FILTRATION AS A BALLAST WATER TREATMENT MEASURE

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Abstract
Filtration has been proposed as a ballast treatment in both shipboard and shore-based applications. Operated at the port of origin, filtration can dramatically reduce densities of larger plankton and other taxa in the ballast intake stream without generating chemical or thermal residuals. It also could enhance or complement performance of biocidal treatment systems. Pilot scale tests suggest that filtration is already operationally and economically feasible for some classes of ships, including many of concern in the global translocation of organisms, such as container and passenger ships. Applications to larger ships with higher flow-rates could become feasible with design improvements to today's filter technology. This chapter describes current uses of filtration on ships, types of filtration proposed for the ballast treatment application, performance evaluations of filtration as a ballast treatment, filtration as a component in compound treatment systems, pore size considerations, and the merits of filtration versus cyclonic separation as a primary treatment method.

1 Introduction

Filtration of ballast water is a straightforward means of reducing transfers of aquatic organisms by ships. It has been proposed as both a stand-alone treatment and the primary component of compound treatment systems (Laughton et al. 1992; AQIS 1993; Carlton et al. 1995; National Research Council 1996; Oemcke 1999). Pilot (340 $m^3 h^{-1}$) and bench-scale demonstrations of filtration as a potential ballast treatment have shown it to be extremely effective at removing zooplankton and some forms of phytoplankton from harbor water (Cangelosi et al. 2001; Galil 2001). Mechanical tests at the pilot scale suggest that filtration can be both operationally and economically feasible for at least some ship applications (Parsons & Harkins 2000).

Filtration offers the advantage of producing no residuals such as waste heat or chemical by-products. As a shipboard treatment, filtration would be best employed during ballast uptake, removing and returning matter entrained in the intake stream to the source harbor prior to the ship's departure. In this way, filtration could prevent altogether the movement of many near coastal organisms across the open ocean – formerly a natural barrier to transoceanic dispersal – as well as the accumulation of sediments in ballast systems. As a component of a port-based treatment system, filtration could offer a contingency treatment strategy for vessels unable to affect ballast water exchange due to safety concerns, or otherwise treat their ballast water through shipboard technology. If operated at the discharge point, ballast filtration would require proper disposal of filtered matter.

Clearly, filters alone cannot prevent all ballast-mediated organism transfers. Operational and space requirements of filters increase as mesh size decreases. Accordingly, these requirements restrict the lower bound of effective removal size in a shipboard applica-

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tion; some organisms will always be able to pass through a shipboard filtration system. Still, the potential window of effectiveness of shipboard ballast filtration subsumes a large proportion of the taxa of known concern, including fish, benthic and epibenthic organisms, and many forms of plankton. Moreover, in both the shipboard and port-based applications, filtration can improve performance of secondary treatment systems such as ultraviolet radiation and chemical biocides through reducing particulate matter that may consume or interfere with these treatments. Filtration also reduces the treatment burden on secondary treatment by largely removing many zooplankton and phytoplankton taxa from the intake stream

Size requirements also restrict the upper bound flow-rates at which a shipboard filtration system can function effectively, and filter vendors are actively exploring ways to make their systems more compact. However, the full range of flow requirements of many classes of ships of concern in global movements of organisms – including container ships, small tankers, cruise ships and some St. Lawrence Seaway-sized bulk cargo carriers – already can be accommodated by today's filter designs.

2 Filters, ships and ballast water

Filters have a long history of shipboard use. Manually cleaned cartridge strainers cleanse fuel oil and lubrication oil for diesel engines and generators. Filters also remove water from ship air compressors. It is not uncommon for these filters to have a nominal wire mesh pore size of 30 µm – low enough to remove most zooplankton from an intake stream. These shipboard uses of filters, however, have involved relatively low flow-rates (100-150 $m^3 h^{-1}$) compared to the flow requirements of ballast water treatment. Still, these uses attest to the fact that filters can operate successfully in the shipboard environment, and that they have a legitimate place in the suite of potential ballast water treatments (R. Harkins pers. comm.).

Filtration comprises several distinct technologies, which vary fundamentally in their approach to removing particles and self-cleaning. These differences in turn imply a variety of pump capacities, back pressure demands, numbers of moving parts, and structural materials among other features. Filter designs which commercial vendors have proposed for testing in the Great Lakes Ballast Technology Demonstration Project (the Project), and those proposed for approval under the California State ballast regulations provide some insight into leading ballast treatment filter technologies. Each approach offers intriguing advantages and warrants testing at the pilot- and full-scales.

The filtration systems proposed for testing by the Project were all envisioned for installation in the engine or pump room of the ship in-line with the ballast pump to treat water upon intake. Each design was self-cleaning and balanced in different ways the variables of unit size, mechanical complexity, and demands on ship operational systems to maximize biological efficiency and minimize diverted energy, intake flow and routine maintenance required for cleaning and operation. The designs offered included:

(i) A cylindrical mesh screen filter that self-cleans automatically (triggered by a drop in flow pressure) through periodic backflushing of a small volume of the ballast intake flow and spiral suction removal of the filter cake for discharge back into the source harbor (Amiad Filtration Systems - www.amiadusa.com).

(ii) A depth filter consisting of stacked discs a centimeter or two in width with microscopic grooves and ridges. Water flows laterally through the stacked discs and particles tumble and become entrained. The mechanism self-cleans (triggered by a drop in flow pressure) by releasing pressure on the discs such that they separate using the pressure head of the ship's cooling water or fire main systems. (Arkal – www.arkal-filters.com).

(iii) A wedge wire strainer, which automatically self-cleans by direct contact of the filter membrane with a rotating wire brush and backflushing of the debris (Helland – www.hellandstrainer.com).

An externally mounted shipboard filtration concept also has been proposed to the State of California Lands Commissions. According to this concept, a filter suspended from the ship's hull strains intake into or discharge from the ship's ballast system and is retracted for storage on the ship deck during the voyage. This concept, if viable, could be quite useful for ships for which retrofitting a system into the engine room is overly expensive or impracticable. It could also provide a useful shore- or barge-based back-up system in ports.

3 Effectiveness testing of filtration as ballast treatment

Intensive testing of filter systems as potential ballast treatment systems is now underway primarily in the United States (Cangelosi et al 2001, Parsons & Harkins 2000, 2001; Waite 2001) and Singapore (J. Matheichal pers. comm.). The Great Lakes Ballast Technology Demonstration Project (the Project) was the first to undertake comprehensive biological and operational tests on commercially available filter systems in the United States, and has the longest running test program. The Project filtration trials have provided valuable early benchmarks on operational and biological performance of various filter types and sizes.

3.1 M/V ALGONORTH TRIALS

The first tests took place in 1997 at a flow rate of 340 $m^3 h^{-1}$ on board an operating commercial bulk cargo vessel (*M/V Algonorth*) at various locations in the Great Lakes/St. Lawrence Seaway System. The Project performed these shipboard trials using a deck-mounted automatic back-flush screen filter (ABSF) designed by Ontario Hydro Technologies, Inc. Two filter units (a 250 μm pre-filter and a 25, 50, 100, or 150 μm polishing filter) were installed in series on the ship's deck along with a diesel pump piped to draw water either from the ballast tanks or the sea. Biological trials utilized matched control and treatment upper wing tanks equipped with cable trolleys for direct tank sampling using identical plankton net transects.

Operational assessments revealed that the 250 μm prescreen was not necessary to enhance polishing filter performance even at the finest polishing screen pore sizes, and that all polishing filters performed well enough to warrant further evaluation (Parsons & Harkins 2000). In terms of biological effectiveness, each polishing filter mesh size tested significantly reduced zooplankton density relative to the controls. The smaller size screens appear to have performed better than the larger screen sizes though the effect was not statistically significant due to variation of the ambient species assemblages present in the various source waters. The sizes of the organisms in the control samples did not differ across trials or treatment sets. Fig. 1 shows the percent zooplankton removed by the various screen sizes tested.

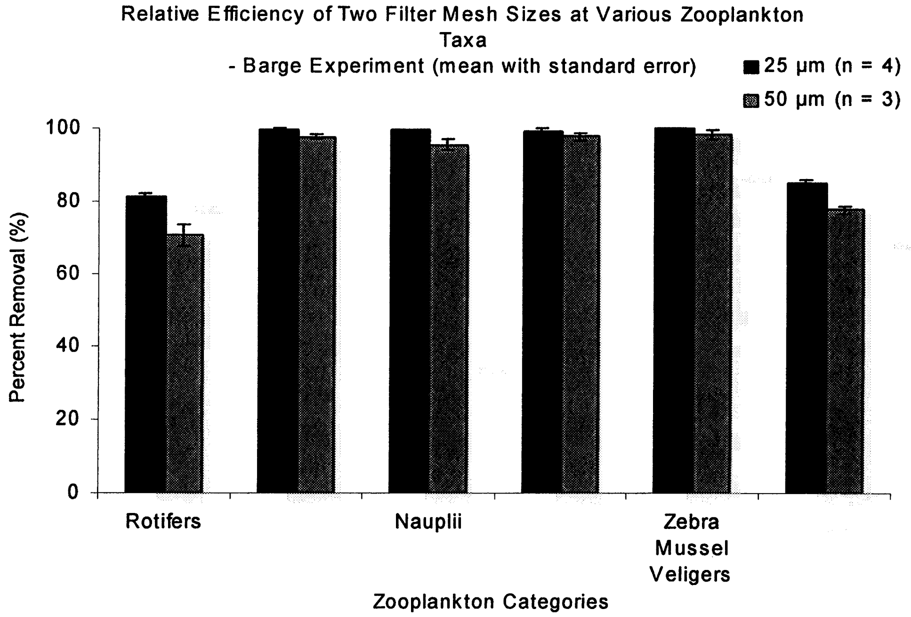

Figure 1. Zooplankton removal efficiency by various filter screen sizes.

3.2 GREAT LAKES BARGE TRIALS

From 1998 until the present, Project equipment trials have continued upon a stationary barge platform. These trials also were conducted at a flow-rate of 340 m^3 h^{-1}, and took place at two locations in Lake Superior with sharply contrasting physical, chemical and biological characteristics. As part of these barge-based trials, the Project also has evaluated depth filtration, cyclonic separation and ultraviolet radiation as prospective treatment system components.

The Project tests of the ABSF system under harbor conditions onboard the stationary barge (Fig. 2) were more rigorous and controlled than the shipboard. The effectiveness of 25 μm ABSF was compared with 50 μm ABSF at a single site in Lake Superior (Duluth/Superior Harbor). The barge experimental platform for these tests comprised the 340 m^3 h^{-1} diesel pump, ABSF and three identical catchment tanks of 700 L each. The 250 μm prefilter was replaced with an intake strainer with 48 mm pore size.

Samples were collected from in-line taps located upstream and downstream of the treatment system, concentrated with a 20 μm net, and analyzed immediately using Acusizer Particle Sizing System. The mechanical tests showed the commercially available ABSF at 50 μm to be more operationally efficient and better suited to shipboard application than at 25 μm. However, both screens showed strong performance removing about 90% of all particles above 50 µm, and the 25 µm screen removing about 85% of all particles above 25 µm (Parsons & Harkins 2000).

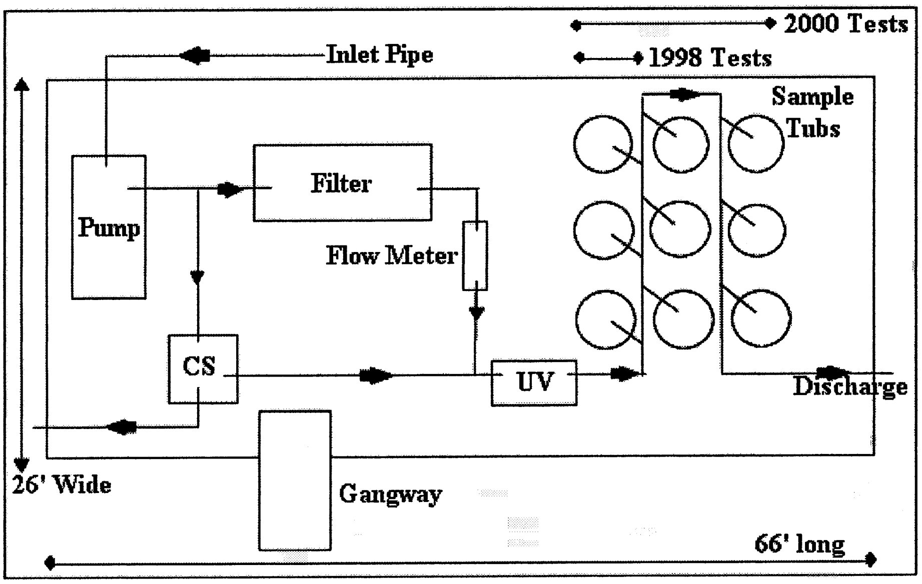

Figure 2. Great Lakes Ballast Technology Demonstration Project barge-based experimental platform.

Biological samples were collected from the triplicate catchment tubs, which were filled consecutively with treated or untreated water. Whole water samples were taken for bacteria counts, and all of the water in the catchment tubs was drained through bottom outlets into a 20 µm plankton net and concentrated to 1 L for plankton and attached bacteria analysis. The objectives, methods, and findings of the biological experiment are detailed in Cangelosi et al. (2001). Figures 3 and 4 show percent removal relative to controls of ambient zooplankton and phytoplankton taxa by the two filter sizes.

The Project tests also showed that the filters did not have the effect of increasing relative to controls the number of smaller particles in the discharge stream through break-up of algal filaments or colonies. Fig. 5 shows the distribution of algal filament sizes in treatment and control samples.

4 Filtration as compound system component

Most documented biological invasions are of larger zooplankton, benthos, fouling organisms and fish (Waite & Kazumi 2001). However, several studies (Hallegraeff & Bolch 1991; Carlton & Geller 1993; McCarthy & Khambaty 1994; Knight et al. 1999; Ruiz et al. 2000) highlight the threat that microzooplankton, phytoplankton, even bacteria and viruses pose. Red tide, for example, caused by toxic dinoflagellates, is a well-known public health threat. It can be transported via ballast water in the form of cysts of 20-40 µm diameter. Scientists suspect that toxic dinoflagellates can reproduce to high densities from only a few propagules (Hallegraeff & Bolch 1991). Some zooplankton are also quite small (10 µm) and capable of asexual reproduction. Though very little is known about the ecological changes that may result from ship-mediated transfers of free-standing bacteria, if microecological communities vary greatly from one region of the world to the next, these changes could be profound.

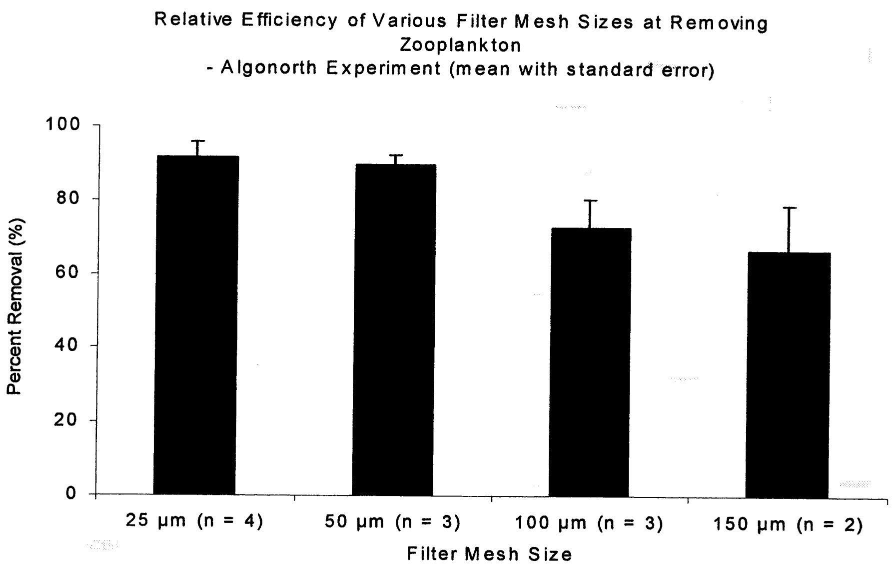

Figure 3. Efficiency of removal of ambient zooplankton taxa by 25 and 50 µm filtration.

Filtration by itself is inadequate to treat against the threats posed by very small (i.e. < 50 µm) freestanding organisms. Indeed, there is no known single treatment that can effectively guard against ballast-transfers of every form of aquatic life that is not accompanied by untenable economic, environmental or safety trade-offs. Yet filtration's special forte — the ability to exclude larger aquatic life forms (i.e. > 50 or 100 µm in width) and sediment particles from ballast intake with no environmental residuals - is an extremely valuable one because these taxa are indeed notorious culprits of ballast-mediated biological invasions. Efforts are therefore underway to make filtration technology more compact and practical for application to many classes of ships, and to combine filtration with a secondary treatment, such as ultraviolet radiation (UV) or an environmentally sound biocide, to optimize biological and operational effectiveness.

In 2000 and 2001, the Project tested UV as a possible secondary treatment with 40 µm prefiltration, and experiments with UV and 100 µm depth prefiltration are underway. The experiments involving UV radiation measure effects of treatment on phytoplankton growth and zooplankton mortality and reproduction, and bacteria and virus viability. The results so far show that UV contributes significantly to system effectiveness by significantly reducing culturable bacteria, viruses and phytoplankton. UV alone, however, did not reduce zooplankton to the extent possible with filtration as a pretreatment. This provides empirical evidence for the advantages of a compound treatment system in which zooplankton removal is achieved in the primary stage (Cangelosi et al. 2001).

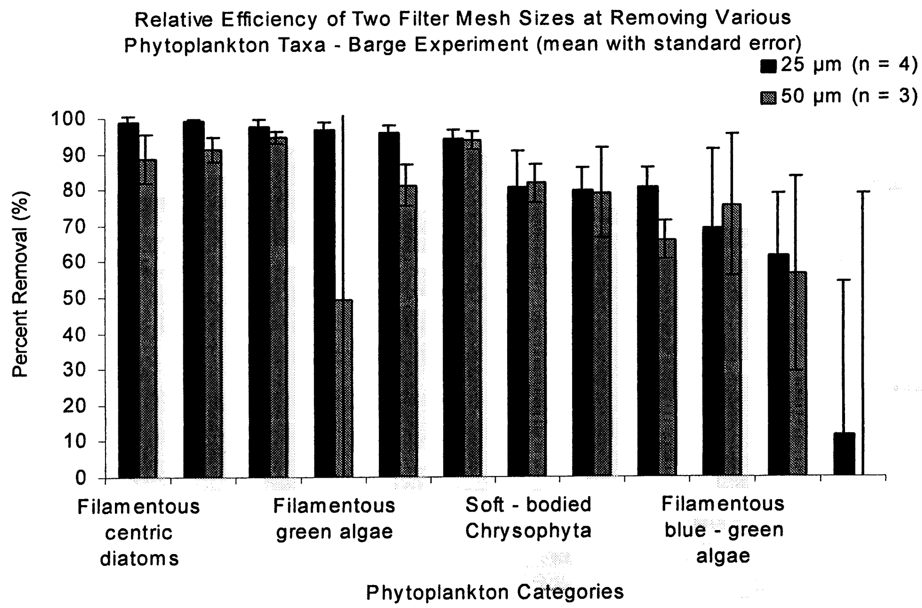

Figure 4. Efficiency of removal of ambient phytoplankton taxa by 25 and 50 µm filtration.

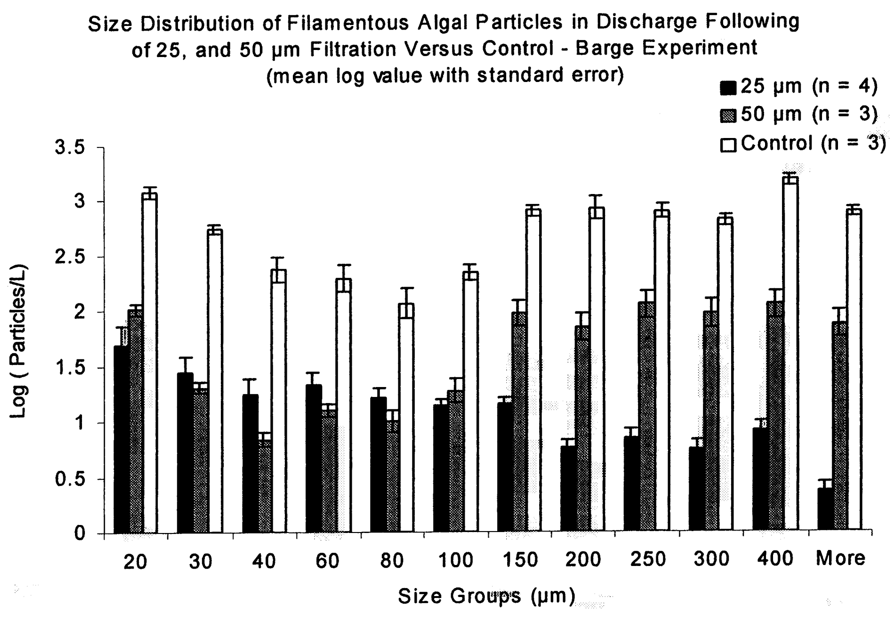

Figure 5. Size distribution of algal filaments with and without filtration at 25 and 50 µm

5 Filter pore size considerations

Clearly, the finer the filtration, the greater the operational challenges associated with it, while biological performance improves. However, the Project found that these trends are not necessarily linear, helping to define the level of filtration that is most efficient. The Project 's filter trials showed that the screen filtration at 50 μm is much more operationally efficient than at 25 μm (Parsons & Harkins 2000). Meanwhile, the biological tests showed that biological effectiveness improvements were only subtle; most of the advantages of filtration at 25 μm (e.g. almost complete removal of macrozooplankton and most microzooplankton) can be reaped at 50 μm.
The limitations of filtration (relative to microalgae and bacteria) remained the roughly same at both levels of filtration. This research indicates that there is little reason to suffer the operational difficulties of pushing filtration to 25 μm, especially if it is to be coupled with a secondary treatment to address smaller organisms.

On-going project tests explore whether the same logic holds true for 100 μm filtration, which offers even more operational advantages. Much will depend upon the strength of the UV system downstream from the filter. At 100 μm, some macrozooplankton will likely pass through the filter treatment stage, shifting a significant task to the secondary treatment stage that is not there in source water filtered to 50 μm. If the secondary treatment is less effective on larger organisms (such as UV), this shift may create the need for significantly higher doses of the secondary treatment to achieve target reductions. This need may outweigh the operational advantages of coarser filtration for some classes of ships.

Ultimately, the treatment vendor and the ship owner will weigh these advantages and disadvantages to arrive at the optimum treatment combinations for each class and make of ship. It is important to note that the type of filtration will likely confound direct comparisons of filter effectiveness based on pore sizes alone. Depth filtration at 100 μm may well remove a wider range of zooplankton than screen filtration at 100 μm because organisms tumble through the depth filter exposing both their long and short dimensions to the filter pores. Organisms orient to the flow of the uniplanar screen filters, with high odds of presenting their narrowest dimension to the screen (Cangelosi et al. in prep).

6 Filtration versus cyclonic separation

The Project also evaluated a commercially available cyclonic separator (Hyde-Optimarin) as a possible substitute for filtration. Cyclonic separation (CS) has been offered as an alternative primary treatment to filtration that has fewer moving parts and can handle higher flow rates. Unfortunately, Project experiments revealed that the CS system tested did not significantly reduce organism numbers or increase mortality. The CS also did not enhance the biological effectiveness of UV in these tests (Cangelosi et al. 2001).

A pilot-scale study of the same system reported only minimal removal of certain organisms by CS (Jelmert 1999). The system, rated to 100 μm, also had a low overall particle removal efficiency. It removed only 30.5% of all particles 100 μm and greater in size. In comparison, screen and disc filtration removed over 90% of all particles above the ratings tested (50 μm and 100 μm, respectively) (Parsons & Harkins in prep.) (Fig. 5).

At present, CS may contribute to treatment through performing a mechanical role in helping to protect the UV system from larger damaging particles over time.

It also may reduce particle loadings in those circumstances in which large numbers of heavier particles are entrained in the ballast intake. Until CS technology applications to ships improve, however, CS should not be considered as a substitute for filtration for particle or organism removal.

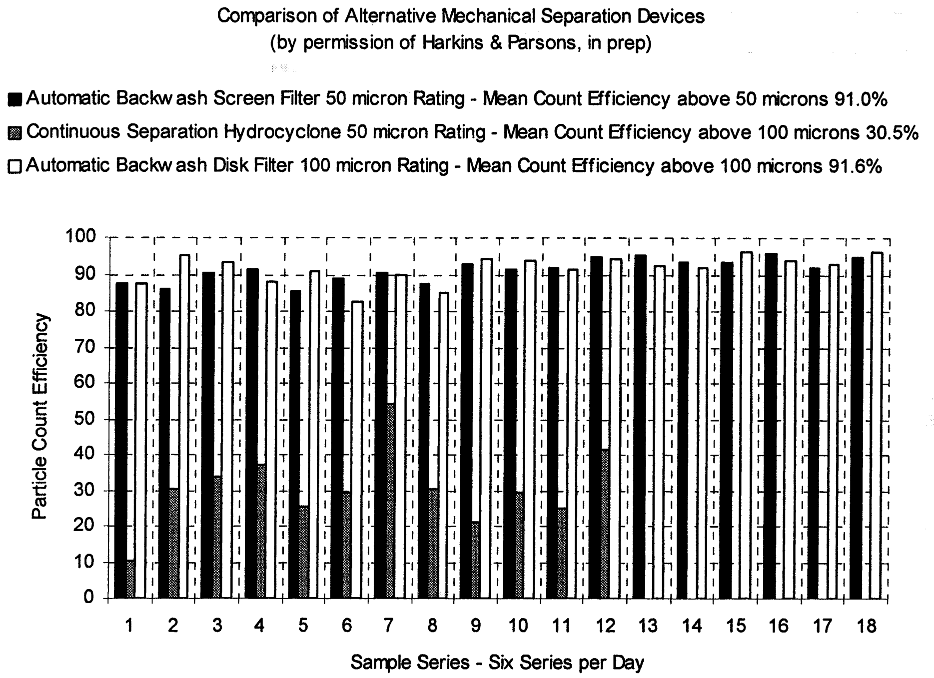

Figure 6. Mean particle removal efficiencies of a cyclonic separator and two filtration technologies at 340 $m^3 h^{-1}$.

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