samples taken from Pond & Balancing Tank (S1 Inlet)

If the management at Slimbridge decides to use this or a similar process to clean the water in their ponds, the balancing tank would not be used and the above situation would not arise.

In the early stages of the trial, the sand and the RGM performed equally well. However, when the glass media was changed after 6 weeks, the glass performed even better but the sand began to deteriorate and did not recover after backwashing.

5.2 SCA Histon

Two types of glass were tested at SCA, both supplied by AllGlass, i.e. grade 1 (0.5 – 1.0mm) & grade 2 (1.0 - 2.0mm).

The first glass tested was grade 2. After just four weeks, the inlet pumps broke down due to both the very fine colloidal nature of the influent as well as the stop-start nature of the flow, i.e. the liquor being treated was only available every Friday and occasionally on other weekdays.

Between those times, the SCA effluent solidified into a sticky "glue-like" substance in the two inlet pumps. To overcome this, the treated liquor was re-circulated and not discharged into the sewer. However, when the liquor was not re-circulated, the liquor soon became solidified and the pumps were damaged, so the plant was out of action for a few days.

5.2.1 Suspended Solids

The laboratory data is presented in **Appendix 4**, which shows the average removal efficiency for both filters.

The efficiency for removal of suspended solids was, on average:

	Filter 1	Filter 2
Period 1	Allglass grd 2	sand
SS efficiency removal rate %	77.3%	87.9%
Period 2	Allglass grd 1	sand
SS efficiency of removal rate %	84.8%	65.6%

Table 5.4: SS average removal at SCA Histon

Table 5.4 shows that the sand removed more of the suspended solids than the Allglass grade 2 media, by about 11%. However, the glass tested here was a coarse grade, whereas the suspended particles in the effluent are very fine. A finer grade of RGM was later installed in filter 1 when the pumps were repaired.

The SS removal efficiency rose some 10% when the Allglass grade1 was installed in F1, but the sand deteriorated by some 20%.

Fig 5.3 shows the variation of the suspended solids removal rate, for the two periods of the trial.

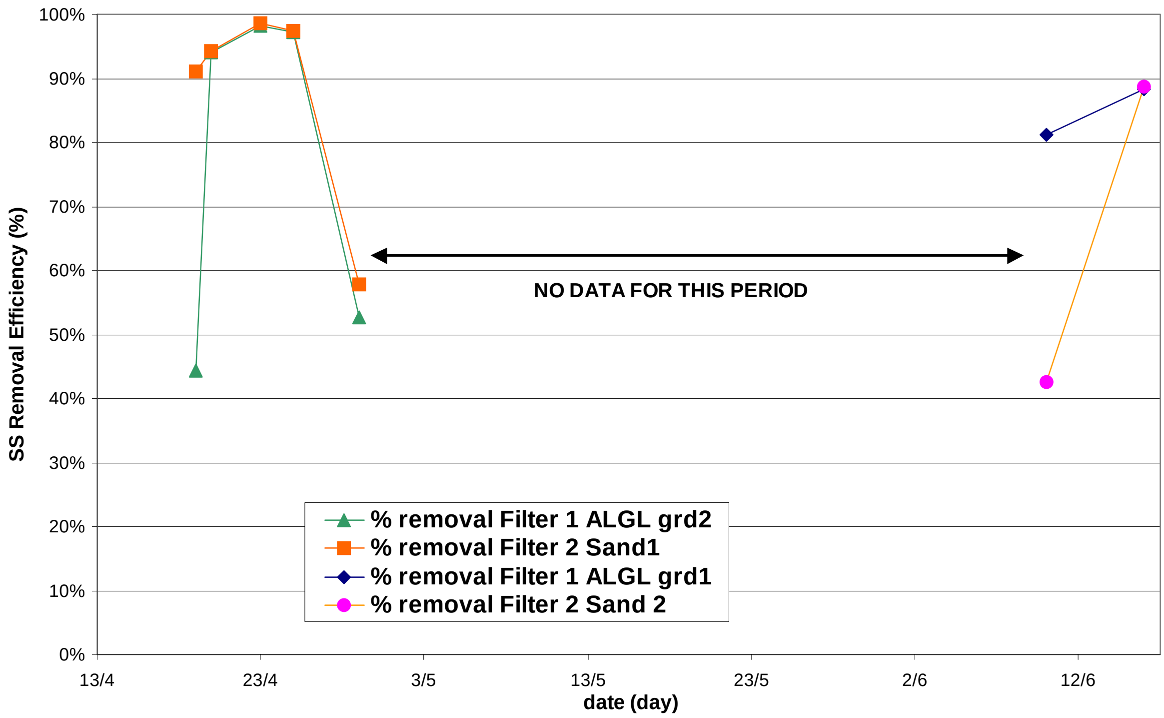


Fig 5.3: SS removal efficiency at SCA Histon

5.2.2 COD

The laboratory data is presented in **Appendix 4**, which shows the average removal efficiency for:

	Filter 1	Filter 2
Period 1	Allglass grd 2	sand
COD efficiency of removal rate %	57.9 %	59.8%
Period 2	Allglass grd 1	sand
COD efficiency of removal rate %	80.5 %	75.0%

Table 5.5: COD average removal at SCA Histon

When Allglass grade1 was installed in F1, after the repair, the COD removal efficiency rose some 22% and the sand improved by some 15%.

Both filters "appear" to have reduced the COD levels by some 70 – 80 % but it is likely that, in a similar way to the trial at Slimbridge, the COD was attached or contained within the suspended solids and removed with those solids.

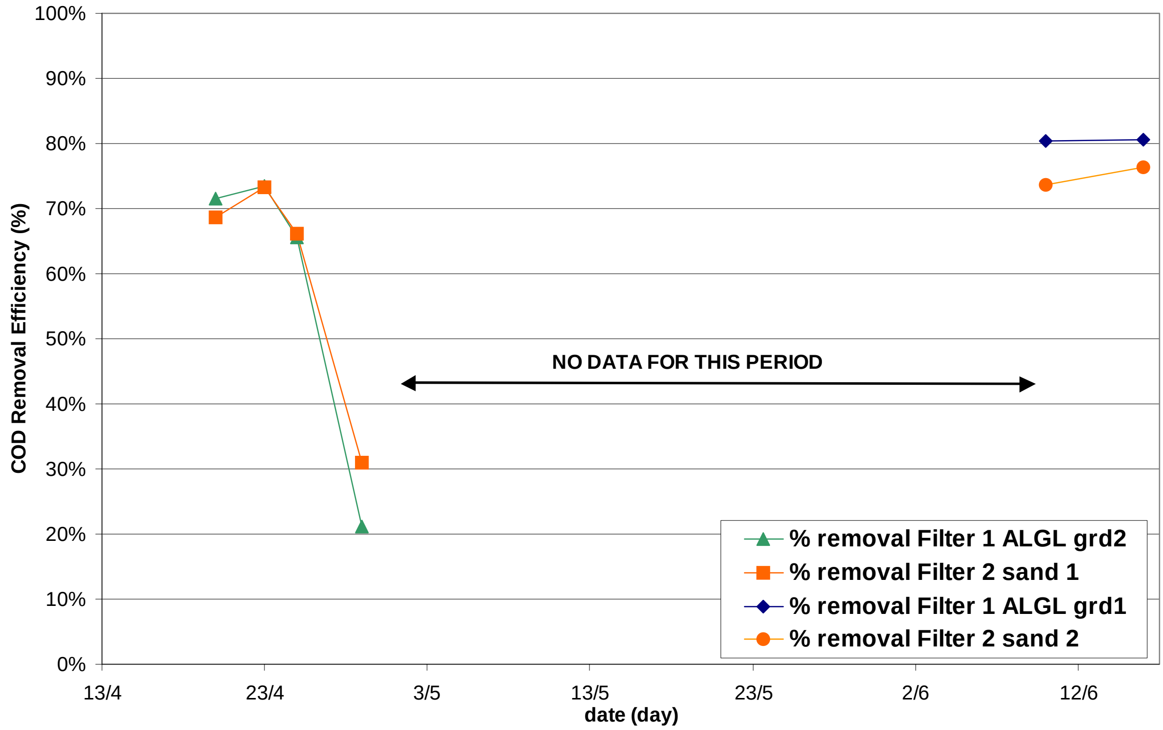


Fig 5.4: COD removal efficiency at SCA Histon

5.2.3 Discussion

In the early stages of the trial, the sand filter performed better than the grade 2 RGM. This was probably due to the grade of the RGM being tested, i.e. too big for the fine particles of starch in the effluent.

Also, the flow was intermittent, i.e. it only worked "fully" once, sometimes twice, a week, which allowed the liquor in the system to solidify. This aspect was resolved by circulating the treated liquor continuously during the week and ensuring that there was no opportunity for the liquor to set in the pipes.

Eventually, the high starch liquor caused damage to the trial plant and during the repairs the glass media was changed to grade 1 Allglass (a finer grade). The replacement glass media performed over 10% better, whilst the sand was worse by some 20% for SS removal but 10% better for COD removal. It is expected that the sand would deteriorate further if the trial plant is left on site for an extended period.

5.3 Premier Foods

In the Premier Foods trial unit, the media tested was Krysteline grade 2 (0.75 – 1.5 mm) and Sand for the first month, after which time the glass was changed to Krysteline grade 1 (0.25 – 0.75 mm).

During the first month, the sand performed better than the glass but this was expected because the glass was grade 2, which was too coarse and the liquor was very fine and high in SS. At the end of the first period, there was a problem when the valves in the head of Filter 2 (sand) became blocked and so there was no sand media data until it was repaired.

5.3.1 Suspended Solids

The laboratory data is presented in **Appendix 5.**

The suspended solid concentration in the inlet was low (in comparison with the two other sites). For the first part of the trial, the average removal rate for suspended solids is presented in Table 5.6, and its variation on the Fig 5.5.

Period 1	Krysteline grd 2	sand
SS efficiency of removal rate %	71%	73%
Period 2	Krysteline grd 1	sand
SS efficiency of removal rate %	72%	No data

Table 5.6: SS average removal at Premier Foods

When the RGM was changed to grade 1, the removal rate was similar, whilst there was no comparable data for the sand filter, which was inoperable.

Both filters removed suspended solids at about the same rate.

When the glass media was changed to Krysteline grade 1, the SS removal rate remained the same for Filter 1. Unfortunately, the sand filter became inoperable when the filter heads became blocked and so there are no comparable results for this period.

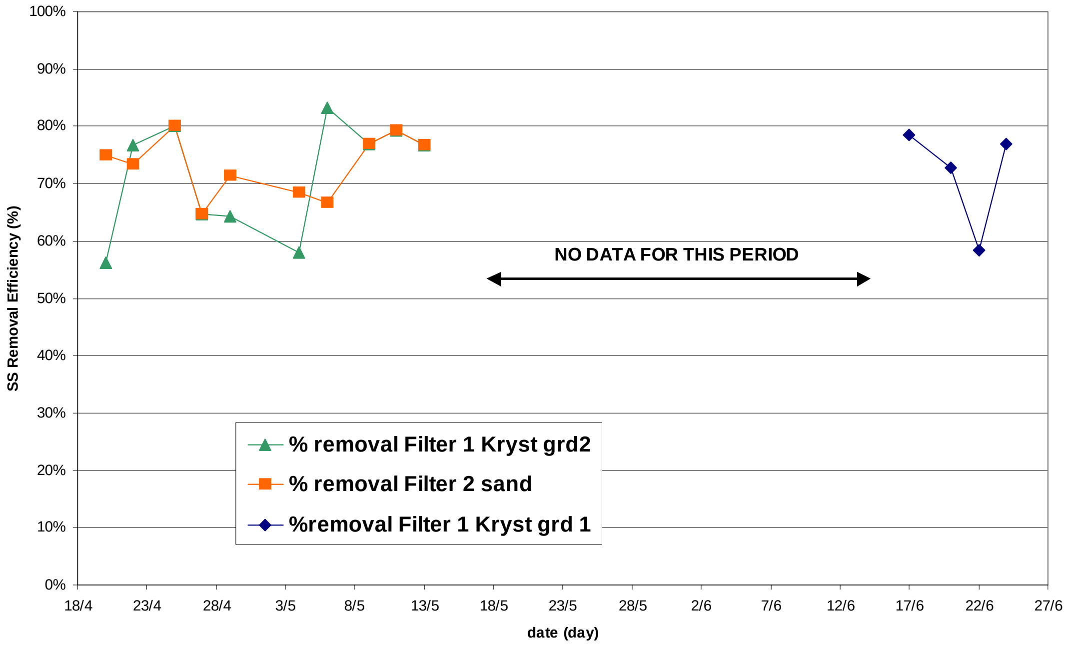


Fig 5.5: SS removal efficiency at Premier Foods

5.3.2 COD

The COD removal rate average during the first period is presented in Table 5.7 and its variation in Fig 5.6:

Period 1	Krysteline grd 2	sand
% COD efficiency of removal rate %	56.5%	55.8%
Period 2	Krysteline grd 1	sand
COD efficiency of removal rate %	75%	Not working

Table 5.7: COD average removal at Premier Foods

In the first period, with the suspended solids, the COD removal rate was similar with the sand and the glass, i.e. about 55%; but they were both quite low and fluctuating, as shown in Fig 5.6.

In the second period, the sand filter was not working but the COD removal rate for the grade 1 RGM improved significantly by 20 % to 75%, as shown in Table 5.7.

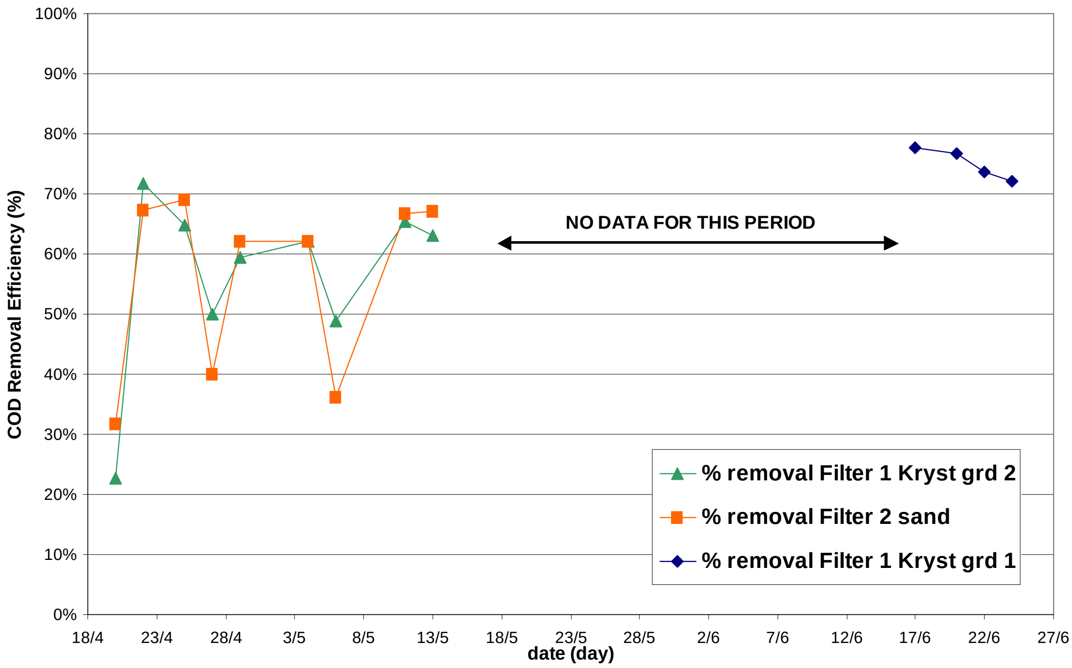


Fig 5.6: COD removal efficiency at Premier Foods

5.3.3 Discussion

For the first four weeks of the trial, both filters worked more or less the same. There was then an operational problem with the head on Filter 2 so that there was no data for the sand media for several weeks. The glass was changed from grade 1 to grade 2 in Filter 1, which has then worked with the same efficiently for SS removal but nearly 20% better at COD removal.

5.4 Overview

At all three trial sites, the RGM performed as well as sand for filtration of the wastewater streams but towards the latter stages the performance of the sand started to decrease, as bio-fouling restricted backwashing. The RGM however continues to perform without any marked diminution in performance.

The performance of the RGM from the four different suppliers did not vary significantly within the limitations of the trials and no one product performed better than another in their respective grading.

The independent analysis of the RGM from the four suppliers did not give a clear picture as to which complied, or otherwise, with the PAS 102 Section 7.

At Slimbridge, where the liquor being treated was very “slimy”, high in suspended solids and bacteria (from the bird droppings) the treatment by both filters was effective in that some 95% of SS were removed in the first period, which was maintained in the second month by the replaced RGM but fell away to less than 70% for the sand filter. The COD levels were reduced by some 60% in the first period and 90% for the RGM filter and 63% for the sand in the second period. This variation was probably attributable to a tenfold increase in the influent COD.

For the third period of the trial, a mix of RGM was used for the filtration media (see Section 4.3.2), and the SS removal rate for that filter was reduced by some 18% with the COD removal rate returned to less than 60%. Meanwhile, the sand continued to deteriorate and fell to 49% removal (SS) and 34%(COD).

At SCA Histon, the influent liquor was high in wheat starch from the “glue” used to make the cardboard, and therefore was very fine in nature. During the first period when grade 2 RGM was used, the sand performed better than the RGM, i.e. 88% SS removal (sand) and 77% removal (glass), whereas in the second period when the smaller grade 1 RGM was used, the performance improved to 85% SS removal for RGM whilst the sand began to show signs of deterioration with a 66% removal rate.

The removal of COD improved by some 20% by changing the glass grades, i.e. from 60 to 80% but the sand performance also improved by 15% from 60 to 75%. Again, the COD removal was probably related to the SS removal in that COD was contained within the SS.

The Premier Foods site was different to the other two sites in that the trial plant was located at the end of the factory’s own treatment works and testing was carried out on the effluent currently discharged to the local river. Unlike the other two the filters provided tertiary treatment rather than as the primary treatment regime. The SS removal for the first period was 71% for RGM (grade 2) and 73% for sand

When the media was changed to grade 1 RGM in filter 1, the SS removal remained the same but the COD removal improved by some 20%. The sand filled filter was inoperable during this period.

The sand filters (benchmarks) were retained throughout the full length of the trials and at each location, there were indications that the sand was starting to deteriorate, probably due to bio fouling. This phenomenon would probably become more pronounced in time.

6 Conclusions

The operational trials provided clear evidence that RGM is superior to sand as a filtration media, when used under similar conditions. The trials were carried out on three very different liquors/effluents from diverse applications, for which RGM performed very well under difficult circumstances.

<u>Wetlands and Wildfowl Trust, Slimbridge</u>

Pond water at Slimbridge is generally heavily contaminated with bird droppings and has both high bacteria and suspended solids levels. The trial at Slimbridge was successful as filtration using RGM proved effective in reducing suspended solids by at least 75% and more often by over 90%; but for the sand the reduction was from 94% to 50%. The COD reduction for RGM varied from 91% to 56% whilst the sand varied from 63% at best to 34% in the third period.

- For this effluent, AFM uniform grade 1 showed an improvement in SS removal over that of sand, while GRG uniform grade 1 showed an even better performance compared to virgin sand, even allowing for the varying influent quality.

- The quality of treated liquor following filtration was equal to, or better than the current discharge consent levels for effluent treated using reed beds, which subsequently discharges into the Severn Estuary.

i.e. BOD – 4 to 6 mg/l (consent)
SS – 12 to 40 mg/l (consent)
AFM glass achieved less than 7 mg/l for SS compared with GRG, which is high at 51 mg/l for the same influent quality.

- AFM and GRG both performed over 30 % better than sand for the removal of suspended solids.

- Evidence suggests that once sand had bio fouled, it was not possible to restore full operating performance even after repeated and extensive backwashing. It is expected that the performance of sand will deteriorate further with time.

As the treatment plant/system was sited next to one of the worst polluted pools at Slimbridge, it is expected that the same plant would perform equally as well on other ponds. Management at Slimbridge is considering the use of RGM water treatment as part of their long-term strategy for the development of the site.

<u>SCA Histon</u>

Effluent arising from the wash-down of corrugating machines contains high levels of wheat starch (glue). The collection system used by SCA stores the liquor, which is allowed to settle so that the supernatant, which overflows into the foul sewer has as low a suspended solids level as possible. The settled solids are periodically removed by tanker. However, SCA still receive substantial bills from the local Water Company for their highly polluted discharge.

Despite all attempts at improving the quality of the discharge at SCA, the trial showed that filtration is not the best means of treating this effluent consistently, because the glue-like effluent solidifies when the liquor is concentrated. Also, as waste liquor is produced only two days a week, the plant operated under a stop/start regime, which exacerbated the solidification. To mitigate this solidification, continuous recirculation/treatment was introduced.

Nonetheless the test data showed:

- Grade 2 RGM did not perform as efficiently as sand when sand is in a "virgin" state.

- Both grade 1 and 2 RGM reduce SS by over 80%, which will provide the customer a saving of some 300p/m^3 on the SS parameters in the Mogden formula.

- Similarly, COD was reduced by over 60%, which again reduces the trade effluent charge by 380p/m^3 for COD in the Mogden.

- The effect is an overall saving in trade effluent charges for SCA of more than £13,000 per year.

- Sand has deteriorated since early June, which shows RGM to be better.

Further work on improving the treatment process is required at this site as filtration as a stand-alone process has not been the most efficient option. Coagulation and the breakdown of the starch by bacteria prior to filtration need to be studied as part of the process.

<u>Premier Foods</u>

Premier Foods have a major problem with regard to the current discharge of some 3000 m^3/day into a river some 2.5 miles away. The trial was designed to ascertain whether the treated effluent could be improved sufficiently so that most of that discharge may be used to replace mains water in the reverse osmosis plant for use in the boiler water system.

At the Premier Foods site, the trials demonstrated that filtration is an excellent process for 'polishing' the effluent from their wastewater treatment plant. Having evaluated the SS and COD removal, the treated water is a potential feedstock for the RO plant and thence for use in the boilers. Further investigation into the hardness and bacteriological content of the water will be required to confirm this potential.

Because of the aggressive effluent hardness, delays were experienced on the project due to seals on the filter heads becoming damaged, resulting in liquor short-circuiting the filters and flowing directly to waste.

The raw liquor has been very inconsistent with the Client periodically discharging very high levels of solids (peas, beans) into the waste stream, which has caused the filters to block almost instantaneously resulting in the system being overloaded.

However the results indicate:

- The grade 2 RGM was as effective as sand in the short term but it is anticipated the latter will become bio-fouled in due course from the high COD levels and become ineffective.

- Grade 1 RGM was better than sand by 10 – 15%

<u>Summary</u>

From all of the work carried out by WDS, albeit over a relatively short period, on three very different applications for the use of recycled glass as a filtration media, there is no doubt that re-cycled glass has outperformed sand.

Recycled glass from different suppliers has shown some interesting variations in performance with none being outstandingly better than the others.

As a filtration media recycled glass has considerable potential, but every application needs to be considered carefully to ensure the best grade and mix is used, and in some applications it may be necessary to undertake trials before the best product and optimum grade is selected.

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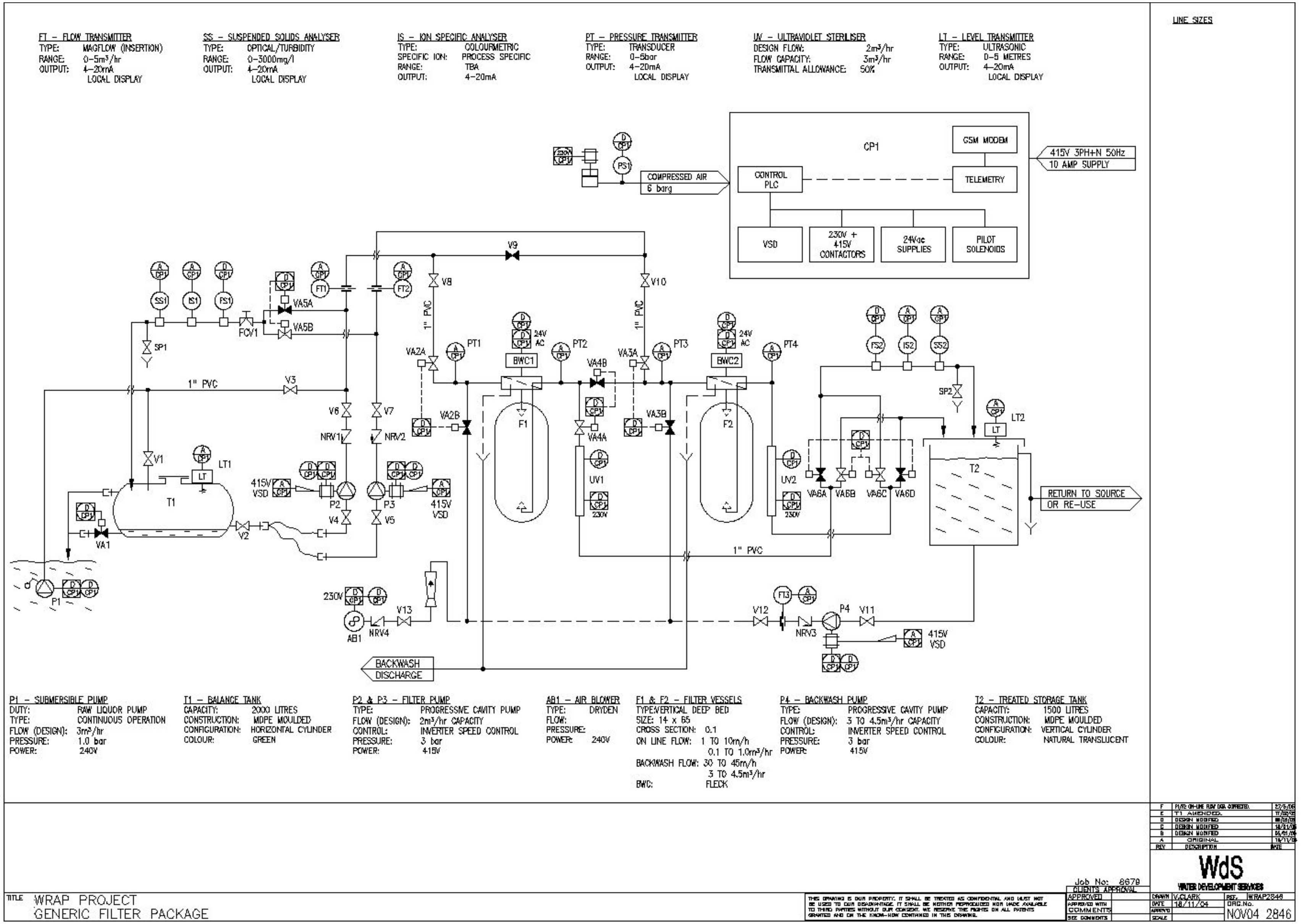
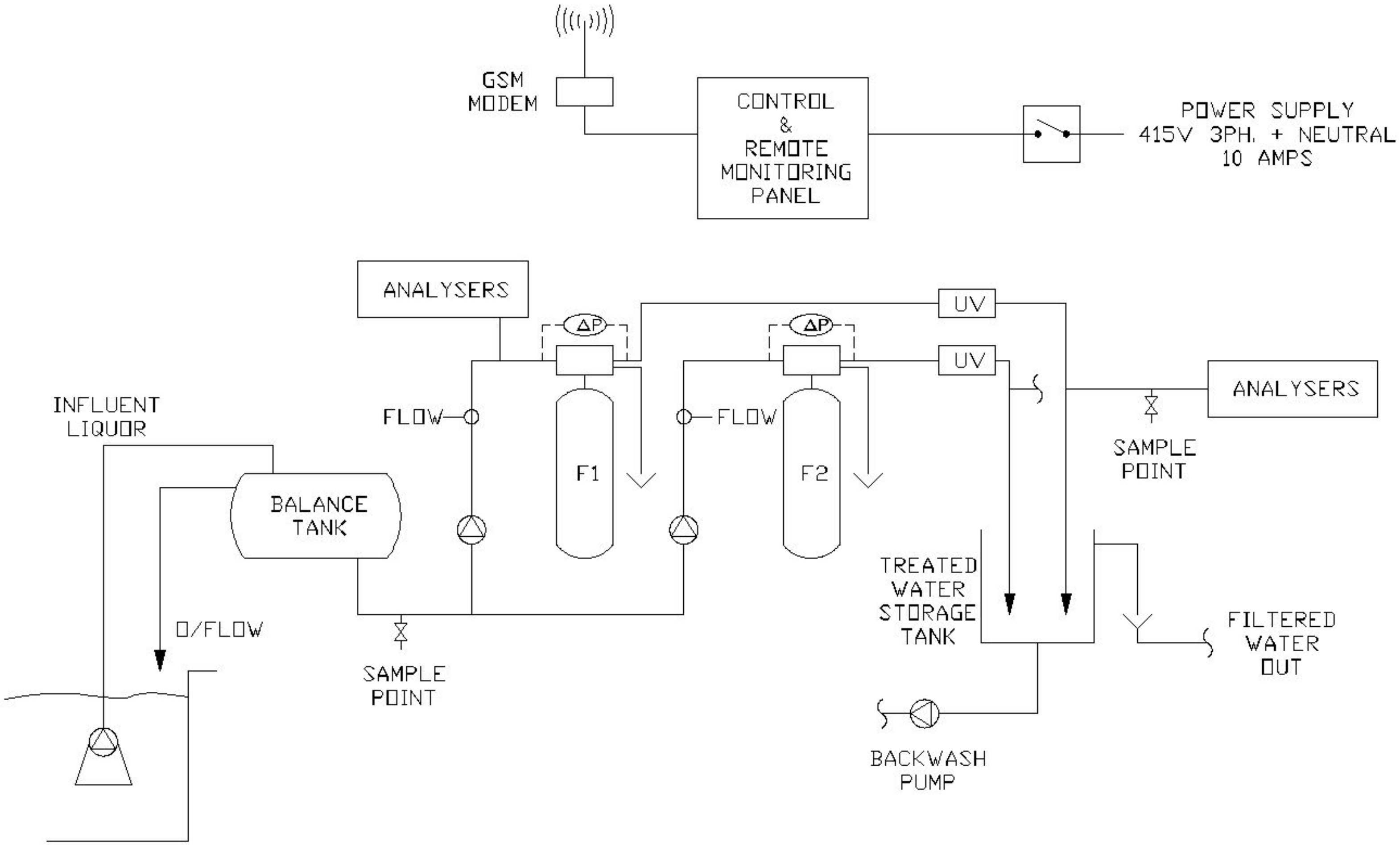
APPENDIX 1



FT – FLOW TRANSMITTER
TYPE: MAGFLOW (INSERTION)
RANGE: 0–5m³/hr
OUTPUT: 4–20mA LOCAL DISPLAY
SS – SUSPENDED SOLIDS ANALYSER
TYPE: OPTICAL/TURBIDITY
RANGE: 0–3000mg/l
OUTPUT: 4–20mA LOCAL DISPLAY
IS – ION SPECIFIC ANALYSER
TYPE: COLOURMETRIC
SPECIFIC ION: PROCESS SPECIFIC
RANGE: TBA
OUTPUT: 4–20mA
PT – PRESSURE TRANSMITTER
TYPE: TRANSDUCER
RANGE: 0–5bar
OUTPUT: 4–20mA LOCAL DISPLAY
UV – ULTRAVIOLET STERILISER
DESIGN FLOW: 2m³/hr
FLOW CAPACITY: 3m³/hr
TRANSMITTAL ALLOWANCE: 50%
LT – LEVEL TRANSMITTER
TYPE: ULTRASONIC
RANGE: 0–5 METRES
OUTPUT: 4–20mA LOCAL DISPLAY
LINE SIZES
CP1
GSM MODEM
CONTROL PLC
TELEMETRY
VSD
230V + 415V CONTACTORS
24Vac SUPPLIES
PILOT SOLENOIDS
415V 3PH+N 50Hz 10 AMP SUPPLY
COMPRESSED AIR 6 barg
PS1
V9
V8
V10
1" PVC
FT1
FT2
SS1
IS1
FS1
FCV1
VA5A
VA5B
SP1
V3
V6
V7
NRV1
NRV2
V1
LT1
T1
VA1
V2
415V VSD
P2
P3
V4
V5
P1
BWC1
BWC2
24V AC
PT1
PT2
PT3
PT4
VA2A
VA2B
VA3A
VA3B
VA4A
VA4B
F1
F2
UV1
UV2
230V
FS2
IS2
SS2
SP2
LT2
T2
VA6A
VA6B
VA6C
VA6D
RETURN TO SOURCE OR RE-USE
230V
AB1
NRV4
V13
V12
FT3
NRV3
P4
V11
BACKWASH DISCHARGE
P1 – SUBMERSIBLE PUMP
DUTY: RAW LIQUOR PUMP
TYPE: CONTINUOUS OPERATION
FLOW (DESIGN): 3m³/hr
PRESSURE: 1.0 bar
POWER: 240V
T1 – BALANCE TANK
CAPACITY: 2000 LITRES
CONSTRUCTION: MDPE MOULDED
CONFIGURATION: HORIZONTAL CYLINDER
COLOUR: GREEN
P2 & P3 – FILTER PUMP
TYPE: PROGRESSIVE CAVITY PUMP
FLOW (DESIGN): 2m³/hr CAPACITY
CONTROL: INVERTER SPEED CONTROL
PRESSURE: 3 bar
POWER: 415V
AB1 – AIR BLOWER
TYPE: DRYDEN
FLOW:
PRESSURE:
POWER: 240V
F1 & F2 – FILTER VESSELS
TYPE: VERTICAL DEEP BED
SIZE: 14 x 65
CROSS SECTION: 0.1
ON LINE FLOW: 1 TO 10m/h 0.1 TO 1.0m³/hr
BACKWASH FLOW: 30 TO 45m/h 3 TO 4.5m³/hr
BWC: FLECK
P4 – BACKWASH PUMP
TYPE: PROGRESSIVE CAVITY PUMP
FLOW (DESIGN): 3 TO 4.5m³/hr CAPACITY
CONTROL: INVERTER SPEED CONTROL
PRESSURE: 3 bar
POWER: 415V
T2 – TREATED STORAGE TANK
CAPACITY: 1500 LITRES
CONSTRUCTION: MDPE MOULDED
CONFIGURATION: VERTICAL CYLINDER
COLOUR: NATURAL TRANSLUCENT
TITLE WRAP PROJECT GENERIC FILTER PACKAGE
Job No: 8679
CLIENTS APPROVAL
WdS
WATER DEVELOPMENT SERVICES
V.CLARK
18/11/04
WRAP2846
NOV04 2846

APPENDIX 2



F1 & F2 ARE THE TRIALS FILTERS IN WHICH WE WILL TRIAL MEDIAS TO ESTABLISH OPTIMUM SELECTION & OPERATION.

REV	DESCRIPTION	DATE
B	UPDATED TO LATEST DESIGN	15/6/05
A	ORIGINAL	02/02/05

WdS
WATER DEVELOPMENT SERVICES

Job No:

CLIENTS APPROVAL
APPROVED
APPROVED WITH COMMENTS
SEE COMMENTS

DRAWN V.CLARK
DATE 02/02/2005
APPRV'D
SCALE –
REF. WRAP2893
DRG.No. FEB05 2893

TITLE WRAP - FILTER TRIALS PACKAGE
OUTLINE FLOW DIAGRAM

S1 = INLET
F1 = F1 OUTLET
F2 = F2 OUTLET

SUSPENDED SOLIDS **SLIMBRIDGE**

	Suspended Solids (mg/L)			FLOW (m^3/h)		BACKWASH		MEDIA		% SS removal		% flow		SS efficiency	
DATE	S1	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
average	429,5	4,5	11,4	1,00	1,00					95,6%	94,3%	100%	100%	95,6%	94,3%
17/3	1000	7	45	1	1	12 hrs	?	AFM gr1	Sand	99,3%	95,5%	100%	100%	99,3%	95,5%
23/3	66	3	5	1	1	4 hrs	4 hrs	AFM gr1	Sand	95,5%	92,4%	100%	100%	95,5%	92,4%
29/3	90	3	4	1	1	4 hrs	4 hrs	AFM gr1	Sand	96,7%	95,6%	100%	100%	96,7%	95,6%
30/3	68	7	4	1	1	4 hrs	4 hrs	AFM gr1	Sand	89,7%	94,1%	100%	100%	89,7%	94,1%
31/3	48	4	6	1	1	4 hrs	4 hrs	AFM gr1	Sand	91,7%	87,5%	100%	100%	91,7%	87,5%
5/4	110	5	7	1	1	4 hrs	3 hrs	AFM gr1	Sand	95,5%	93,6%	100%	100%	95,5%	93,6%
11/4	2000	7	12	1	1	4 hrs	3 hrs	AFM gr1	Sand	99,7%	99,4%	100%	100%	99,7%	99,4%
14/4	63	4	4	1	1	4 hrs	3 hrs	AFM gr1	Sand	93,7%	93,7%	100%	100%	93,7%	93,7%
18/4	80	4	5	1	1	4 hrs	3 hrs	AFM gr1	Sand	95,0%	93,8%	100%	100%	95,0%	93,8%
25/4	770	1	22	1	1	4 hrs	3 hrs	AFM gr1	Sand	99,9%	97,1%	100%	100%	99,9%	97,1%

	Suspended Solids (mg/L)			FLOW (m^3/h)		BACKWASH		MEDIA		% SS removal		% flow		SS efficiency	
DATE	S1	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
average	2013,3	34,3	36,3	1,0	0,7					98,0%	98,2%	100,0%	70%	98,0%	68,7%
6/5	2100	51	46	1	1	4 hrs	12 hrs	GRG gr1	Sand	97,6%	97,8%	100%	100%	97,6%	97,8%
13/5	640	16	10	1	0,5	4 hrs	12 hrs	GRG gr1	Sand	97,5%	98,4%	100%	50%	97,5%	49,2%
16/5	3300	36	53	1	0,6	6 hrs	6 hrs	GRG gr1	Sand	98,9%	98,4%	100%	60%	98,9%	59,0%

	Suspended Solids (mg/L)			FLOW (m^3/h)		BACKWASH		MEDIA		% SS removal		% flow		SS efficiency	
DATE	S1	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
average	594,0	13,3	20,2	0,8	0,5					96,7%	95,0%	79,4%	52,0%	76,8%	49,2%
6/6	1100	5	9	0,8	0,6	6 hrs	6 hrs	GRG mix	Sand	99,5%	99,2%	80%	60%	79,6%	59,5%
13/6	340	20	47	1	0,6	6 hrs	6 hrs	GRG mix	Sand	94,1%	86,2%	100%	60%	94,1%	51,7%
16/6	590	6	17	0,85	0,5	6 hrs	6 hrs	GRG mix	Sand	99,1%	97,1%	85%	50%	84,2%	48,6%
6/7	240	14	13	0,7	0,5	6 hrs	6 hrs	GRG mix	Sand	94,2%	94,6%	70%	50%	65,9%	47,3%
11/7	700	22	15	0,62	0,4	6 hrs	6 hrs	GRG mix	Sand	96,9%	97,9%	62%	40%	60,1%	39,1%

COD

SLIMBRIDGE

S1 = INLET
F1 = F1 OUTLET
F2 = F2 OUTLET

	COD (mg O2/L)			FLOW (m^3/h)		BACKWASH		MEDIA		% COD removal		% flow		COD efficiency	
DATE	S1	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
average	78,67	25,56	26,89	1,00	1,00					56,7%	57,3%	100%	100%	56,7%	57,3%
21/3	46,0	32,0	30,0	1	1	12 hrs	?	AFM gr1	Sand	30,4%	34,8%	100%	100%	30,4%	34,8%
23/3	94,0	30,0	24,0	1	1	4 hrs	4 hrs	AFM gr1	Sand	68,1%	74,5%	100%	100%	68,1%	74,5%
29/3	50,0	24,0	26,0	1	1	4 hrs	4 hrs	AFM gr1	Sand	52,0%	48,0%	100%	100%	52,0%	48,0%
31/3	44,0	24,0	16,0	1	1	4 hrs	4 hrs	AFM gr1	Sand	45,5%	63,6%	100%	100%	45,5%	63,6%
5/4	66,0	34,0	34,0	1	1	4 hrs	3 hrs	AFM gr1	Sand	48,5%	48,5%	100%	100%	48,5%	48,5%
11/4	58,0	30,0	32,0	1	1	4 hrs	3 hrs	AFM gr1	Sand	48,3%	44,8%	100%	100%	48,3%	44,8%
14/4	50,0	20,0	22,0	1	1	4 hrs	3 hrs	AFM gr1	Sand	60,0%	56,0%	100%	100%	60,0%	56,0%
18/4	60,0	22,0	24,0	1	1	4 hrs	3 hrs	AFM gr1	Sand	63,3%	60,0%	100%	100%	63,3%	60,0%
25/4	240,0	14,0	34,0	1	1	4 hrs	3 hrs	AFM gr1	Sand	94,2%	85,8%	100%	100%	94,2%	85,8%

	COD (mg O2/L)			FLOW (m^3/h)		BACKWASH		MEDIA		% COD removal		% flow		COD efficiency	
DATE	S1	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
average	564,67	42,67	46,67	1,00	0,70					91,0%	89,3%	100%	70%	91,0%	63,2%
6/5	560,0	48,0	40,0	1	1	4 hrs	12 hrs	GRG gr1	Sand	91,4%	92,9%	100%	100%	91,4%	92,9%
13/5	234,0	30,0	44,0	1	0,5	4 hrs	12 hrs	GRG gr1	Sand	87,2%	81,2%	100%	50%	87,2%	40,6%
16/5	900,0	50,0	56,0	1	0,6	6 hrs	6 hrs	GRG gr1	Sand	94,4%	93,8%	100%	60%	94,4%	56,3%

	COD (mg O2/L)			FLOW (m^3/h)		BACKWASH		MEDIA		% COD removal		% flow		COD efficiency	
DATE	S1	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
average	182,00	44,00	50,00	0,79	0,52					70,9%	65,9%	79,4%	52,0%	56,8%	34,1%
6/6	318,0	34,0	34,0	0,8	0,6	6 hrs	6 hrs	GRG mix	Sand	89,3%	89,3%	80%	60%	71,4%	53,6%
13/6	144,0	36,0	76,0	1	0,6	6 hrs	6 hrs	GRG mix	Sand	75,0%	47,2%	100%	60%	75,0%	28,3%
16/6	180,0	56,0	50,0	0,85	0,5	6 hrs	6 hrs	GRG mix	Sand	68,9%	72,2%	85%	50%	58,6%	36,1%
6/7	88,0	46,0	50,0	0,7	0,5	6 hrs	6 hrs	GRG mix	Sand	47,7%	43,2%	70%	50%	33,4%	21,6%
11/7	180	48	40	0,62	0,4	6 hrs	6 hrs	GRG mix	Sand	73%	78%	62%	40%	45,5%	31,1%

APPENDIX 4

S1 = INLET
F1 = F1 OUTLET
F2 = F2 OUTLET

SUSPENDED SOLIDS

SCA

	Suspended Solids (mg/L)			FLOW (m^3/h)		BACKWASH		MEDIA		% SS removal		% flow		SS efficiency	
DATE	S1	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
average	7760	1542	947	1	1					77,3%	87,9%	100%	100%	77,3%	87,9%
19/4	5 400	3 000	480	1	1	10 hrs	10 hrs	AlGl gr2	Sand	44,4%	91,1%	100%	100%	44,4%	91,1%
20/4	15 000	880	870	1	1	10 hrs	10 hrs	AlGl gr2	Sand	94,1%	94,2%	100%	100%	94,1%	94,2%
23/4	6 900	120	89	1	1	10 hrs	10 hrs	AlGl gr2	Sand	98,3%	98,7%	100%	100%	98,3%	98,7%
25/4	3 900	110	98	1	1	10 hrs	10 hrs	AlGl gr2	Sand	97,2%	97,5%	100%	100%	97,2%	97,5%
29/4	7 600	3 600	3 200	1	1	10 hrs	10 hrs	AlGl gr2	Sand	52,6%	57,9%	100%	100%	52,6%	57,9%

	Suspended Solids (mg/L)			FLOW (m^3/h)		BACKWASH		MEDIA		% SS removal		% flow		SS efficiency	
DATE	S1	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
average	25300	3000	3210	1	1					84,8%	65,6%	100,0%	100,0%	84,8%	65,6%
10/6	1 600	300	920	1	1	10 hrs	10 hrs	AlGl gr1	Sand	81,3%	42,5%	100%	100%	81,3%	42,5%
16/6	49 000	5 700	5 500	1	1	10 hrs	10 hrs	AlGl gr1	Sand	88,4%	88,8%	100%	100%	88,4%	88,8%

COD

SCA

	COD (mg O2/L)			FLOW (m^3/h)		BACKWASH		MEDIA		% COD removal		% flow		COD efficiency	
DATE	S1	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
average	12500	5415	5180	1	1					57,9%	59,8%	100,0%	100,0%	57,9%	59,8%
20/4	17600	5000	5500	1	1	10 hrs	10 hrs	AlGl gr2	Sand	71,6%	68,8%	100%	100%	71,6%	68,8%
23/4	10200	2700	2720	1	1	10 hrs	10 hrs	AlGl gr2	Sand	73,5%	73,3%	100%	100%	73,5%	73,3%
25/4	8000	2760	2700	1	1	10 hrs	10 hrs	AlGl gr2	Sand	65,5%	66,3%	100%	100%	65,5%	66,3%
29/4	14200	11200	9800	1	1	10 hrs	10 hrs	AlGl gr2	Sand	21,1%	31,0%	100%	100%	21,1%	31,0%

	COD (mg O2/L)			FLOW (m^3/h)		BACKWASH		MEDIA		% COD removal		% flow		COD efficiency	
DATE	S1	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
average	33800	6580	8120	1	1					80,5%	75,0%	100,0%	100,0%	80,5%	75,0%
10/6	10000	1960	2640	1	1	10 hrs	10 hrs	AlGl gr1	Sand	80,4%	73,6%	100%	100%	80,4%	73,6%
16/6	57600	11200	13600	1	1	10 hrs	10 hrs	AlGl gr1	Sand	80,6%	76,4%	100%	100%	80,6%	76,4%

S1 = INLET
F1 = F1 OUTLET
F2 = F2 OUTLET

SUSPENDED SOLIDS

PREMIER FOOD

	Suspended Solids (mg/L)			flow(m^3/h)		BACKWASH		MEDIA		% SS removal		% flow		SS efficiency			
DATE	**S1**	**F1**	**F2**	**F1**	**F2**	**F1**	**F2**	**F1**	**F2**	**F1**	**F2**	**F1**	**F2**	**F1**	**F2**		
average	**42,00**	**11,40**	**10,80**	**1,0**	**1,0**					**71,6%**	**73,2%**	**100%**	**100%**	**71,6%**	**73,2%**		
20/4	32,00	14,00	8,00	1,0	1,0	6 hrs	6 hrs	Kry gr2	Sand	56,3%	75,0%	100%	100%	56,3%	75,0%		
22/4	60,00	14,00	16,00	1,0	1,0	6 hrs	6 hrs	Kry gr2	Sand	76,7%	73,3%	100%	100%	76,7%	73,3%		
25/4	60,00	12,00	12,00	1,0	1,0	6 hrs	6 hrs	Kry gr2	Sand	80,0%	80,0%	100%	100%	80,0%	80,0%		
27/4	34,00	12,00	12,00	1,0	1,0	6 hrs	6 hrs	Kry gr2	Sand	64,7%	64,7%	100%	100%	64,7%	64,7%		
29/4	28,00	10,00	8,00	1,0	1,0	6 hrs	6 hrs	Kry gr2	Sand	64,3%	71,4%	100%	100%	64,3%	71,4%		
4/5	38,00	16,00	12,00	1,0	1,0	6 hrs	6 hrs	Kry gr2	Sand	57,9%	68,4%	100%	100%	57,9%	68,4%	F1 eff aver	F2 eff aver
6/5	24,00	4,00	8,00	1,0	1,0	6 hrs	6 hrs	Kry gr2	Sand	83,3%	66,7%	100%	100%	83,3%	66,7%	69,0%	71,4%
9/5	26,00	6,00	6,00	1,0	1,0	4 hrs	4 hrs	Kry gr2	Sand	76,9%	76,9%	100%	100%	76,9%	76,9%		
11/5	58,00	12,00	12,00	1,0	1,0	4 hrs	4 hrs	Kry gr2	Sand	79,3%	79,3%	100%	100%	79,3%	79,3%	F1 eff aver	F2 eff aver
13/5	60,00	14,00	14,00	1,0	1,0	4 hrs	4 hrs	Kry gr2	Sand	76,7%	76,7%	100%	100%	76,7%	76,7%	77,6%	77,6%

	Suspended Solids (mg/L)			flow(m^3/h)		BACKWASH		MEDIA		% SS removal		% flow		SS efficiency	
DATE	**S1**	**F1**	**F2**	**F1**	**F2**	**F1**	**F2**	**F1**	**F2**	**F1**	**F2**	**F1**	**F2**	**F1**	**F2**
average	**25,00**	**7,00**		**1,00**						**71,6%**		**1,00**		**71,6%**	
17/6	28,00	6,00		1,0		6 hrs		Kry gr1	Sand	78,6%		100%		78,6%	
20/6	22,00	6,00		1,0		6 hrs		Kry gr1	Sand	72,7%		100%		72,7%	
22/6	24,00	10,00		1,0		6 hrs		Kry gr1	Sand	58,3%		100%		58,3%	
24/6	26,00	6,00		1,0		6 hrs		Kry gr1	Sand	76,9%		100%		76,9%	

APPENDIX 5 p.1

APPENDIX 5 p.2

S1 = INLET
F1 = F1 OUTLET
F2 = F2 OUTLET

COD **PREMIER FOOD**

	COD (mg O2/L)			flow(m^3/h)		BACKWASH		MEDIA		% COD removal		% flow		COD efficiency			
DATE	S1	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2		
average	58,00	23,67	23,89	1,0	1,0					56,5%	55,8%	100%	100%	56,5%	55,8%		
20/4	44,00	34,00	30,00	1,0	1,0	6 hrs	6 hrs	Kry gr2	Sand	22,7%	31,8%	100%	100%	22,7%	31,8%		
22/4	92,00	26,00	30,00	1,0	1,0	6 hrs	6 hrs	Kry gr2	Sand	71,7%	67,4%	100%	100%	71,7%	67,4%		
25/4	71,00	25,00	22,00	1,0	1,0	6 hrs	6 hrs	Kry gr2	Sand	64,8%	69,0%	100%	100%	64,8%	69,0%		
27/4	40,00	20,00	24,00	1,0	1,0	6 hrs	6 hrs	Kry gr2	Sand	50,0%	40,0%	100%	100%	50,0%	40,0%		
29/4	37,00	15,00	14,00	1,0	1,0	6 hrs	6 hrs	Kry gr2	Sand	59,5%	62,2%	100%	100%	59,5%	62,2%		
4/5	37,00	14,00	14,00	1,0	1,0	6 hrs	6 hrs	Kry gr2	Sand	62,2%	62,2%	100%	100%	62,2%	62,2%	F1 eff aver	F2 eff aver
6/5	47,00	24,00	30,00	1,0	1,0	6 hrs	6 hrs	Kry gr2	Sand	48,9%	36,2%	100%	100%	48,9%	36,2%	54,3%	52,7%
11/5	78,00	27,00	26,00	1,0	1,0	4 hrs	4 hrs	Kry gr2	Sand	65,4%	66,7%	100%	100%	65,4%	66,7%	F1 eff aver	F2 eff aver
13/5	76,00	28,00	25,00	1,0	1,0	4 hrs	4 hrs	Kry gr2	Sand	63,2%	67,1%	100%	100%	63,2%	67,1%	64,3%	66,9%

	COD (mg O2/L)			flow(m^3/h)		BACKWASH		MEDIA		% COD removal		% flow		COD efficiency	
DATE	S1	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
average	65,25	16,25		1,00						75,0%		100,0%		75,0%	
17/6	67,00	15,00		1,0		6 hrs		Kry gr1	Sand	77,6%		100%		77,6%	
20/6	69,00	16,00		1,0		6 hrs		Kry gr1	Sand	76,8%		100%		76,8%	
22/6	57,00	15,00		1,0		6 hrs		Kry gr1	Sand	73,7%		100%		73,7%	
24/6	68,00	19,00		1,0		6 hrs		Kry gr1	Sand	72,1%		100%		72,1%	

GTS
SERVING THE WORLD OF GLASS

NBK/TAG18157/TAG18178 21st June 2005

COMMERCIAL IN CONFIDENCE

ANALYSIS REPORT

The results and/or opinions contained in this report, may not be used out of context or for purposes other than those expressed in the contract between GTS and the Client

DETAILS

CUSTOMER:	Water Development Services
CONTACT:	Chris Dean
SAMPLES:	Provided by Chris Dean
DATE RECEIVED:	Samples 1, 2, 3, 5. 6 & 7 received on 9th June 2005
	Samples 4 & 8 received on 20th June 2005
ANALYST:	Henry Foxhall

INTRODUCTION

WDS requested that GTS assessed cullet samples in accordance with PAS102:2004 section 7 “Requirement for processed container glass as water filtration media”. This is a relatively new specification and GTS has followed the procedures as described wherever possible. However, where the procedure was not practical the procedure was adapted to suit. Figure 1 shows the sampling and assessment protocol used for this contract.

This report includes the result reported on 15th June 2005 (TAG18157) and the analysis of the two additional samples received on 20th June 2005. The results are reported in conformity with PAS102:2004 section 7. This report supersedes previous report TAG18157.

RESULTS

APPENDIX 6 p.2

Colour Specification (section 7.3)

Sample	Colour specification	Classification
1	95% Flint	C
2	95% Brown	A
3	Mixed	D
4	Mixed	D
5	Mixed	D
6	Mixed	D
7	Mixed	D
8	95% Green	B

Table 1 Colour specification results

In PAS102:2004 there are only two classes, A & B, for brown and green glass respectively. As all these samples expect samples 2 & 8 did not fulfil the specified classes for colour, two classes were devised for clear and mixed colour glass, C & D respectively.

Contamination limits (Section 7.4)

Four classes of contaminates were screened for, these being non ferrous, ferrous, inorganic and other. The 'other' class includes:

Medical refuse (eg needles or syringes)
Chemical refuse
Hazardous or toxic materials

Due to the relatively small particle size it was not possible to determine if the cullet was contaminated with other glass types.

Sample	Non-Ferrous	Ferrous	Inorganic	Other	Reference Images of Contaminates
1	<0.01% (5)	none	<0.01% (2)	none	Inorganic - figure 2
2	<0.01% (1)	<0.01% (11)	none	none	Ferrous - figures 3,4 & 5
3	none	<0.01% (4)	<0.01% (2)	none	Inorganic - figure 6 Ferrous - figure 7
4	none	0.02% (82)	<0.01% (13)	none	
5	none	<0.01% (3)	none	none	Ferrous - figure 8
6	none	None	none	none	
7	<0.01% (15)	<0.01% (2)	<0.01% (24)	none	Non-ferrous - figure 9 Ferrous - figure 10 Inorganic – figure 11
8	none	<0.01% (11)	<0.01% (4)	none	

Table 2 Contamination levels in weight %. The numbers in brackets () is the number of particles found in the 1 kg sample.

PAS102:2004 does not specify actual contamination limits, therefore, it is not possible to classify the samples. However, all the samples had a relatively low contamination level, accept for sample 4 which had iron filing particles and sample 7 that had numerous inorganic contamination particles.

Water Moisture (Section 7.4)

Sample	Water content (weight)	Classification
1	0.07%	Pass
2	0.07%	Pass
3	0.07%	Pass
4	0.09%	Pass
5	0.05%	Pass
6	0.08%	Pass
7	0.05%	Pass
8	0.07%	Pass

Table 3 Water Moisture content results

All the samples passed the requirement of PAS102:2004 for less than 0.5 weight % water moisture content.

Organic Content (Section 7.4)

Sample	Organic content (weight)
1	0.01%
2	0.02%
3	0.06%
4	0.28%
5	0.07%
6	0.01%
7	0.03%
8	0.24%

Table 4 Organic content results

PAS102:2004 does not specify actual contamination limits for organic contaminates, therefore, it is not possible to classify the samples. However, all the samples had a relatively low organic contamination level.

Particle size (Section 7.5)

Sample	Particle size (mm) in weight %						Classification
	> 2	1 to 2	0.7 to	0.5 to 0.7	0.25 to 0.5	< 0.25	
1	1.01	98.90	0.05	0.01	0.01	0.02	Grade 2 (coarse)
2	0.00	19.66	71.02	9.15	0.16	0.01	NC (medium)
3	0.07	87.21	10.53	2.08	0.07	0.04	NC (coarse)
4	0.00	0.45	8.48	44.97	40.69	5.28	NC (fine)
5	0.00	10.74	66.65	21.74	0.86	0.03	NC (medium)
6	0.00	0.00	0.00	7.17	84.24	8.89	NC (fine)
7	4.78	94.26	0.89	0.02	0.03	0.02	Grade 3 (coarse)
8	0.00	21.18	49.28	28.27	1.18	0.02	NC (medium)

Table 5 Particle size results, NC (not classified) indicates that the cullet does not fulfil PAS102:2004. The relative particle size is given in the brackets.

The particle size distribution is shown in table 5, only sample 1 satisfied the particle size distribution in PAS102:2004 section 7.5. The particle size grades in PAS102:2004 section 7.5 are shown below:

Grade 0 Min 95% passing 0.7 mm
Max 5% passing 0.25 mm

Grade 1 Min 95% passing 1.0 mm
Max 5% passing 0.5 mm

Grade 2 Min 95% passing 2.0 mm
Max 5% passing 1.0 mm

Particle shape (Section 7.6)

Ten particles from each sieve fraction were randomly taken and two dimension measurements to ascertain length to width ratio was taken using an optical microscope.

Sample	Particle shape ratio <5:1 % of particles	Classification
1	6	Fail
2	4	Pass
3	8	Fail
4	0	Pass
5	0	Pass
6	0	Pass
7	0	Pass
8	0	Pass

Table 6 Particle shape results.

Samples 1 & 3 were the only samples to fail the particle shape specification, figure 12 shows the particle shape for sample 2. The results in table 6 report the % of particles with a length to width ratio <5:1.

Summary

Based on the cullet specification in PAS102:2004 section 7, none of the samples fully complied with the described specification. Table 7 summaries the results.

Sample	Colour	Contam-ination	Water content	Organic content	Particle size	Particle shape
1	Fail	NS	Pass	NS	Pass	Fail
2	Pass	NS	Pass	NS	Fail	Pass
3	Fail	NS	Pass	NS	Fail	Fail
4	Fail	NS	Pass	NS	Fail	Pass
5	Fail	NS	Pass	NS	Fail	Pass
6	Fail	NS	Pass	NS	Fail	Pass
7	Fail	NS	Pass	NS	Pass	Pass
8	Pass	NS	Pass	NS	Fail	Pass

Table 7 Summary of results, NS denotes ‘Not Specified’.

In our opinion the other samples were of relatively good quality except for samples 7 & 4. The cullet quality assessment undertaken should be used to judge whether the cullet is fit for purpose.

Dr Nick Kirk
Principal Technologist

Please note: *Samples submitted for testing etc. will normally be disposed of three months after date of reporting results unless otherwise arranged.*

Distribution

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Water Development Services
142 Whitchurch Road
Cardiff
CF12 3NA

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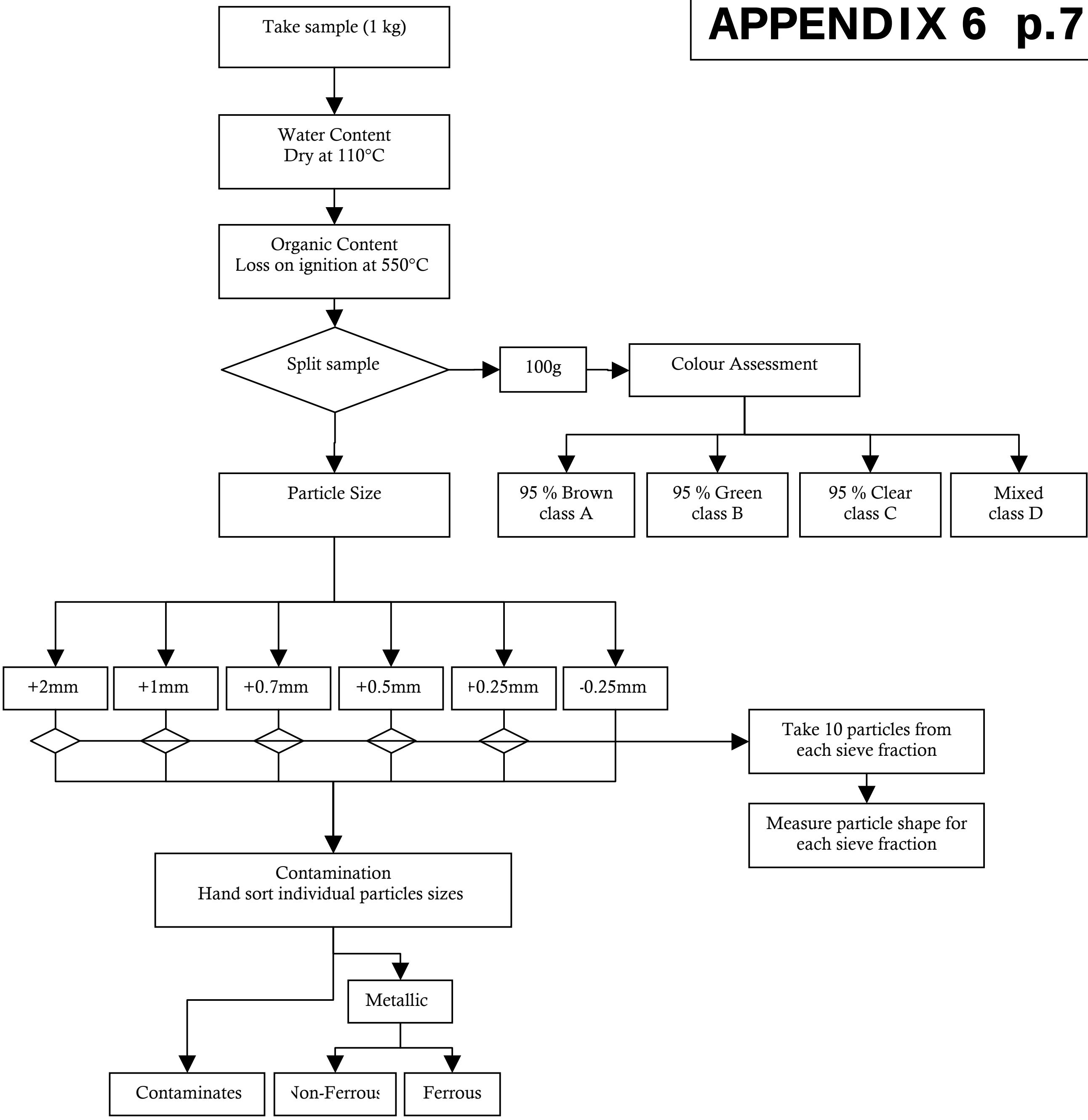


Report:

1) Colour specification
2) Contamination level
3) Water content
4) Organic content
5) Particle size
6) Particle shape

Figure 1 Cullet sampling and assessment procedure.

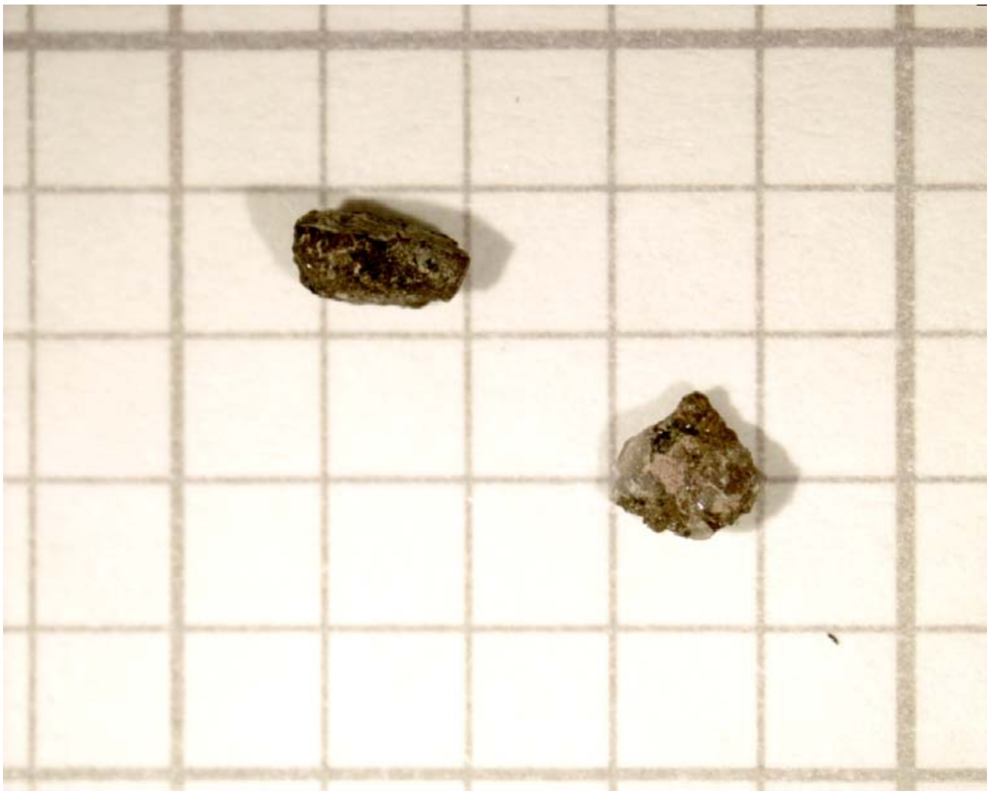


Figure 2 Inorganic contaminates found in sample 1 (1 mm grid).

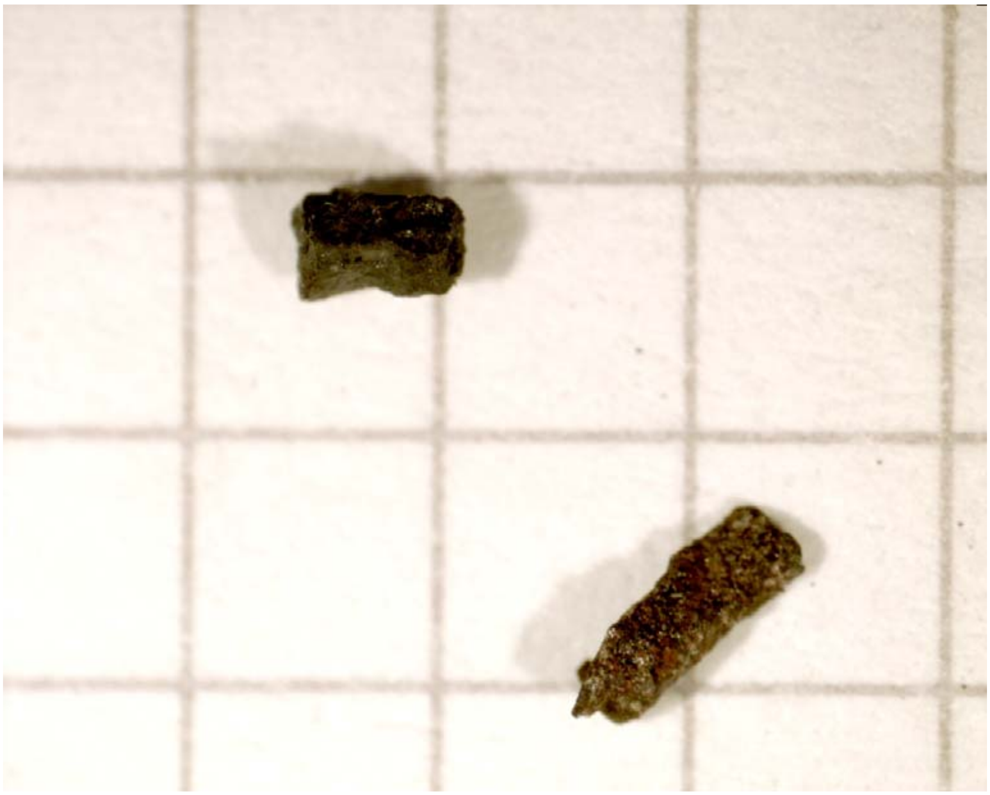


Figure 3 Ferrous contaminates (>0.7mm) found in sample 2 (1 mm grid).

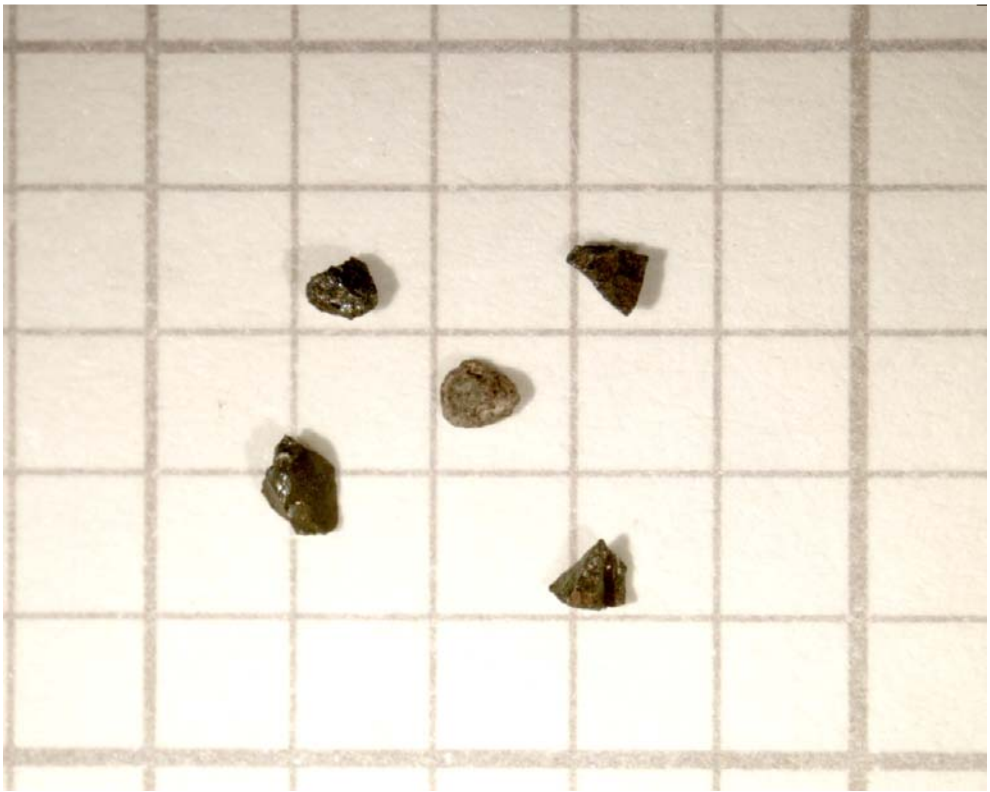


Figure 4 Ferrous contaminates (0.7 to 0.5 mm) found in sample 2 (1 mm grid).

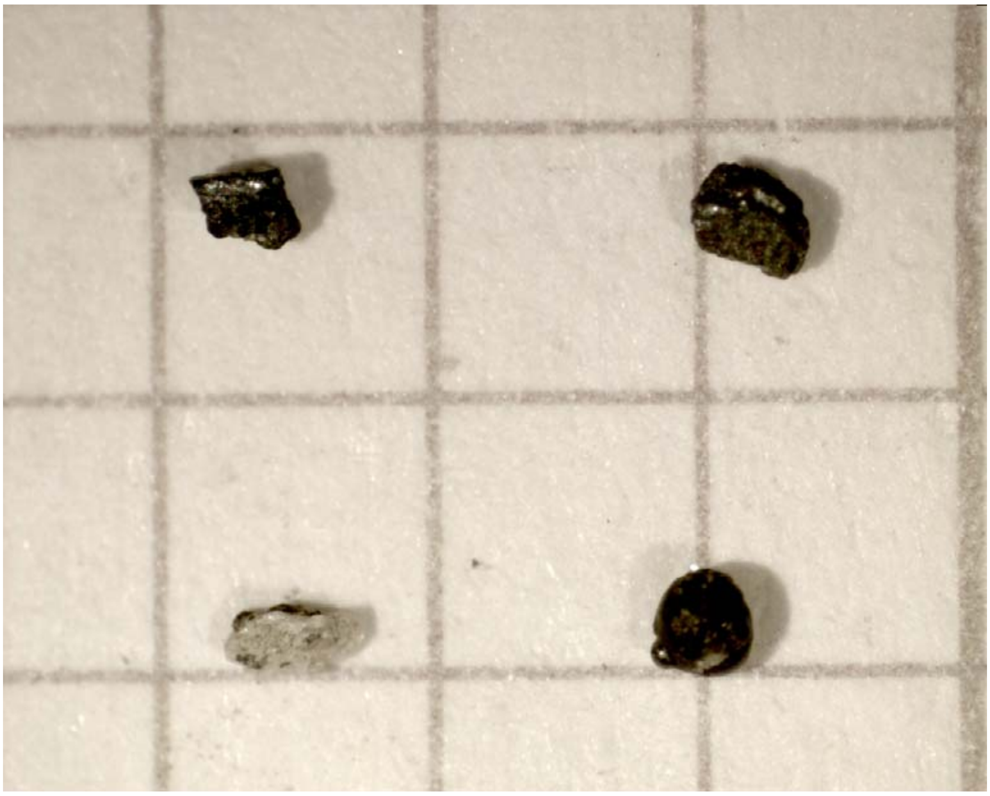


Figure 5 Ferrous contaminates (<0.5mm) found in sample 2 (1 mm grid).

Figure 6 Inorganic contaminates found in sample 3 (1 mm grid).

Figure 7 Ferrous contaminates found in sample 3 (1 mm grid).

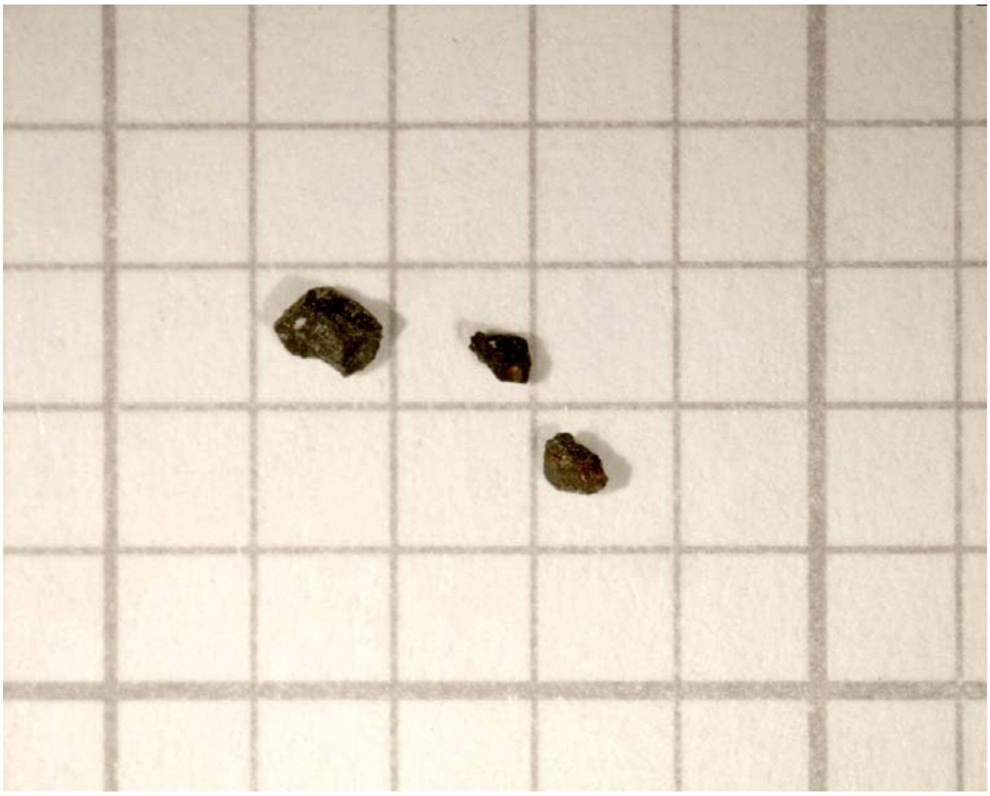


Figure 8 Ferrous contaminates found in sample 5 (1 mm grid).

Figure 9 Non-ferrous contaminates found in sample 7 (1 mm grid).

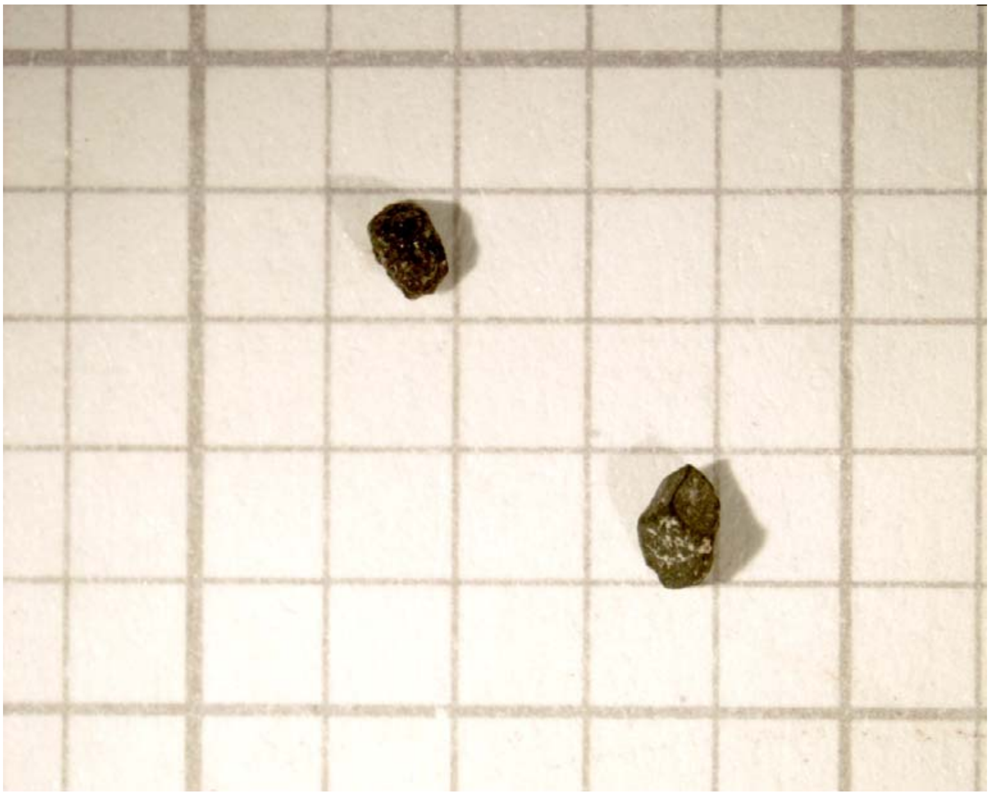


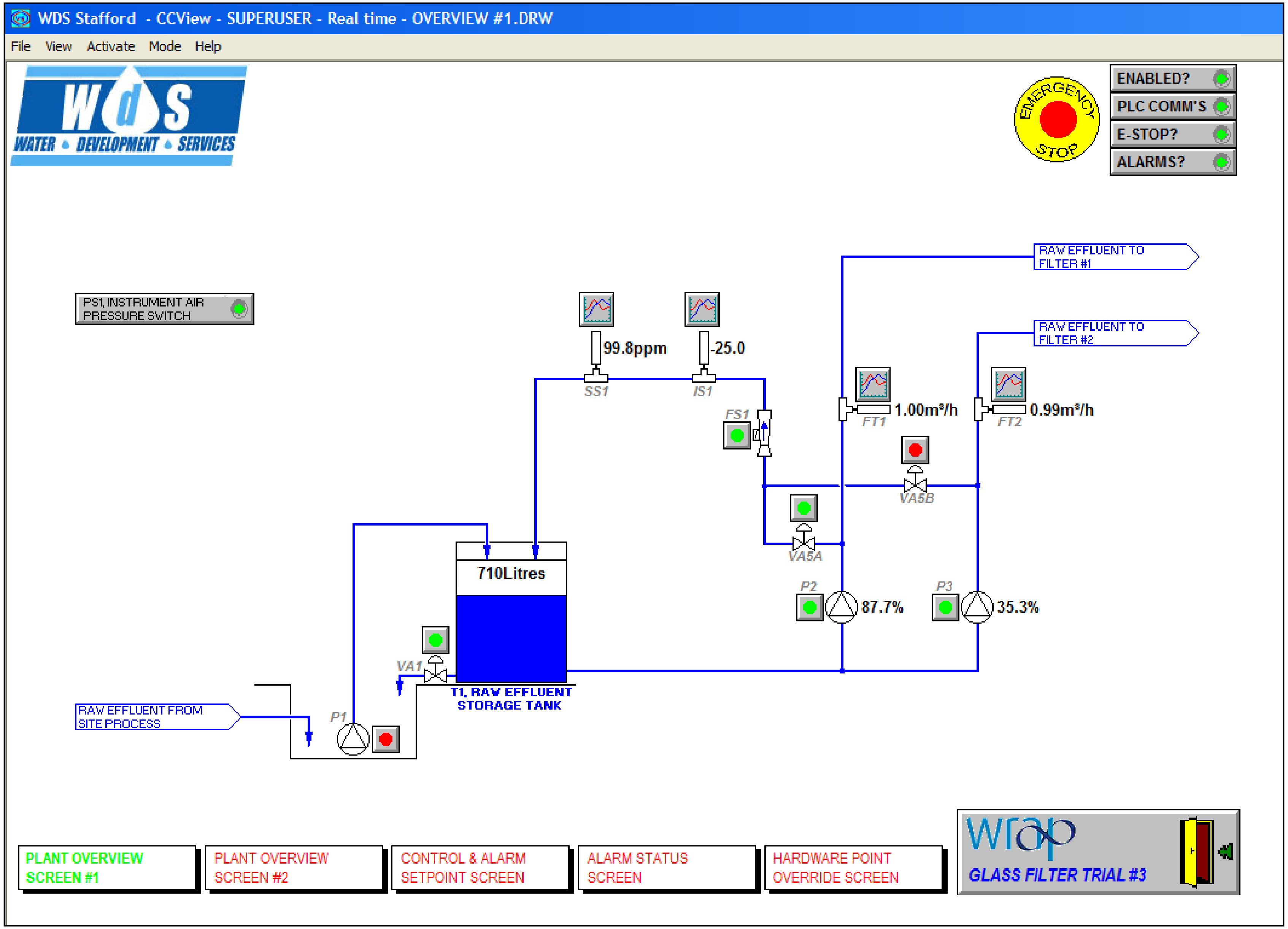
Figure 10 Ferrous contaminates found in sample 7 (1 mm grid).

Figure 11 Inorganic contaminates found in sample 7 (1 mm grid).

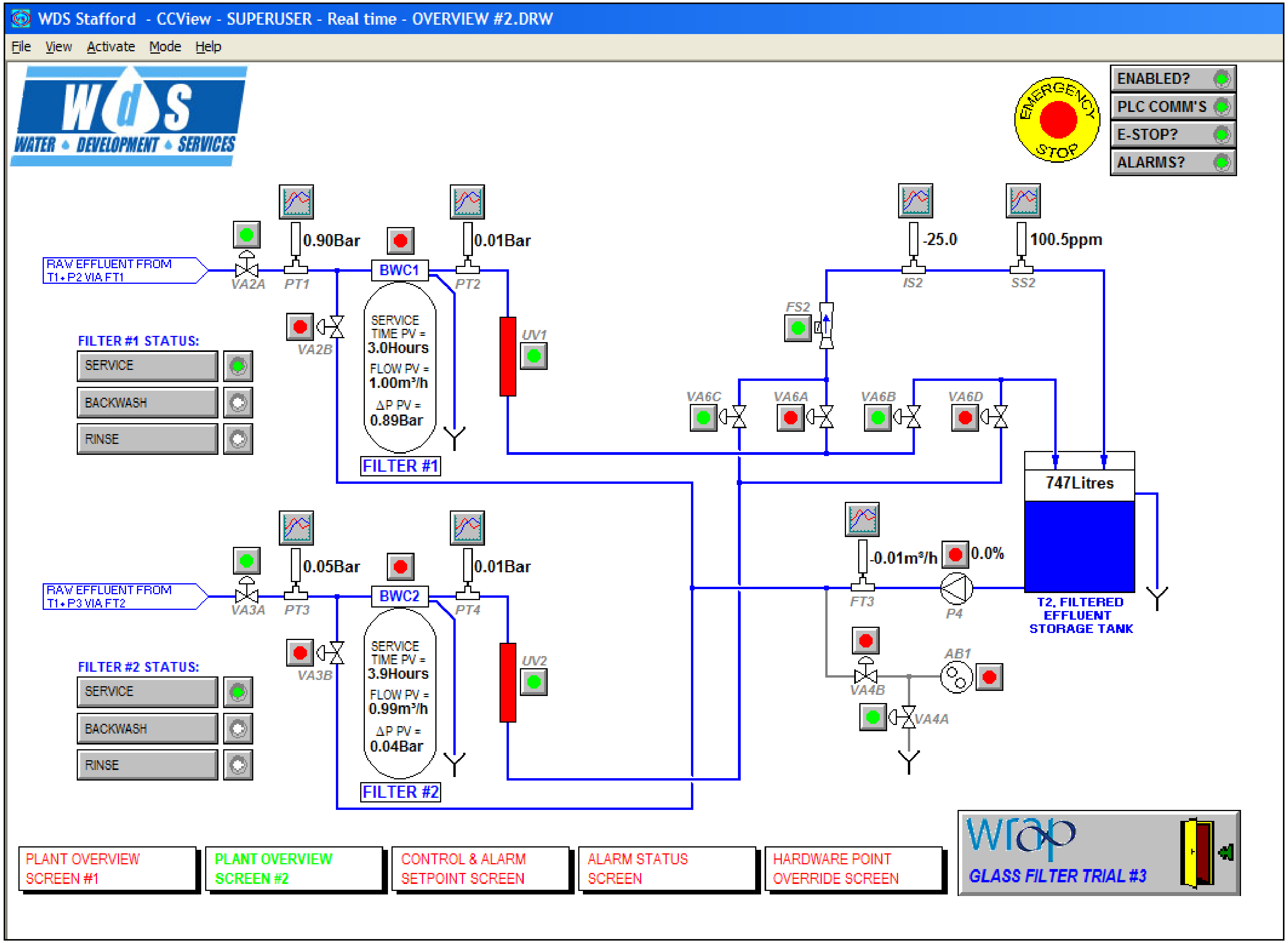
Figure 12 The particle shape for sample 2 (0.25 to 0.50 mm particle size fraction.


WDS Stafford - CCView - SUPERUSER - Real time - STARTUP.DRW
File View Activate Mode Help
LOGOUT FROM REMOTE SYSTEM
wrap
Creating markets for recycled resources
RECYLED GLASS FILTRATION
MEDIA TRIAL PLANT #3
ENGINEERED BY
WdS
WATER DEVELOPMENT SERVICES
PLANT OVERVIEW SCREEN #1
PLANT OVERVIEW SCREEN #2
CONTROL & ALARM SETPOINT SCREEN
ALARM STATUS SCREEN
HARDWARE POINT OVERRIDE SCREEN

APPENDIX 7.1


WDS Stafford - CCView - SUPERUSER - Real time - OVERVIEW #1.DRW
File View Activate Mode Help
WdS
WATER DEVELOPMENT SERVICES
EMERGENCY STOP
ENABLED?
PLC COMM'S
E-STOP?
ALARMS?
PS1, INSTRUMENT AIR PRESSURE SWITCH
RAW EFFLUENT TO FILTER #1
RAW EFFLUENT TO FILTER #2
99.8ppm
-25.0
SS1
IS1
FS1
1.00m³/h
FT1
0.99m³/h
FT2
VA5B
VA5A
P2
87.7%
P3
35.3%
710Litres
VA1
T1, RAW EFFLUENT STORAGE TANK
RAW EFFLUENT FROM SITE PROCESS
P1
PLANT OVERVIEW SCREEN #1
PLANT OVERVIEW SCREEN #2
CONTROL & ALARM SETPOINT SCREEN
ALARM STATUS SCREEN
HARDWARE POINT OVERRIDE SCREEN
wrap
GLASS FILTER TRIAL #3

APPENDIX 7.2


WDS Stafford - CCView - SUPERUSER - Real time - OVERVIEW #2.DRW
File View Activate Mode Help
WdS
WATER DEVELOPMENT SERVICES
EMERGENCY STOP
ENABLED?
PLC COMM'S
E-STOP?
ALARMS?
RAW EFFLUENT FROM T1+P2 VIA FT1
VA2A
PT1
0.90Bar
BWC1
PT2
0.01Bar
VA2B
SERVICE TIME PV = 3.0Hours
FLOW PV = 1.00m³/h
ΔP PV = 0.89Bar
FILTER #1
UV1
FILTER #1 STATUS:
SERVICE
BACKWASH
RINSE
RAW EFFLUENT FROM T1+P3 VIA FT2
VA3A
PT3
0.05Bar
BWC2
PT4
0.01Bar
VA3B
SERVICE TIME PV = 3.9Hours
FLOW PV = 0.99m³/h
ΔP PV = 0.04Bar
FILTER #2
UV2
FILTER #2 STATUS:
SERVICE
BACKWASH
RINSE
IS2
-25.0
SS2
100.5ppm
FS2
VA6C
VA6A
VA6B
VA6D
747Litres
T2, FILTERED EFFLUENT STORAGE TANK
FT3
-0.01m³/h
0.0%
P4
AB1
VA4B
VA4A
PLANT OVERVIEW SCREEN #1
PLANT OVERVIEW SCREEN #2
CONTROL & ALARM SETPOINT SCREEN
ALARM STATUS SCREEN
HARDWARE POINT OVERRIDE SCREEN
wrap
GLASS FILTER TRIAL #3

APPENDIX 7.3

WDS Stafford - CCView - SUPERUSER - Real time - SETPOINTS.DRW

File View Activate Mode Help

WDS WATER DEVELOPMENT SERVICES

EMERGENCY STOP

ENABLED?

PLC COMM'S

E-STOP?

ALARMS?

CONTROL AND ALARM SETPOINT SCREEN

FILTER #1 SERVICE CONTROL SETPOINTS	
FILTER #1 ENABLE	Enable
P2 FILTER #1 SERVICE FLOW SP	1.0m^3/h
P2 PID LOOP GAIN (P) SP	10.0
P2 PID LOOP INTEGRAL (I) SP	2.0
P2 PID LOOP DIFFERENTIAL (D) SP	3.0
FILTER #1 BACKWASH CONTROL SETPOINTS	
FILTER #1 RUNTIME SP TO TRIGGER BACKWASH	4.0Hours
FILTER #1 AIR SCOUR DURATION SP	4.0Min
FILTER #1 BACKWASH DURATION SP	5.0Min
FILTER #1 RINSE DURATION SP	8.0Min
FILTER #2 SERVICE CONTROL SETPOINTS	
FILTER #2 ENABLE	Enable
P3 FILTER #2 SERVICE FLOW SP	1.0m^3/h
P3 PID LOOP GAIN (P) SP	10.0
P3 PID LOOP INTEGRAL (I) SP	2.0
P3 PID LOOP DIFFERENTIAL (D) SP	3.0
FILTER #2 BACKWASH CONTROL SETPOINTS	
FILTER #2 RUNTIME SP TO TRIGGER BACKWASH	4.0Hours
FILTER #2 AIR SCOUR DURATION SP	4.0Min
FILTER #2 BACKWASH DURATION SP	5.0Min
FILTER #2 RINSE DURATION SP	8.0Min

BACKWASH PUMP CONTROL SETPOINTS	
P4 BACKWASH FLOW SP	3.0m^3/h
P4 RINSE FLOW SP	1.0m^3/h
P4 PID LOOP GAIN (P) SP	10.0
P4 PID LOOP INTEGRAL (I) SP	2.0
P4 PID LOOP DIFFERENTIAL (D) SP	3.0
COMMON CONTROL SETPOINTS	
PLANT ENABLE	Enable
T1 HIGH CONTROL SP	800Litres
T1 LOW CONTROL SP	700Litres
SAMPLING CYCLE TIME SP	15Min
MANUAL FILTER SAMPLING SWAP REQUEST	Off
T1 SLUDGE DUMP SCHEDULE	
ALARM SETPOINTS	
T1 HIGH LEVEL ALARM SP	950Litres
T1 LOW LEVEL ALARM SP	250Litres
T2 HIGH LEVEL ALARM SP	900Litres
T2 LOW LEVEL ALARM SP	200Litres
FT1 HIGH FLOW ALARM SP	1.0m^3/h
FT1 LOW FLOW ALARM SP	0.5m^3/h
FT2 HIGH FLOW ALARM SP	1.0m^3/h
FT2 LOW FLOW ALARM SP	0.5m^3/h
FT3 HIGH FLOW ALARM SP	2.5m^3/h
FT3 LOW FLOW ALARM SP	0.5m^3/h

PLANT OVERVIEW SCREEN #1

PLANT OVERVIEW SCREEN #2

CONTROL & ALARM SETPOINT SCREEN

ALARM STATUS SCREEN

HARDWARE POINT OVERRIDE SCREEN

wrap GLASS FILTER TRIAL #3

APPENDIX 7.4

WDS Stafford - CCView - SUPERUSER - Real time - ALARM STATUS.DRW

File View Activate Mode Help

WATER DEVELOPMENT SERVICES

EMERGENCY STOP

ENABLED?

PLC COMM'S

E-STOP?

ALARMS?

ALARM STATUS SCREEN

UC32_1	
ALARM No. 1: T1 high level alarm	O.K.
ALARM No. 2: T1 low level alarm	O.K.
ALARM No. 3: PLC comms failure	O.K.
ALARM No. 4: Filter #1 raw effluent sample flow alarm	O.K.
ALARM No. 5: Filter #2 raw effluent sample flow alarm	O.K.
ALARM No. 6: PS1 low instrument air pressure	O.K.
ALARM No. 7: UV1 fault	Alarm
ALARM No. 8: P2 tripped	O.K.
ALARM No. 9: P1 tripped	O.K.
ALARM No. 10: E-stop activated	O.K.
ALARM No. 11: Filter #1 backwash start fault alarm	O.K.
ALARM No. 12: Filter #1 backwash stall fault alarm	O.K.
ALARM No. 13: FT1 high flow alarm	O.K.
ALARM No. 14: FT1 low flow alarm	O.K.

UC32_2	
ALARM No. 1: FT2 high flow alarm	O.K.
ALARM No. 2: FT2 low flow alarm	O.K.
ALARM No. 3: FT3 high flow alarm	O.K.
ALARM No. 4: FT3 low flow alarm	O.K.
ALARM No. 5: T2 high level alarm	O.K.
ALARM No. 6: T2 low level alarm	O.K.
ALARM No. 7: P3 tripped	O.K.
ALARM No. 8: UV2 fault	Alarm
ALARM No. 9: Filter #1 filtered effluent sample flow alarm	Alarm
ALARM No. 10: Filter #2 filtered effluent sample flow alarm	O.K.
ALARM No. 11: P4 tripped	O.K.
ALARM No. 12: AB1 tripped	O.K.
ALARM No. 13: Filter #2 backwash start fault alarm	O.K.
ALARM No. 14: Filter #2 backwash stall fault alarm	O.K.

PLANT OVERVIEW SCREEN #1

PLANT OVERVIEW SCREEN #2

CONTROL & ALARM SETPOINT SCREEN

ALARM STATUS SCREEN

HARDWARE POINT OVERRIDE SCREEN

wrap

GLASS FILTER TRIAL #3

APPENDIX 7.5

APPENDIX 7.6

WDS Stafford - CCView - SUPERUSER - Real time - OVERRIDE.DRW

File View Activate Mode Help

WDS WATER • DEVELOPMENT • SERVICES

UNITRON CONTROLLER HARDWARE POINT OVERRIDE SCREEN

EMERGENCY STOP

ENABLED?
PLC COMM'S
E-STOP?
ALARMS?

UC32_1	
1_1 IS1, raw effluent ion specific analyser	-25.0%
1_2 SS1, raw effluent suspended solids analyser	99.8%
1_3 FT1, filter #1 inlet flow transmitter	33.1%
1_4 PT1, filter #1 inlet pressure transducer	24.3%
1_5 PT2, filter #1 outlet pressure transducer	0.3%
1_6 LT1, raw effluent storage tank level transmitter	76.8%
1_7 Spare 4-20mA analogue input	-25.0%
1_8 Spare 4-20mA analogue input	-25.0%
1_9 Filter #1 feed pump P2 healthy	O.K.
1_10 BWC1 status indication	Service
1_11 Filter #1 UV steriliser (UV1) alarm contact	Alarm
1_12 Raw effluent analsyer sample manifold flowswitch, FS1	Flow
1_13 Raw effluent transfer pump P1 healthy	O.K.
1_14 E-stop actuated signal	O.K.
1_15 Instrument air pressure switch, PS1	O.K.
1_16 P2, Filter #1 feed pump speed request	89.8%
1_17 P2, Filter #1 feed pump enable	On
1_18 BWC1 backwash start signal	Off
1_19 UV1, Filter #1 UV steriliser	On
1_20 VA2-A and VA2-B, filter #1 backwash inlet valves	Service
1_21 VA5-A and VA5-B, raw effluent analyser sample valves	On
1_22 P1, Raw effluent transfer pump	Off*
1_23 VA4-A and VA4-B, AB1 drain/scour valves	Off*
1_24 VA1, T1 sludge dump valve	Off

UC32_2	
2_1 IS2, filtered effluent ion specific analyser	-25.0%
2_2 SS2, filtered effluent suspended solids analyser	100.5%
2_3 FT2, filter #2 inlet flow transmitter	33.7%
2_4 PT3, filter #2 inlet pressure transducer	0.5%
2_5 PT4, filter #2 outlet pressure transducer	0.3%
2_6 LT2, filtered effluent storage tank level transmitter	74.6%
2_7 FT3, filter backwash flow transmitter	-0.3%
2_8 Spare 4-20mA analogue input	-25.0%
2_9 Filter #2 feed pump P3 healthy	O.K.
2_10 BWC2 status indication	Service
2_11 Filter #2 UV steriliser (UV2) alarm contact	Alarm
2_12 Filtered effluent analsyer sample manifold flowswitch, FS2	Off
2_13 Filter backwash pump P4 healthy	O.K.
2_14 Backwash air blower AB1 healthy	O.K.
2_15 Spare volt-free digital input	Off
2_16 P3, Filter #2 feed pump speed request	35.3%
2_17 P3, Filter #2 feed pump enable	On
2_18 BWC2 backwash start signal	Off
2_19 UV2, Filter #2 UV steriliser	On
2_20 VA3-A and VA3-B, filter #2 backwash inlet valves	Service
2_21 VA6-A and VA6-B, filtered effluent analyser sample valves	On
2_22 P4, Filter backwash pump speed request	0.0%
2_23 P4, Filter backwash pump enable	Off
2_24 AB1, backwash airblower	Off

PLANT OVERVIEW SCREEN #1

PLANT OVERVIEW SCREEN #2

CONTROL & ALARM SETPOINT SCREEN

ALARM STATUS SCREEN

HARDWARE POINT OVERRIDE SCREEN

wrap GLASS FILTER TRIAL #3