Project title:	**Slow sand filtration in HNS production: assessment of pre-filtration treatments of water to reduce the frequency of filter cleaning operations.**	
Report:	**Final Report**	
Project Number:	**HNS 88b**	
Project Leader:	**Dr Tim Pettitt** **HRI Efford** **Lymington** **Hants SO41 0LZ**	
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Foreword to project HNS 88b by Grower Co-ordinator Hugh Nunn

Tim Pettitt has done it again!

Done what?

He has once again addressed a very real problem which growers face when seeking to clean up contaminated water for irrigation use. Earlier work showed how slow sand filters can take out the 'nasties' which can have a very serious, nay devastating, effect on nursery crops. His workshops for HDC levy payers have created lots of interest as well as furnishing us all with practical insights and money-saving information. If you haven't followed his earlier work, HDC office will speed you the info.

This work shows how the basic, often visible 'gunge' in contaminated water can be removed before introducing the water to the slow sand filter for final clean up. If you think a 'backwash' is something you do in the shower then this report will give you another interpretation. Don't put this report down until you have absorbed some of Tim's vital work on our behalf!

PRACTICAL SECTION FOR GROWERS

Background and Objectives

This project is the last in a series showing the value of, and demonstrating how to install and run, slow sand filters (SSF) for removing plant pathogens from contaminated irrigation water. Projects in the series so far have been: HNS 88 which used microbiological test procedures to monitor the successful installation of two full-scale commercial SSF; HNS 88a a project which demonstrated that a wide range of sands are effective for SSF and also developed a pilot filter concept; and HNS 88c which is a series of HDC funded workshops on all aspects of SSF installation and operation. The current project addresses the question of filter blockage, the only major practical problem that can hinder effective SSF operation. In project HNS 88 two large filters were operated and monitored under commercial HNS production conditions. In the absence of pre-filtration systems, both SSF frequently became blocked by the accumulation at the sand surface of fine particles suspended in the raw untreated water. Such blockages had to be cleaned by scraping off the top centimetre of clogged sand from the filter surface. The aim of the current project was to reduce the frequency of these clean-ups and to increase their efficiency to cut the overall labour costs of SSF operation.

A number of techniques are available for removing fine particles from water, but whilst their individual efficacy may be understood, the impact of their use on the efficacy of a horticultural SSF is not properly understood. Other techniques have been tried by the water industry for increasing the speed of filter cleaning operations, but have not been widely adopted by the water companies because they were not readily adapted to their very large-scale SSF units. However, some of these procedures including fabric covers (Graham *et al.*, 1996), or sand cleaning apparatus, which operate by stirring the top 10 cm of sand and siphoning off the re-suspended silt and fines (Burman & Lewin, 1961), might be suitable for use on the relatively small filters used in horticulture.

The key objectives of this project were:

A Identification of effective pre-filtration water cleaning techniques, including both water cleaning equipment and fabric SSF covers.

B Identification of the parameters that can guide selection of appropriate pre-filtration strategies for individual nurseries.

C Testing the feasibility and reliability of SSF cleaning techniques, especially *in situ* 'scouring'.

Key Results and Conclusions

- A test rig was constructed to deliver water at a consistent level of particulates contamination to small SSF units. This was achieved by maintaining water in a header tank under constant agitation. The rig was capable of delivering this 'raw' water either *via* a pumped outlet or by gravity feed depending on the pre-filtration system to be tested.

- A simple regime for water contamination was established. After assessing materials from a variety of sources, two classes of contaminating material were used: 1) 'silt', using material collected from a local river bed and 2) 'peat', which consisted of peat fines mixed with loam-derived silt. These materials were added to the header tank in different experiments, but always at a rate maintaining a total suspended solids loading of 150 mg/litre.

- The test rig was used both in experiments to test pre-filtration techniques and to generate SSF blockages to carry out filter clean-up experiments.

- Pre-filtration was demonstrated to be very effective in reducing the rate of SSF head-loss development. Using the Cross 'EasyClean' system to pre-filter raw water, the rate of head-loss development was reduced from an average of 1.2 cm day^{-1} to 0.16 cm day^{-1} with the 50 µm filter element and to 0.09 cm day^{-1} with the 25 µm filter element.

- Of the three pre-filtration approaches tested, the Cross 'EasyClean' system gave the best results with low volumes of water required for backwash cycles. The run-down separator (gravity filter) gave good filtration results but it was not possible to test its impact on SSF head-loss development in longer-term experiments.

- Whilst some forms of pre-filtration covers worked reasonably well at reducing the rate of SSF head-loss development (shredded rockwool = 76% reduction compared to controls over 56 days and gravel = 36-56% over 60 days), the fabrics assessed failed. Although the use of fabric covers to reduce the rate of head-loss development is a proven concept, our work has simply demonstrated that capillary matting and Mypex fabrics are inappropriate for this technique.

- Assessment of samples of surface sand from blocked SSF showed wide variation in the sizes of suspended particles in the raw water of different nurseries. In the small number of representative samples assessed, a surprisingly similar proportion of weight of contaminant particles to weight of sand (approximately 4%) was observed, irrespective of the size distribution of the particles. These results illustrate the importance of determining the quantity of suspended particles and range of particle sizes present in the raw water before deciding on what type of pre-filtration treatment to adopt.

- No form of pre-filtration will completely eliminate the eventual need for SSF clean-ups.

- Cleaning of SSF by using a backwash of the top few centimetres of sand worked well both in terms of reducing head-loss and the amount of disruption to SSF microbiological efficacy. The disruption to efficacy was comparable to cleaning by scraping. The advantage to this *in situ* cleaning approach is a major saving in labour plus a modest reduction in filter ‘down time’.

- *In situ* cleaning of the SSF was improved by the placement of a gravel cover on the surface of the filter sand. This allowed the backwash to be performed in a much reduced volume of supernatant water whilst leaving the actual sand layer undisturbed. In addition, the presence of a gravel cover increased the length of SSF run-times between clean-ups, although the use of a gravel cover in this way alone is not recommended as an alternative to pre-filtration.

Action Points

- ***Pre-filtration:***

  Large increases in SSF run-times are possible using pre-filtration to reduce the rate of head-loss development. Before selecting a pre-filtration system it is very important to carry out an assessment of the size distribution and quantities of suspended particles present in the raw water to be treated. Such an assessment should include the analysis of water samples taken on several occasions over a period of months. Ideally at least one sample should be taken immediately after heavy rainfall. There are two levels of information to be gained from this assessment of the raw water.

  The first is an estimate of the **expected particulates load**, this will indicate whether or not pre-filtration is necessary. For example a raw water source derived largely from greenhouse roof water may have a very low particulates load and therefore not necessitate pre-filtration. Using the data on particulates load it may be possible to make a rough estimate of the expected SSF run-time (this can be done using data from this project that indicates that approximately 4% by weight of suspended particulates in the top 1 cm of SSF sand will result in the development of terminal head-loss – this is equivalent to 60-70 mg/cm^2 of filter surface). From this estimate, the cost of installing pre-filtration equipment and the cost of labour involved in routine maintenance, an economic decision can be made as to the practicality of pre-filtration.

  The second level of information is the **size distribution of the particles** in the raw water. This information is vital in deciding what type of pre-filtration to use and in some cases (for example, where the raw water contains very large quantities of clay particles <30 µm) whether SSF or even recycling water will be an economic proposition. For water where a large proportion (60-70% by weight) of suspended particles are greater than 50 µm in diameter a good pre-filtration performance can be expected using the systems tested in this project (Cross Ltd 'EasyClean' with 50 µm filter element & Run-down separator or Gravity filter with 50 µm filter mesh). Other filtration equipment will be capable of similar results in terms of reducing the rate of SSF head-loss development, however, it is important to determine (a) the quantities of water required for and the amount of time spent back-washing, and (b) the amount of labour that may be required if the equipment is cleaned manually.

  Use of **filter covers** or layers of materials such as fabrics, rockwool or gravel placed on top of the upper surface of the SSF sand can reduce the rate of head-loss development and therefore increase filter run times. However, care must be exercised using this approach. Firstly, many fabrics are inappropriate, and all four of the capillary matting fabrics assessed in this project failed to work. In addition, although at first appealing, the removal of fabric covers from a clogged SSF for cleaning is probably not a practical solution to either extending filtration runs or filter clean-ups. Conversely, the use of shredded rockwool or gravel as a cover layer, at least 10 cm deep, did reduce the rate of SSF head-loss development and thereby increase filter run times. These materials if used alone for pre-filtration without any modifications to the basic SSF design would probably not be economic because increased labour requirements at clean-ups for only a comparatively modest increase in SSF run-time. However, excellent results were obtained in this project when gravel covers were used in combination with an *in situ* cleaning system.

- ***Improving the efficacy of SSF clean-ups:***
  The use of a gravel layer, at least 10 cm deep, on top of the SSF in combination with back-washing proved to be an effective way of cleaning a clogged SSF. Two prototype SSF designs using overhead irrigation nozzles, placed either just below or just at the surface of the gravel layer, to deliver a backwash were shown to be effective both in terms of cleaning and the short time for the filter to recover microbiologically from the disruption of cleaning. As wash water velocities of 10-30 m/h are sufficient to clean sand, it may be possible to use lower pressure water outlets than nozzles to clean the gravel surface. An important aspect to the installation of *in situ* washing of a gravel cover layer is the placement of drainage ports close to the gravel surface to remove the backwash water. This minimises the volume of water required for a backwash. The advantages of using a backwash system like this are; a substantial reduction in labour required for clean-ups, a reduction in filter down-time and a clean-up system that lends itself to becoming a routine operation. Based on experiences in this project, it is not recommended to use a gravel cover plus back-washing as the only system for pre-filtration and cleaning unless the particulates load of the raw water is very low. However, if used in combination with a pre-filter this approach should help to further increase filter run-times and reduce the cost of clean-up operations.

Anticipated Practical and Financial Benefits

The potential financial benefits of successfully installing slow sand filtration to allow recirculation of irrigation water have been outlined in previous work sponsored by the HDC (HNS 88, HNS 88a & especially HNS 88c). The benefits include:

- savings in water costs
- help in compliance with ever-tighter legislation on water use and disposal
- increased flexibility in the management of water supply (especially in periods of drought).

Two areas where our experience has shown that the efficiency of horticultural SSF operation can be greatly improved are a reduction in the frequency of filter blockages and cutting down on labour costs and down-times when filters do eventually become blocked. This project addresses both of these issues; pre-filtration deals with the first and *in situ* cleaning deals with the second. The procedures described in this report may incur greater capital cost to install but will increase the efficacy of the water cleaning operation, and greatly reduce the labour requirements for routine filter operations. The information on pre-filtration has wider application than for just SSF as most water cleaning processes (eg UV) require some form of pre-filtration to operate at optimal efficacy.

SCIENCE SECTION

Introduction

This project is the last in a series showing the value of, and demonstrating how to install and run, slow sand filters (SSF) for removing plant pathogens from contaminated irrigation water. Projects in the series so far have been: HNS 88 which used microbiological test procedures to monitor the successful installation of two full-scale commercial SSF; HNS 88a a project which demonstrated that a wide range of sands are effective for SSF and also developed a pilot filter concept; and HNS 88c which is a series of HDC funded workshops on all aspects of SSF installation and operation. The current project addresses the question of filter blockage, the only major practical problem that can hinder effective SSF operation. In project HNS 88 two large filters were operated and monitored under commercial HNS production conditions. In the absence of pre-filtration systems, both SSF frequently became blocked by the accumulation at the sand surface of fine particles suspended in the raw untreated water. Such blockages had to be cleaned by scraping off the top centimetre of clogged sand from the filter surface. The aim of the current project was to reduce the frequency of these clean-ups and to increase their efficiency to cut the overall labour costs of SSF operation.

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A Identification of effective pre-filtration water cleaning techniques, including both water cleaning equipment and fabric SSF covers.

B Identification of the parameters that can guide selection of appropriate pre-filtration strategies for individual nurseries.

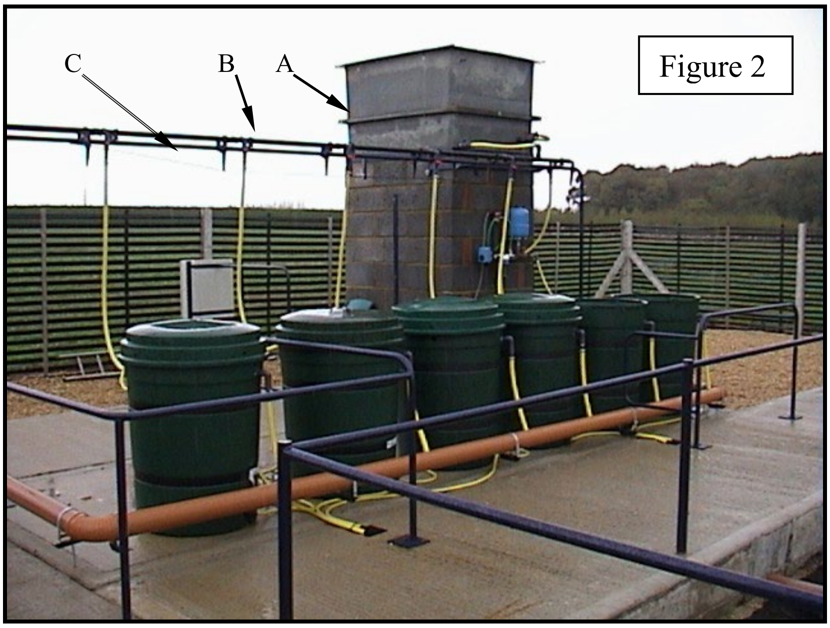
C Testing the feasibility and reliability of SSF cleaning techniques, especially *in situ* ‘scouring’.

Materials and Methods

Pre-filtration test rig

A test rig was constructed using the rain-water butt pilot filter design developed in project HNS 88a as the basic SSF unit. The rig was designed to supply raw water with a consistent level of predetermined particulate contamination to six SSF units (Figures 1 & 2). The rig was capable of delivering water either *via* a pumped outlet or by gravity feed depending on the pre-filtration device to be tested.

Figures 1 & 2: Views of the SSF test rig from the North (1) and the South (2), showing the header tank (A) and the high (B) and low (C) pressure raw water supply lines



Water was artificially contaminated with measured amounts of particulate material, and this was kept suspended using a submersible pump to agitate the water in the header tank (Figures 1 & 2, marked 'A'). A simple regime of water contamination was established using material from, a) a local river bed and b) peat fines and silt. These materials were added to give a total suspended solids loading of 150 mgl^{-1}, the proportions by weight of particles of different size ranges was determined by wet sieving and drying down sieved fractions before weighing. In addition small sub-samples were assessed under the microscope.

Figure 3: Close-up photograph of the Cross EasyClean filter set up with a 50µm filtration cartridge (for details of this pre-filtration system see Appendix I).

Pre-filtration assessments

Detailed assessments of the effects of pre-filtration on SSF maturation and run-times were carried out using a filtration device, **'Easyclean Automatic'**, kindly supplied by Cross Manufacturing Co. (1938) Ltd. (Bath, BA2 5RR, UK). This system filters water through a precisely engineered coil element (Figure 3) which filters in a similar manner to a disk filter but which has a very efficient automatic backwash using only small quantities of water (for full details of this system see Appendix I). Two sizes of filtration element were tested these were 50 µm and 25 µm. The performance of these was assessed in different filtration runs with water contaminated with two types of suspended solids as described above. In a preliminary series of short-term experiments, pre-filtration was assessed for its effect on the time for SSF to reach maturity. However, for the longer-term comparisons of pre-filters and their effect on SSF run time, all SSF on the test rig, including controls treated with non-pre-filtered raw water, were primed using a common source of raw water from the main supply pond. This procedure ensured a uniform start to the timed comparisons.

The development of filter maturity was determined by microbiological assessments (see below), whilst the main measure of filter run-time was the rate of SSF head loss development (see HDC report HNS 88a), supplemented with less frequent microbiological efficacy assessments of filtered compared with unfiltered water.

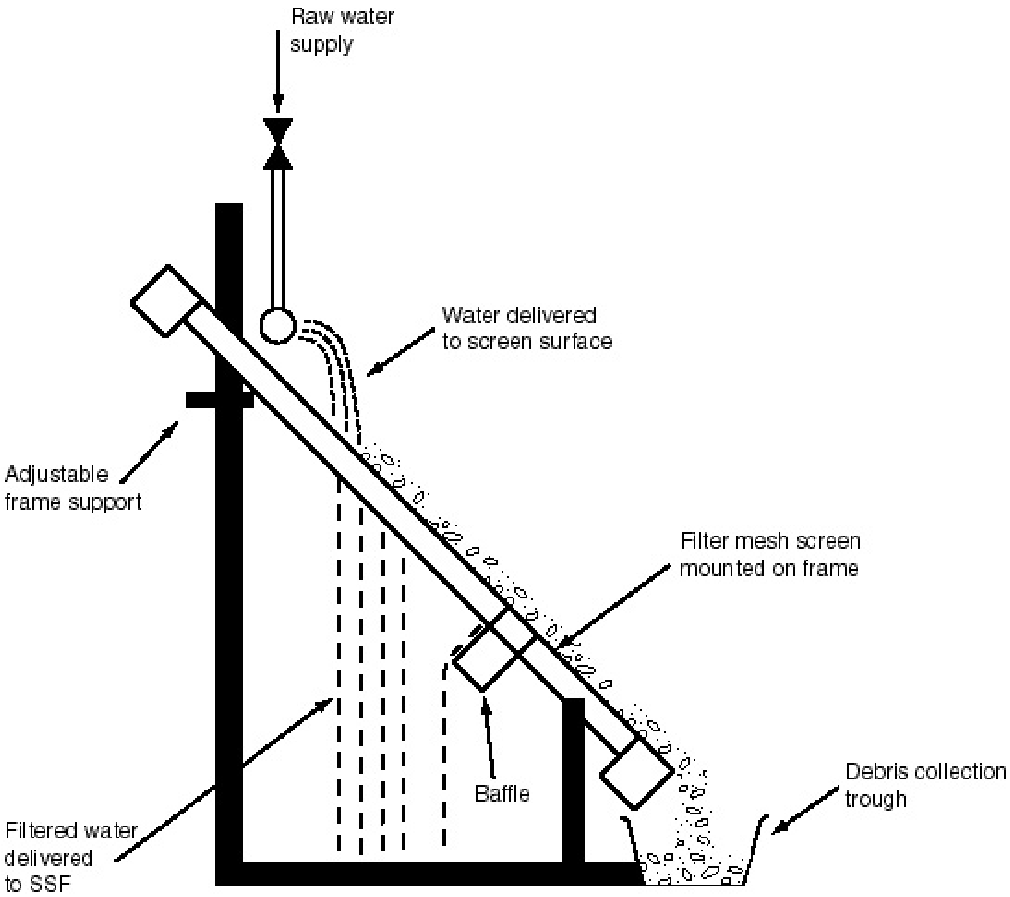
A '***run down separator' or 'gravity filter'*** was constructed to allow the simple assessment of this approach to pre-filtration using a small number of selected nylon fabric filter mesh sizes. The separator consisted of a wooden frame over which fabric panels were attached. The frame was suspended over the top of a SSF on a welded angle steel jig, which allowed the filter frame to be tested at a range of different angles to the vertical flow of low pressure water from the test rig (Figure 4). Raw water was delivered to the top end of the filter panel *via* a 15 mm pvc pipe drilled with a row of 5 mm holes at 20 mm spacings (Figure 4, photograph of front elevation). Filter mesh sizes of 50, 80, 110 and 200 μm were assessed using specialised nylon filter mesh fabrics (Lockertex, Warrington, WA5 5NP, UK).

The concept of protecting the SSF sand from clogging by using some form of permeable, but more ***open-structured cover*** was assessed using seven different materials. These were; four different non-woven capillary matting fabrics (Fibretex Superflor 250, Geerings 2H, Fibretex PPR433 and Flowering Plants Florimat 2), Mypex matting, Rockwool and gravel (effective sizes 3.6 mm & 5.8 mm; uniformity coefficients 2.8 & 2.0 respectively). Matting fabrics were cut to the shape of the SSF surface and placed on the sand I layer thick. Rockwool was gently teased into pieces approximately 4 cm × 4 cm from blocks (Grodan Ltd, 'Talent') and placed in a layer 10 cm deep across the SSF surface. The gravels were similarly placed in layers 10 cm deep over the SSF sand surface.

SSF clean-up assessments

Two variations of a basic design of filter back-washing system were built. The first was developed initially to backwash the top layer of SSF sand as set out in the project proposal. However, this was soon adapted to backwash a gravel layer placed as a cover over the filter sand, as gravel particles were able to settle out quicker from being stirred up by the scouring jets of water used for the back wash (Figure 5A). The underlying back-washing concept was the same in both of the designs, using an adaptation of the *in situ* cleaning idea developed by Burman & Lewin (1961). The main differences were the depth of cleaning, the direction and permanent positioning of the cleaning nozzles within the SSF in the systems developed in the current project.

Figure 4: Diagram showing side elevation and photograph showing front elevation of the run-down separator (gravity filter). Photograph shows filter in operation using a 200µm filter mesh.



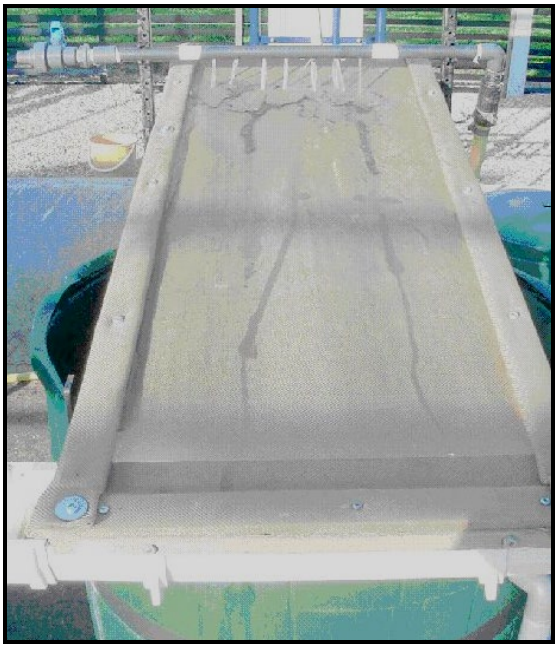
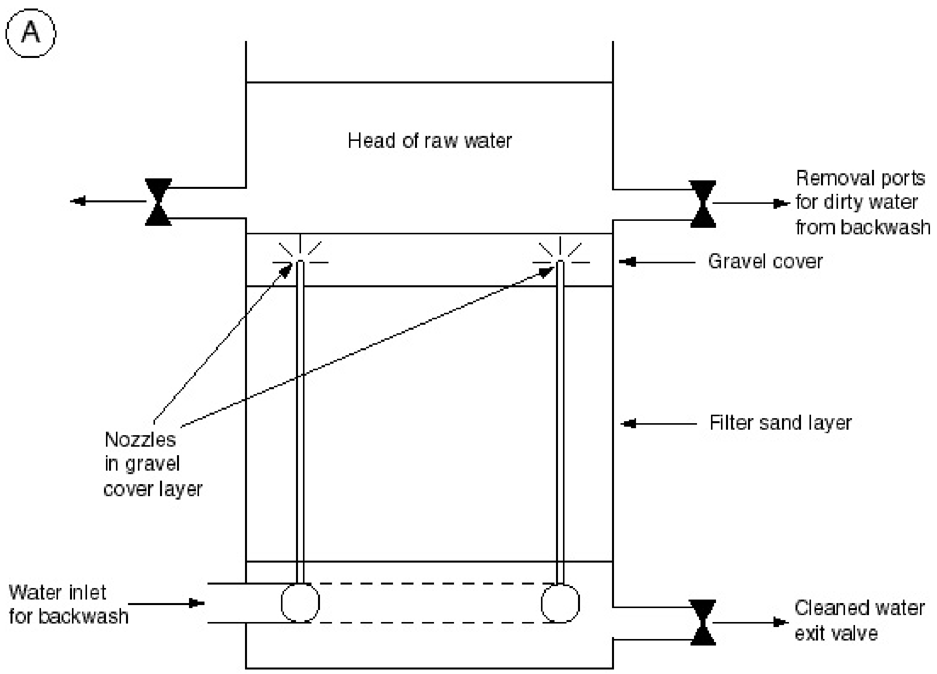
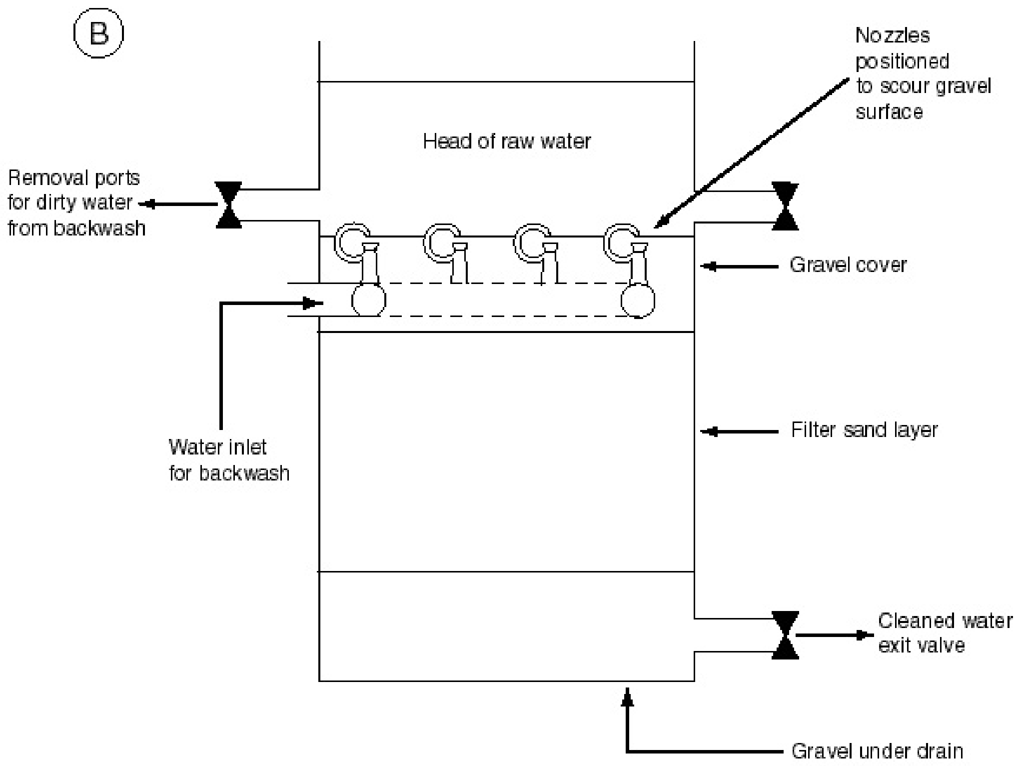


Figure 5: Schematic diagram of two design variants of back-washing system tested for cleaning blocked SSF. (A) was the first design and was initially tested in a column of SSF sand without the gravel cover illustrated. This design deployed nozzles within the upper layer of the filter medium to dislodge blockage material. Design (B) deployed nozzles at the gravel cover surface to achieve cleaning by lateral scouring.





A novel approach possible in horticultural SSF was the placement of nozzles permanently in position to reduce the labour likely to be involved in having to move cleaning apparatus over the filter. Nozzle positions and depths were selected to minimise filter disruption whilst cleaning. The two design variations developed differed mainly in the positioning of, and the way water was delivered to the backwash nozzles (Figure 5 A & B). Since only the very top layer of a SSF becomes blocked, the debris only needs to be removed from this layer in routine clean-ups. Using water jets to scour this layer, the particulate debris that was blocking it was re-suspended in a reduced volume of head water, which could then be drained off, either returning to the dirty water reservoir, or (better) to a separate settling area. The height of the drainage ports for this purpose were placed above the filter surface was initially set by the height at which the filter sand would settle out of suspension to leave just the unwanted fines in suspension. However, when heavier gravels were used, it was found that the drainage ports could be placed close to the filter surface, thereby substantially reducing the volume of water required for the back-washing process. In addition, as only the very top layer of the SSF was being scoured, raw water could be used for the backwash process. Whilst in the first design the nozzles were embedded in the gravel layer and were supplied by pipes entering through the drainage layer (Figure 5A), the second deployed nozzles at the gravel surface, supplied by pipes entering at this level (Figure 5B). This was because after several clean-ups, the gravel surface became uneven in the first design, with 'craters forming around the nozzle positions. To avoid this, a larger gravel size was used in the second design and the nozzles were positioned to try to scour just the surface of the gravel layer.

For filter clean-up assessments, test SSF with the back-washing facility were run to terminal or near-terminal head loss. Normally this was between 35 and 45 cm for the water butt pilot filters used for this work. Terminal head loss generation was attempted using the water supply from the pre-filtration test rig. However, it rapidly became clear that this would be achieved more quickly by adding extra suspended material to the supernatant or head water of individual test filters once they had matured and run for a 'settling in' period of at least 2 weeks.

Apart from the direct effects of back-washing on SSF operational efficacy, the effects on the biological efficacy of the SSF needed to be assessed. Samples of treated and untreated water were collected from test filters, immediately before, immediately after, and over a short time-course up to 3 days after back-washing, to determine the level of disruption to filter biological activity and the speed with which back-washed filters became re-primed. All water samples were tested using the microbiological procedures described below.

Water sampling and analysis

As in previous studies (HDC HNS 88 & HNS 88a), the bulk of the monitoring work carried out in this project consisted of collection and microbiological analysis of water samples. Water samples for biological assessments were collected in sterile bottles (autoclaved 1 litre Nalgene polypopylene bottles). The minimum sample size collected was 1 litre and all samples were processed and plated within 5 hours of collection. Whenever SSF effluent samples were collected, a raw water sample was also collected from the supernatant water as a standard for determining filter efficacy. For convenience in sampling, these two samples were collected at the same time without taking the filter retention time into account. This was justified by observations in DEFRA-funded work indicating that the retention time would range between <1 - 3 hours, over which time the quality of a reasonably large supernatant water volume would not drastically alter.

Before preparation for plating and baiting assays, all samples were divided into two portions: 750 ml for plating, following concentration by membrane filtration, and the remainder (usually 250 ml) for plant tissue piece bait assay. Samples for membrane filtration were passed under vacuum through 47 mm diameter, 3.0 µm cellulose nitrate membrane filters housed in autoclaved Nalgene reusable membrane filtration funnels. Membrane filters were cut into approximately 1 cm squares and placed in sterile glass universal bottles containing 5 ml off a re-suspension medium (0.1% w/v aqueous agar) and shaken for 5 minutes at 500 rpm on a rotary arm flask shaker (Stuart). Aliquots (0.5 ml) of the resulting suspensions were plated out on potato dextrose agar (PDA), *Fusarium*-'selective' agar (Pettitt, Parry & Polley, 1993) and on Phycomycete-selective agar (modified BNPRA - Pettitt & Pegg, 1991). All plates were incubated at 20ºC for 48 h and counts (colony forming units (cfu)/litre) were made of the following fungus species (if present): *Fusarium* spp., *Trichoderma* spp., total Phycomycetes, *Pythium* spp. and *Phytophthora* spp.

Bait tests were also carried out with surface-sterilised *Rhododendron* leaf disks using the method described by Pettitt *et al.* (1998). The water samples were retained in their original sample bottles, to which 10 leaf disks were added. After 24 h incubation at 20ºC, leaf disks were collected in sterile stainless steel sieves, blotted dry on autoclaved tissue paper, and plated onto BNPRA. After a further 36 h incubation, the percentage of baits infected was determined.

Results and Discussion

Pre-filtration assessments

It was quickly realised, that the initially planned project objective of testing a large range of pre-filtration equipment on SSF performance, would be of less use than attempting to define the particle size ranges, whose removal from the raw water would have the greatest effects upon filter run-times, and efficacy against plant pathogens. This information could then be applied by individual nurseries depending upon their raw water quality, which would first need to be assessed preferably from samples collected on several occasions and including 'worst case scenario' conditions (eg from reservoirs or rivers immediately following intense rainfall).

Efficient and consistent filtration was achieved using the Cross Ltd ***'EasyClean Automatic'*** system and because of this and its ready availability from the start of the project, detailed studies were carried out with this device. Both the 50 µm and the 25µm Cross filters were effective at removing suspended particle from the artificially contaminated test water supply (Table 1). Pre-filtration did not appear to have a great effect on the development of SSF maturity (Figure 6), although there was a consistent but non-significant trend towards a slight reduction in the rate of maturation compared to non-pre-filtered controls. Filter run-times, in comparison with non-pre-filtered controls, were greatly increased by the use of either filter element size (Figure 7). As a result of the different particle distributions, filtration of the 'peat'-contaminated water was more effective than that of the 'silt'-contaminated water and this was reflected in the slower rates of head loss development seen in pre-filtered SSF using the former test water supply (Figure 7). The time available for any single filtration run was restricted to approximately 90 days (including the filter maturation period. Unfortunately this meant in practice that none of the pre-filtered treatments could be taken to terminal head loss, although the data illustrated in Figure 7 clearly demonstrated the significant improvement in SSF run-time with both the 25 and the 50 µm pre-filters. Crude estimates of the rates of head-loss development across treatments showed that this was reduced from approximately 1.2 cm day^{-1} in the non-pre-filtered controls to 0.16 cm day^{-1} with the 50 µm filter element and to 0.09 cm day^{-1} with the 25 µm element. Microbiological assessments of SSF efficacy showed that all filters, including controls, remained fully primed throughout the experiments, except for one control filter. This filter showed signs of 'break-down' as terminal head loss was reached (first control run 50µm 'silt' Figure 7). Imminent 'break-down' was indicated by the presence of low counts of cfu of *Trichoderma* spp. in plates of the SSF-filtered water, although the important phycomycetes were still being removed. This is a phenomenon observed with routine water sampling from

Table 1: Comparison of weights of suspended particles of different sieve mesh categories present in the artificially-contaminated water supplies, before and after pre-filtration using the Cross 'EasyClean' system with either 50µm or 25µm filter cartridge installed.

	% by weight of each particle size category					
Water sample	>100µm	100-80µm	80-50µm	50-20µm	<20µm	Total (mg l^{-1})
'Peat' before pre-filtration	31	20	18	16	15	139
'Peat' after 50µm 'EasyClean' pre-filtration	4	3	8	36	49	40
'Peat' after 25µm 'EasyClean' pre-filtration	4	4	4	13	75	34
'Silt' before pre-filtration	25	27	18	14	16	162
'Silt' after 50µm 'EasyClean' pre-filtration	0	3	14	32	51	52
'Silt' after 25µm 'EasyClean' pre-filtration	<1	<1	3	15	82	29

Table 2: Comparisons of weights of suspended particles of different sieve mesh categories in the artificially contaminated water before and after filtration using the run-down separator (gravity filter) fitted with different filter mesh sizes.

	% by weight of each particle size category					
Water sample	>100µm	100-80µm	80-50µm	50-20µm	<20µm	Total (mg l^{-1})
'Silt' before pre-filtration	26	22	21	12	19	155
Pre-filtration with 200µm mesh	18	25	19	17	21	147
Pre-filtration with 110µm mesh	5	18	26	22	29	99
Pre-filtration with 80µm mesh	4	12	30	23	31	97
Pre-filtration with 50µm mesh	<1	8	10	31	51	56

Figure 6: Effect of pre-filtration (using the Cross EasyClean filter) on the rate of development of SSF maturity as determined by % removals of phycomycete propagules or colony forming units (CFU). *Two filter sizes were assessed; 25 and 50 µm. These were tested with two different types of particulate loading described as 'silt' and 'peat', a simple breakdown of particle distributions and loading in the untreated raw water are given in Table 1.*

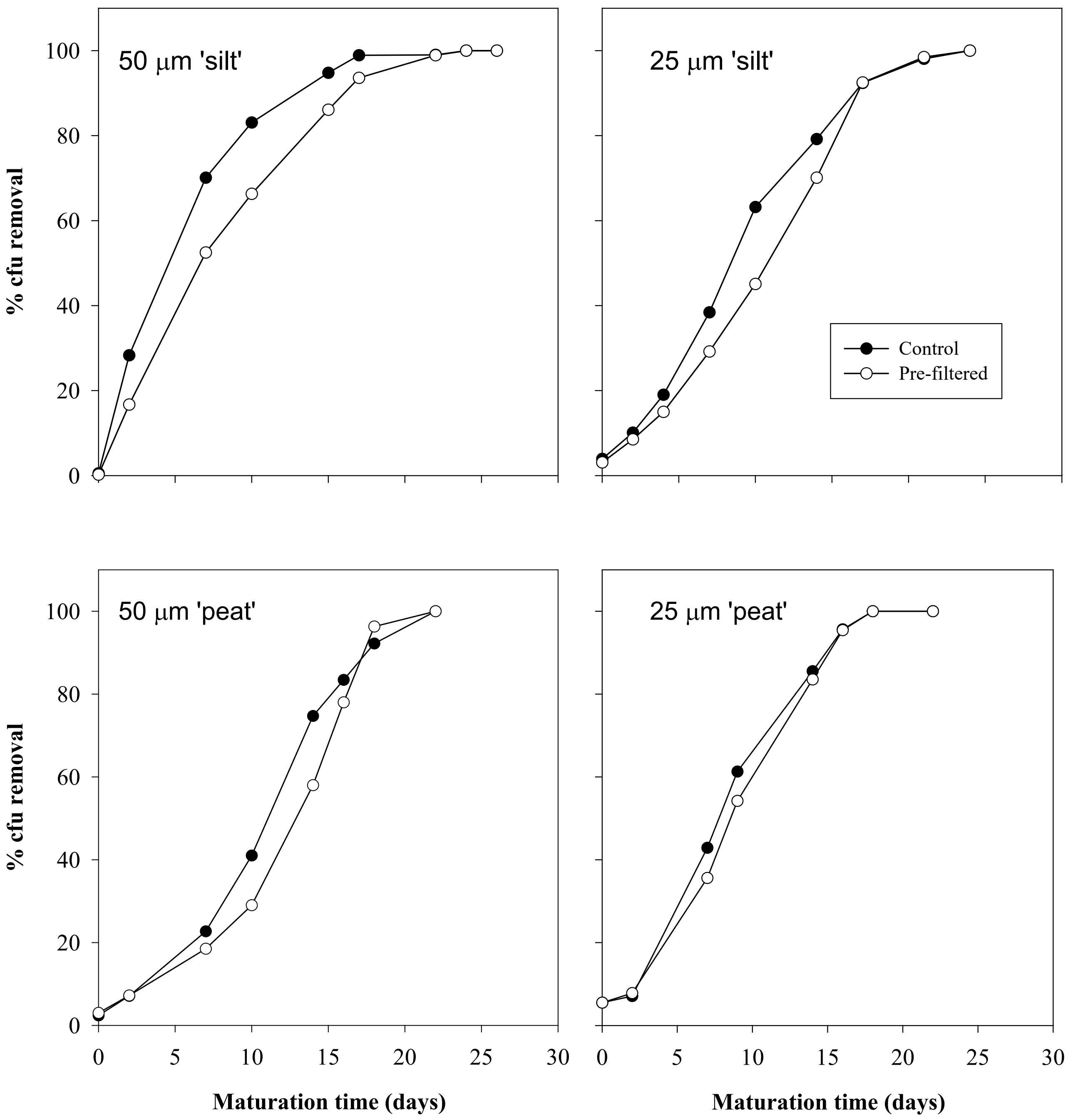
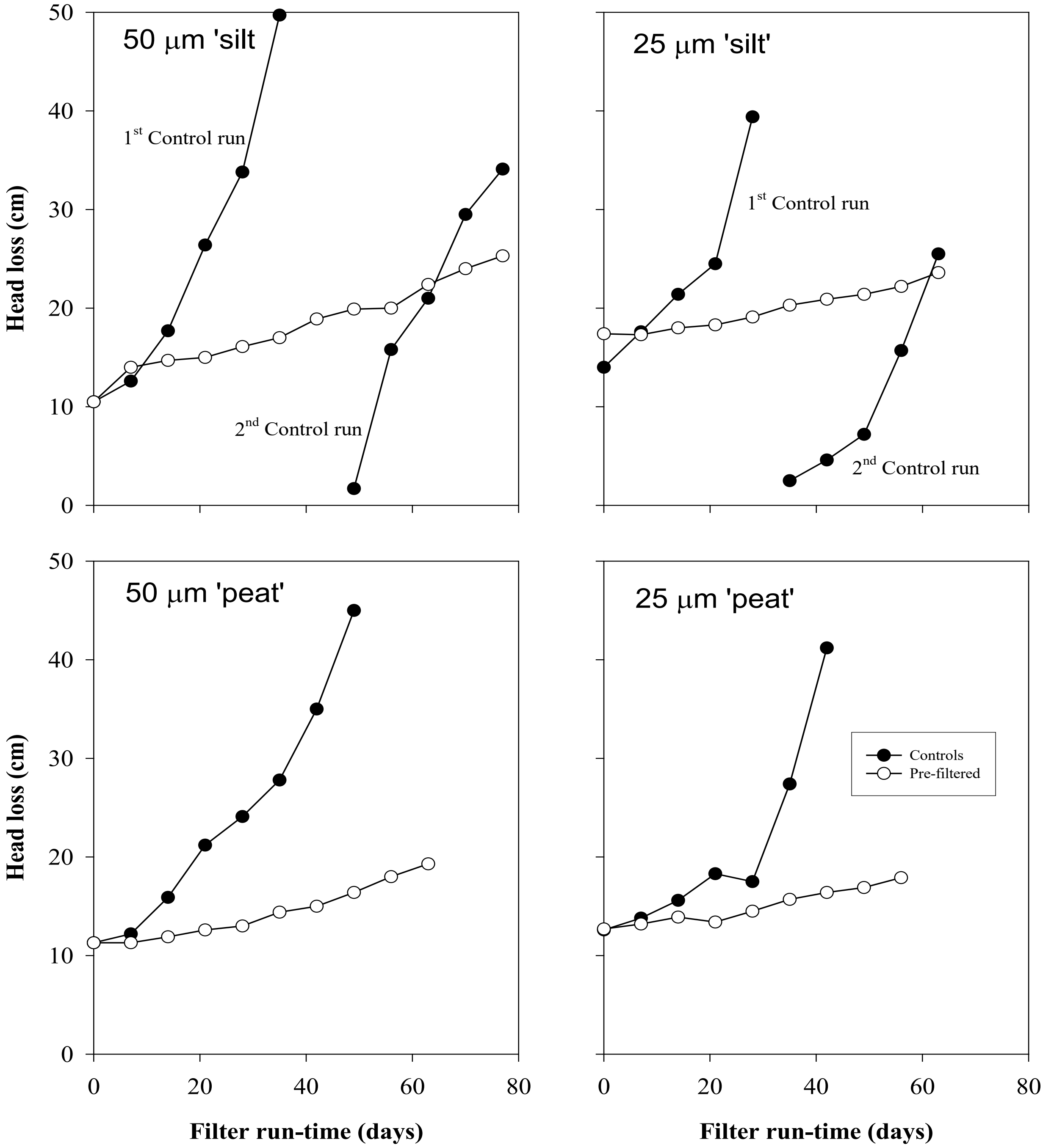


Figure 7: Effect of pre-filtration (using the Cross Ltd EasyClean filter) on the rate of head loss development and therefore effective SSF run-time. *Filtration run-times did not include the maturation period, except where more than one run was assessed in the controls, the second run being after a clean-up scrape. Two filter sizes were assessed; 25 and 50 µm. These were tested with two different types of particulate loading described as 'silt' and 'peat', a simple breakdown of particle distributions and loading in the untreated raw water are given in Table 1.*



commercial SSF and can give a early indication that a filter is becoming too clogged and needs to be cleaned.

Water readily passed through the filter panel on the ***'run down separator'*** at mesh sizes down to 50 µm. The greater the angle of the frame to the flow of water, the more direct was the passage of water through the filter mesh. However, at these greater angles (almost normal to the flow of water) the filtrate material rapidly clogged the filter. The whole point of a run down separator is to maintain a self-cleaning operation, such that debris separated on the mesh would gradually be washed or run down to the collection gutter at the bottom edge of the frame (Figure 4). To achieve this, a smaller angle to the water flow was required. With a shallow angle to the water flow, a large proportion of the treated water passing through the finer filter meshes (especially 50 and 80 µm) tended to run down the lower surface of the mesh and into the debris collection gutter. This undesirable water flow was simply eliminated by pacing a wooden baffle across the bottom edge of the filter mesh panel which directed the water down to the head water of the SSF (Figure 8). Long-term filtration runs were not possible with the run down separator, but good filtration, comparable with the Cross Ltd EasyClean system was obtained in short-term tests using only the 'silt'-contaminated water supply (Table 2).

Figure 8: Run-down separator in operation with a 50 µm filter mesh showing the effect of placing a small baffle on the under surface of the mesh in directing the filtered water to the top of the SSF.

None of the matting ***fabric covers*** gave any significant indication of improved rates of head loss over non-covered controls, and on removal, all showed signs of significant particulates penetration into the SSF sand beneath. This indicated that either the fabrics were not stopping penetration to any extent or that the fabric depth was insufficient to stop the bulk of particles passing through. The comparatively thicker layers of both the Rockwool and the gravel covers did reduce the rate of head loss development and significantly increased filter run-times (Figures 9A & B).

Samples of blocked filter sand were carefully removed from the top 1 cm layer of 7 different blocked SSF. These included four commercial SSF as well as one 'realistic' and two experimental filters from HRI Efford. The debris causing the blockage was re-suspended in water and separated into size categories by sieving. These were dried and weighed and the percentage by weight in each size category is shown in Table 3. From these results it can be seen that there is a wide variation in the size distribution of suspended particles in contaminated water from different nurseries. This shows the importance of carrying out assessments of the particle sizes present in individual nurseries' raw water supplies before deciding upon an appropriate pre-filtration system. Also of great interest in this group of samples is the generally similar proportion by weight of suspended material (3-4 %) required to cause SSF blockage, irrespective of particle size distributions. This will now be part of continued assessments carried out on currently-operating commercial SSF, and if it remains a consistent factor it will prove extremely useful in helping with predicting filter performance on individual nurseries.

Cleaning SSF: assessments of backwash treatments

Back-washing of the top layer of sand achieved reductions in head-loss of between 68 and 85%. However, it required a depth of supernatant water, into which the blockage material was released by the cleaning, of at least 35 cm to allow the suspended sand grains to settle out. This meant that turnover of large volumes of water was required to achieve a useful clean-up. This would be undesirable for most horticultural SSF as to process such a large volume of backwash water would probably require both extra space, and filter down-time. In addition, the surface of the cleaned sand was left extremely uneven, with conical depressions around the positions of each of the scouring nozzles. For these reasons it was decided to alter our approach to *in situ* cleaning, by avoiding actual sand washing. Following the demonstration of the efficacy of certain SSF cover materials, especially gravel, at extending filter run-times in the presence of high concentrations of suspended particles, it was decided to adapt the back-washing system for *in situ* cleaning of gravel SSF covers.

The two designs for *in situ* cleaning of gravel covers illustrated in Figure 5 were assessed, and both showed that the concept worked very well, reducing blocked filter head-loss by up to 90%. As can be seen in Figure 10A-E, the positioning and types of nozzles used in these prototype filter systems did not always achieve complete filter surface clean-ups, and it is possible that head-loss reductions of virtually 100% might be achieved with more appropriate water outlets/nozzles, positioned for maximum effect. In discussing the concept of *in situ* cleaning of SSF, Huisman & Wood (1974) stated that wash-water velocities of the order of 10-30 m/h would be all that would be required to wash filter sand, and it is possible that even lower velocities would be needed to clean gravel. Although beyond the scope of this project, other forms of surface scouring, such as compressed air might also more readily achieve complete clean-ups (Bablon, Ventresque & Ben Aïm, 1988). The primary goal of this study, however, was to test the principle of *in situ* cleaning in SSF. Whilst the physical cleaning of the surface is a vital part of this, once it had been demonstrated to work, its refinement was considered to be a solvable engineering problem. On the other hand, the impact of backwashes on the biological efficacy of SSF was unknown, and if disruption to this was too great, the concept of *in situ* cleaning would be obsolete. The main effort of the study was therefore focused on monitoring the biological efficacy of the two back-washing filter designs described above, before and following filter clean-ups.

The potential disruption to SSF efficacy of *in situ* filter cleaning was assessed in experiments using the natural background of fungal species present in the raw water and in assessments using zoospore inoculum of the plant pathogenic species *Phytophthora cryptogea*. With the exception of one assessment, experiments showed there to be virtually no evidence of disruption to SSF efficacy against phycomycete and *Trichoderma* spp. propagules 24 h after cleaning (Figures 11-13 & Tables 4-6). These rapid returns to efficacy were equivalent to, and often faster than the period of re-priming necessary after a conventional clean-up by scraping (see HDC report for HNS 88, Appendix Tables 5 & 6). This means that *in situ* filter cleaning does present an alternative to conventional filter scraping. On the negative side for this treatment system would be the possible cost and effort involved in its installation. Also, when/if after prolonged operation, the filter does become clogged by penetration of particles in the <20μm range past the gravel layer, the clean-up and replacement of used filter media may incur a large labour cost. However, on the positive side, a backwash system would probably save as much as 90% of labour costs involved in routine clean-ups and would reduce the time required for such operations to be completed. In addition, such a system would provide the possibility of a rapid response to emergency events such as a weekend SSF blockage resulting from a high load of particulates in the raw water following a summer storm. It is important to note that whilst a back-washing system may be an improvement on a SSF operating without pre-filtration, the best performance would be achieved if run in conjunction with a pre-filtration device such as those described above or others of similar performance in particulates removal.

Figure 9: Effects of protecting the SSF sand surface with (A) a layer of rockwool or (B) of gravel on filter run-time compared to non-pre-filtered controls, when treating raw water containing a moderately high load (150 mg l^{-1}) of suspended silt particles.

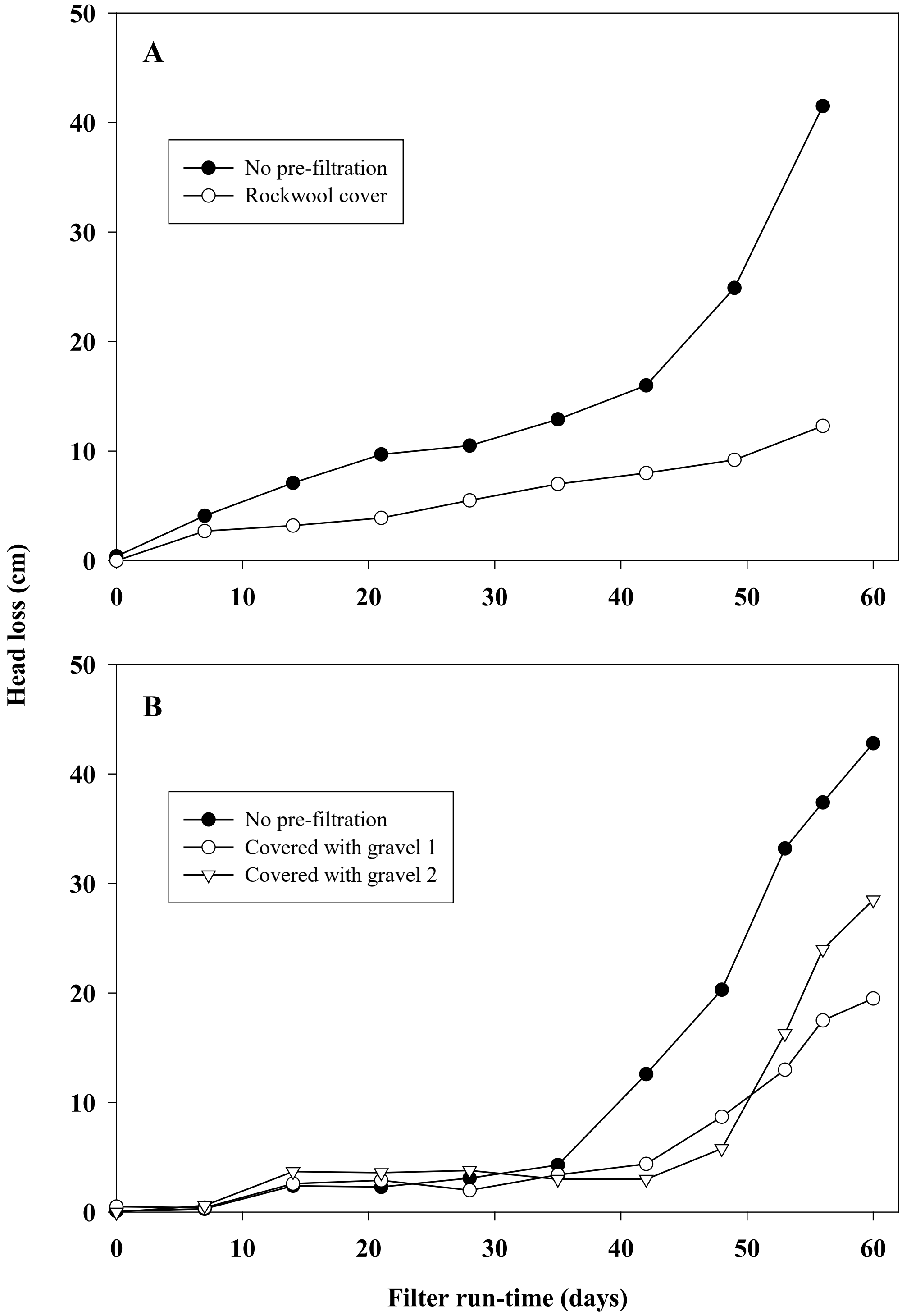


Table 3: Size distributions of particles in 1 cm deep surface scrape samples taken from a range of both experimental and commercial blocked SSF.

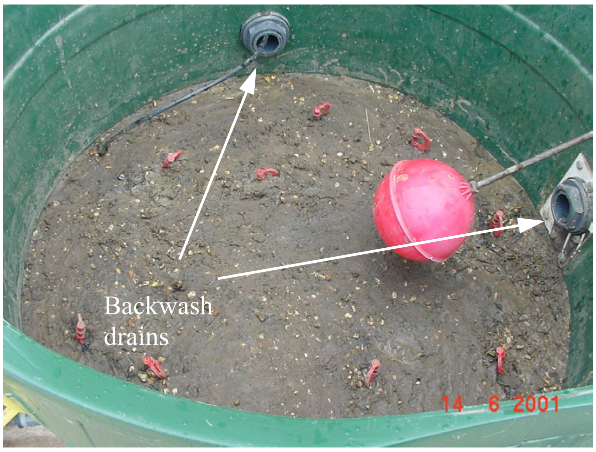
Scrape sample	% of particles (excluding the sand) by weight				Total as % of sand weight
	>200 µm	200-80µm	80-20µm	<20µm	
Efford – supplied by river	33	40	15	12	4.07
Efford – 'silt'	23	28	26	23	4.32
Efford – 'peat'	51	18	16	15	3.16
Nursery 1 - HNS	13	44	31	12	3.74
Nursery 2 - HNS	21	51	19	9	3.54
Nursery 3 - HNS	11	25	57	7	3.72
Nursery 4 - Tomatoes	3	11	22	64	3.81

Figure 10: Results of *in situ* clean ups of gravel-covered SSF using spray nozzles.

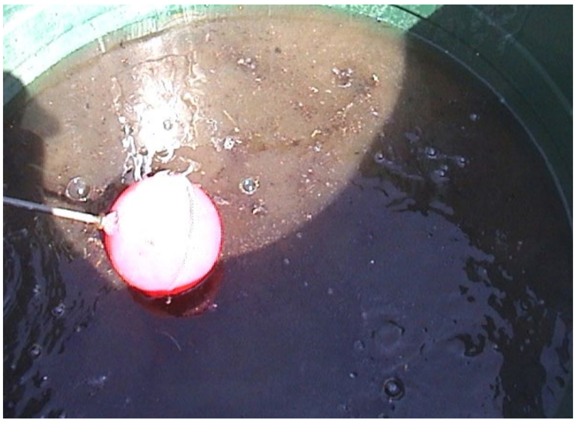
A Design A (see Figure 5), the gravel surface, showing area cleaned by one small nozzle

B As 10A above with nozzle excavated to show its position (arrow), just beneath the surface of the gravel layer

C Design B (see Figure 5) completely drained down gravel-covered SSF, showing the gravel surface blocked with silt.



D Design B: back-washing in progress



E Design B: gravel surface after backwash

Figure 11: Time taken after a backwash treatment (Design A, see Figure5., with sand only), for a SSF to return to full efficacy as indicated by activity against applied propagules of *Phytophthora cryptogea* and by the numbers of propagules of *Trichoderma* spp. detected in the filtered water.

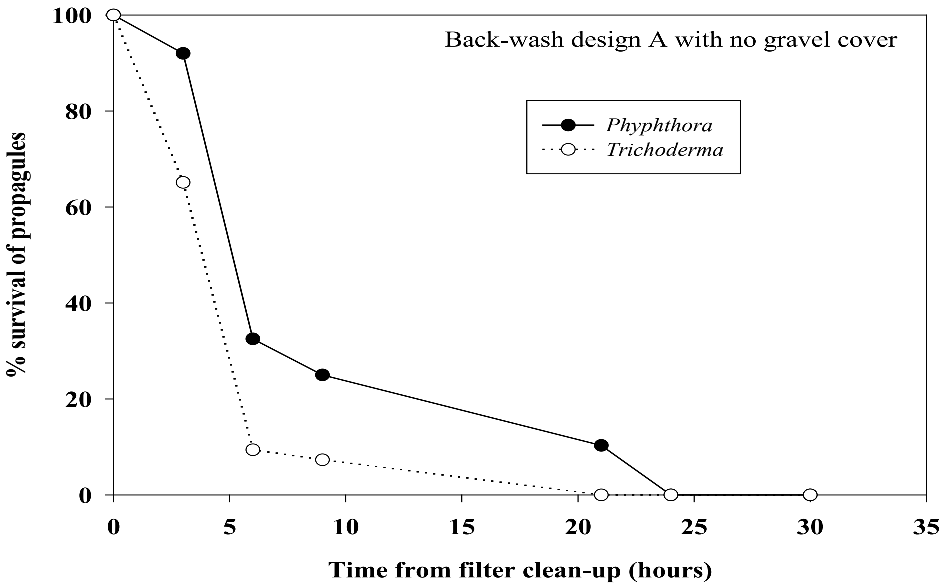


Table 4: SSF efficacy against filamentous fungi and total bacteria over the first 72 hours following a backwash treatment (Design A, see Figure 5., with sand only).

Time from backwash (hours)	Filamentous fungi* (cfu litre^{-1})		Bacteria (cfu litre^{-1})	
	Raw water	Filtered water	Raw water	Filtered water
0	726	3.1×10^3	3.47×10^5	1.67×10^6
3	803	886	2.50×10^5	7.91×10^5
6	826	789	1.22×10^5	3.88×10^5
9	853	565	1.69×10^5	2.25×10^5
21	809	482	1.5×10^5	6.99×10^4
24	705	84	1.36×10^5	6.31×10^4
30	637	89	2.76×10^5	3.86×10^4
45	655	79	1.70×10^5	1.68×10^4
54	718	50	6.75×10^5	1.42×10^4
72	691	18	5.69×10^5	1.25×10^4

* Counts included *Fusarium* spp. although very few cfu of this genus (< 10 cfu/litre) were seen in any assessment.

Figure 12: Time taken after a backwash treatment (Design A, see Figure 5), for a gravel-covered SSF to return to full efficacy as indicated by activity against applied propagules of *Phytophthora cryptogea* and by the numbers of propagules of *Trichoderma* spp. detected in the filtered water.

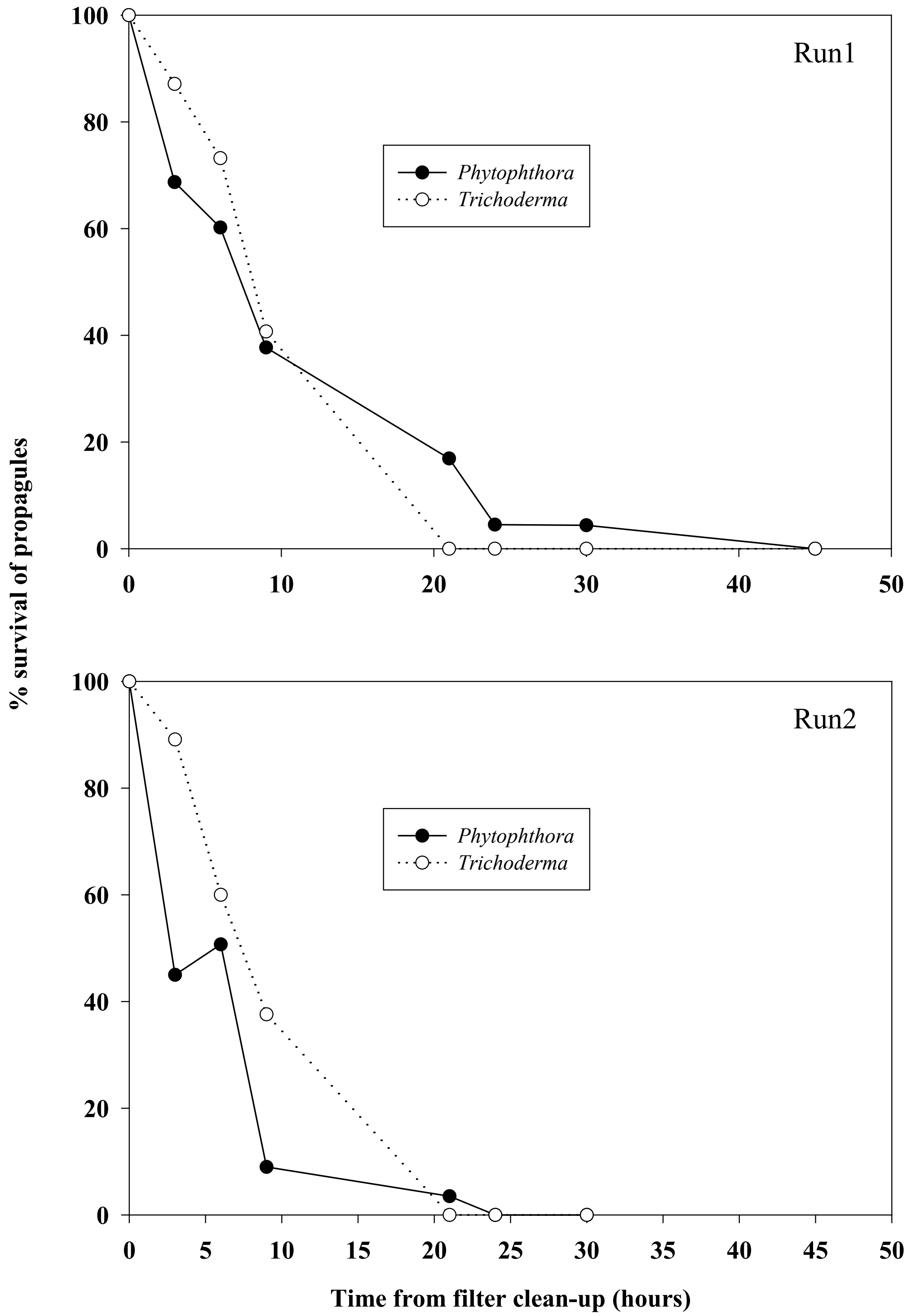


Figure 13: Time taken after a backwash treatment (Design B, see Figure 5), for a gravel-covered SSF to return to full efficacy as indicated by activity against applied propagules of *Phytophthora cryptogea* and by the numbers of propagules of *Trichoderma* spp. detected in the filtered water.

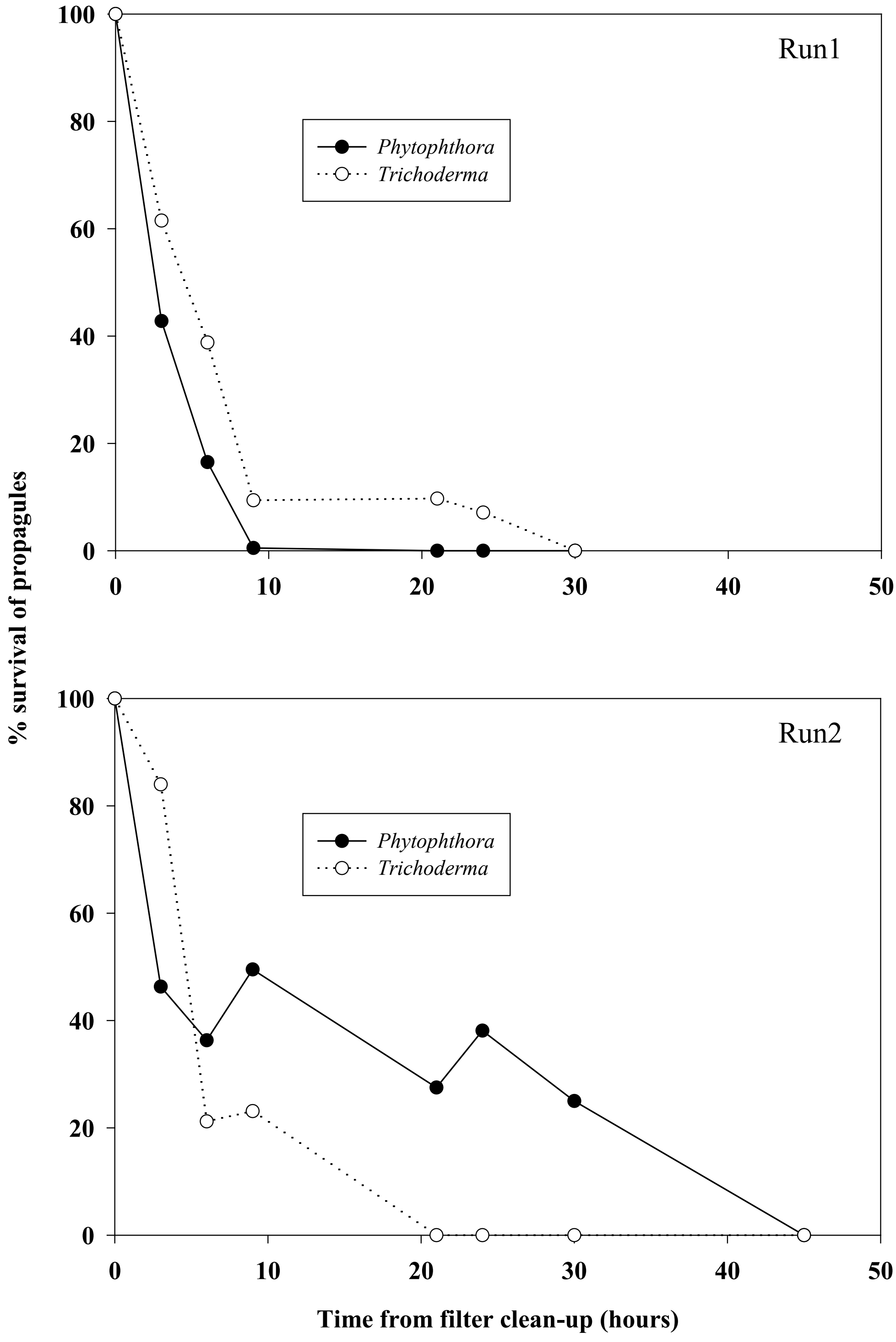


Table 5: SSF efficacy against filamentous fungi and total bacteria over the first 72 hours following a backwash treatment (Design A, see Figure 5).

	Run 1				***Run 2***			
Time from backwash (hours)	Filamentous fungi* (cfu litre^{-1})		Bacteria (cfu litre^{-1})		Filamentous fungi* (cfu litre^{-1})		Bacteria (cfu litre^{-1})	
	Raw water	Filtered water	Raw water	Filtered water	Raw water	Filtered water	Raw water	Filtered water
0	957	2.55 x 10^3	2.58 x 10^5	4.69 x 10^6	1.22 x 10^3	1.90 x 10^3	3.30 x 10^6	1.80 x 10^7
3	998	979	2.72 x 10^5	1.78 x 10^6	1.01 x 10^3	986	2.95 x 10^6	3.46 x 10^5
6	970	671	3.14 x 10^5	7.27 x 10^5	1.06 x 10^3	861	2.55 x 10^6	2.78 x 10^5
9	954	986	2.05 x 10^5	1.03 x 10^5	2.05 x 10^3	693	1.96 x 10^6	2.58 x 10^5
21	882	506	2.60 x 10^5	1.33 x 10^4	1.33 x 10^3	491	2.19 x 10^6	4.01 x 10^4
24	940	461	3.62 x 10^5	7.91 x 10^4	1.79 x 10^3	353	1.78 x 10^6	3.62 x 10^4
30	976	139	3.78 x 10^5	5.06 x 10^4	2.47 x 10^3	26	1.87 x 10^6	7.02 x 10^3
45	856	110	3.53 x 10^5	3.99 x 10^4	2.91 x 10^3	7	2.27 x 10^6	2.05 x 10^4
54	788	29	3.30 x 10^5	2.76 x 10^4	1.93 x 10^3	15	2.25 x 10^6	1.70 x 10^4
72	958	9	3.47 x 10^5	1.81 x 10^4	1.10 x 10^3	0	2.80 x 10^6	1.17 x 10^4

* Counts included *Fusarium* spp. although very few cfu of this genus (< 10 cfu/litre) were seen in any assessment.

Table 6: SSF efficacy against filamentous fungi and total bacteria over the first 72 hours following a backwash treatment (Design B, see Figure 5).

	Run 1				***Run 2***			
Time from backwash (hours)	Filamentous fungi* (cfu $litre^{-1}$)		Bacteria (cfu $litre^{-1}$)		Filamentous fungi* (cfu $litre^{-1}$)		Bacteria (cfu $litre^{-1}$)	
	Raw water	Filtered water	Raw water	Filtered water	Raw water	Filtered water	Raw water	Filtered water
0	557	901	5.99×10^5	3.05×10^6	1.95×10^3	5.20×10^3	8.87×10^6	2.65×10^7
3	838	960	6.10×10^5	3.57×10^6	1.69×10^3	3.00×10^3	7.86×10^6	2.87×10^7
6	725	569	5.36×10^5	7.92×10^5	1.53×10^3	2.37×10^3	8.98×10^6	8.79×10^6
9	749	395	5.85×10^5	1.86×10^4	1.85×10^3	2.46×10^3	9.50×10^6	5.30×10^6
21	800	55	7.59×10^5	2.98×10^4	1.32×10^3	890	7.91×10^6	9.96×10^5
24	861	23	8.47×10^5	2.03×10^4	1.20×10^3	841	8.38×10^6	5.77×10^5
30	722	0	6.13×10^5	8.85×10^3	1.79×10^3	588	7.56×10^6	8.15×10^4
45	719	0	8.07×10^5	9.55×10^3	1.86×10^3	367	7.81×10^6	1.95×10^4
54	788	0	7.82×10^5	9.69×10^3	1.40×10^3	30	8.17×10^6	1.59×10^4
72	787	0	7.28×10^5	8.96×10^3	1.78×10^3	3	8.63×10^6	1.61×10^4

* Counts included *Fusarium* spp. although very few cfu of this genus (< 10 cfu/litre) were seen in any assessment.

Conclusions

- Pre-filtration was demonstrated to be very effective in reducing the rate of SSF head-loss development. Using the Cross 'EasyClean' system to pre-filter raw water, the rate of head-loss development was reduced from an average of 1.2 cm day^{-1} to 0.16 cm day^{-1} with the 50 µm filter element and to 0.09 cm day^{-1} with the 25 µm filter element.

- Of the three pre-filtration approaches tested, the Cross 'EasyClean' system gave the best results with low volumes of water required for backwash cycles. The run-down separator (gravity filter) gave good filtration results but it was not possible to test its impact on SSF head-loss development in longer-term experiments.

- Whilst some forms of pre-filtration covers worked reasonably well at reducing the rate of SSF head-loss development (shredded rockwool = 76% reduction compared to controls over 56 days and gravel = 36-56% over 60 days), the fabrics assessed failed. Although the use of fabric covers to reduce the rate of head-loss development is a proven concept, our work has simply demonstrated that capillary matting and Mypex fabrics are inappropriate for this technique.

- Assessment of samples of surface sand from blocked SSF showed wide variation in the sizes of suspended particles in the raw water of different nurseries. In the small number of representative samples assessed, a surprisingly similar proportion of weight of contaminant particles to weight of sand (approximately 4%) was observed, irrespective of the size distribution of the particles. These results illustrate the importance of determining the quantity of suspended particles and range of particle sizes present in the raw water before deciding on what type of pre-filtration treatment to adopt.

- No form of pre-filtration will completely eliminate the eventual need for SSF clean-ups.

- Cleaning of SSF by using a backwash of the top few centimetres of sand worked well both in terms of reducing head-loss and the amount of disruption to SSF microbiological efficacy. The disruption to efficacy was comparable to cleaning by scraping. The advantage to this *in situ* cleaning approach is a major saving in labour plus a modest reduction in filter 'down time'.

- *In situ* cleaning of the SSF was improved by the placement of a gravel cover on the surface of the filter sand. This allowed the backwash to be performed in a much reduced volume of supernatant water whilst leaving the actual sand layer undisturbed. In addition, the presence of a gravel cover increased the length of SSF run-times between clean-ups, although the use of a gravel cover in this way alone is not recommended as an alternative to pre-filtration.

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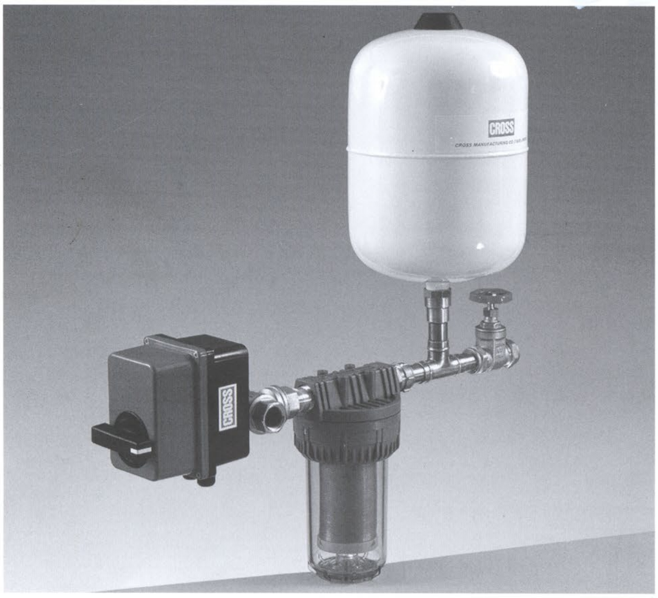
APPENDIX I Details of the Cross Ltd 'EasyClean' filtration system.

Publication: E2/1
Issue date: 4/98

CROSS

EasyClean Filters

High Performance Liquid Filters

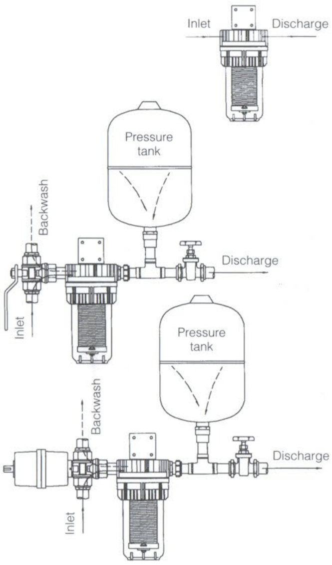


- Low cost
- Absolute filtration from 12 to 400 microns
- Manual, Valve and Automatic options
- Flow rate up to 1.3 l/s
- Multiples available for higher flow rates
- 100% clean with every backwash
- Minimal use of fluid for backwash
- Suitable for pressure to 8 bar
- Easy to install
- Easy to maintain
- 5 year guarantee on filter coil

Suitable Applications

- Domestic and light commercial use
- Rain and grey water
- Pre-filtration
- Nozzle protection
- Potable Water

The Range



Manual

The EasyClean Manual is a simple, inexpensive yet effective means of low flow rate filtration. Cleaning is achieved by removing the element from its housing and washing it by hand. An excellent solution for applications where pressure for self cleaning is not available.

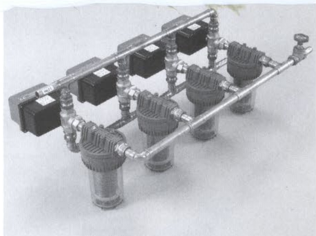
Valve

The EasyClean Valve offers a way of backwashing quickly and effectively with minimum interruption of flow. A simple 90° turn of the valve handle brings about a thorough backwash in seconds using an insignificant quantity of liquid.

Auto

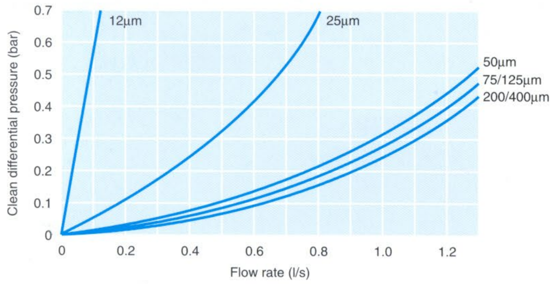
The EasyClean Auto presents a fully automatic, self cleaning filter comprising controller, pressure vessel, actuator and housed element. The controller can be programmed to meet specific application requirements by altering backwash duration and frequency.

Higher Flow Rates



The EasyClean Range can handle higher flow rates by a simple build up of individual units in parallel.

EasyClean Performance



Note: Detailed flow curves available on request.

Specification

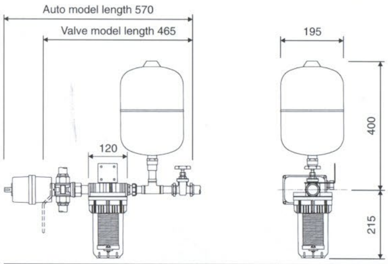
Materials

Filter Coil	Stainless steel 304 to aircraft quality DTD 734
Filter Cage	Glass filled polypropylene and stainless steel
Filter Housing	SAN
Adaptor	Virgin polypropylene
Seals	Nitrile rubber
Housing Top	Polypropylene with brass relief valve
	Valve and Auto only
Pipework	22mm copper (Table X)
Pressure Tank	8 litre - butyl liner in coated steel
Valve	3/4" BSP three way ball valve
	Auto only
Actuator	Nylon and coloured ABS

All materials suitable for potable water

Connections	**Manual**
Inlet	3/4" BSP threaded female
Discharge	3/4" BSP threaded female
	Valve and Auto only
Inlet	3/4" BSP threaded female
Backwash	3/4" BSP threaded female
Discharge	22mm compression fitting

Dimensions



Electrical Supply – Auto only
12 Vdc 2.4 A

Number of Elements
1 per housing

Maximum Recommended Flow Rate
1.3 l/s

Maximum Operating Pressure
8 bar

Maximum Operating Temperature
50°C

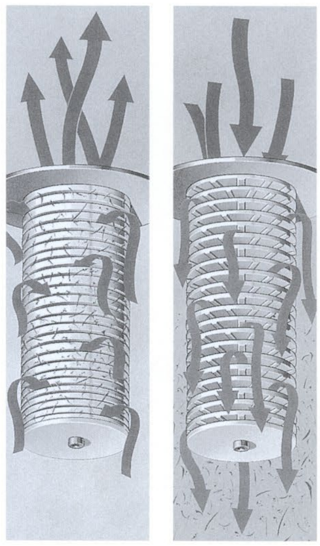
Filter Ratings
12, 25, 50, 75, 125, 200 and 400 µm

Backwash Control

Manual	Hand wash
Valve	Hand operated valve
Automatic	Adjustable duration Adjustable interval Manual override

Weight	*Dry*	*Wet (max)*
Manual	1.25 kg	2.25 kg
Valve	3.40 kg	14.00 kg
Auto	5.70 kg	15.00 kg

100% Cleaning with Every Backwash

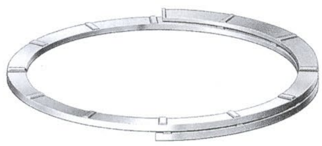


Filtering *Backwashing*

The zero gravity coil design enables filter elements to be completely cleaned with every backwash, minimising backwash frequency and water consumption.

Filtration Ratings

Filter elements are available in seven different micron ratings: 12, 25, 50, 75, 125, 200 and 400 and are completely interchangeable. In some heavily contaminated systems, it may be advantageous to install a set of coarse or 'commissioning' elements in the early stages of the filter operation and replace them with finer elements at a later stage once the backwash frequency has stabilised.



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