Pilot Evaluation of Bag and Cartridge Filters

A Technical Assessment of Commercially-Available Bag and Cartridge Filters for Removal of Cryptosporidium-sized Particles from Drinking Water

Technical Report

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REPORT SUMMARY

Small water utilities are looking for economical ways to meet increasingly stringent water quality requirements. This pilot field study evaluated the effectiveness of commercially available bag and cartridge filters in meeting EPA turbidity requirements.

Background

Drinking water regulations implemented in the past 20 years present a challenge to all U.S. water utilities but especially to small utilities with limited resources and funding. Many small water utilities and the U.S. Environmental Protection Agency (USEPA) regional offices that support them are interested in evaluating low-cost technologies that can produce drinking water that meets the many stringent requirements of the new regulations, particularly the turbidity requirements of the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). One such technology is the disposable bag or cartridge filter, which has found widespread use especially in small-scale industrial applications. With this technology, water is pumped under pressure through a woven fabric that filters the particles from the water. While the USEPA has conducted several detailed assessments of a variety of filters and cartridges in a laboratory setting, there is little field data available. This study was initiated to provide the USEPA with some field data in order to assess the performance of these units in a "real-world" setting.

Objectives

- To assess whether the bag and cartridge filters are suitable for meeting LT2ESWTR turbidity regulations
- To evaluate the effectiveness of a small sampling of two bags and one cartridge under normal water treatment plant conditions.

Approach

To test the efficacy disposable bags or cartridge filters under field conditions, the project team pumped water from the St. Louis Howard Bend Water Treatment Facility through two bags and one cartridge supplied by the EPA. The water for the study wad already been chemically conditioned by lime softening and had passed through the sedimentation stage in a settling basin. Influent water turbidities were always less than 1.0 NTU. Typical particle counts in the size range from 2 to 10 micrometers ranged from 500 to 1000 particles per ml. The team conducted laboratory tests on samples of the effluent water to measure turbidity and particle size reduction. The investigation focused on operational questions, such as the throughput that can be achieved using the bags and cartridges, optimum operating pressures, and the general level of attention required by the pilot facility.

Results

The evaluation of the bags and cartridge filter was limited in this study to a handful of runs; so sweeping generalizations about the potential performance of these units are limited by the scope of the study. However, the data collected in this study combined with earlier research efforts justifies somewhat broader statements than what is possible from an examination of the evidence in this study alone.

Single-pass filtration of water using either the nominally-sized or absolutely-sized bag filters does not produce water capable of meeting either turbidity limits or removal of *Cryptosporidium*-sized particles. The cartridge filter results are more promising, particularly as pertains to turbidity removal, but greater pressures may be necessary to ensure that the filter can be used to treat water economically. The results show that the bag filters assessed in this study cannot produce potable water alone with a quality sufficient to meet the turbidity requirements of the LT2ESWTR. The cartridge filter shows more promise as a filtration device, but its economic feasibility is uncertain. A combination of bag filters and cartridge filters seems more likely to produce the quality water needed at a more affordable price.

EPRI Perspective

The information gathered from these preliminary tests will be used to assess performance of the bag and cartridge filters. The next phase of testing will focus on the following:

- Verification of filter material integrity and expected pressure drop at controlled face velocities
- Long-term operation of a nominal bag followed by an absolute bag operated in series
- Long-term operation of a nominal bag followed by a cartridge filter operated in series
- Evaluation of using a simple, inclined tube manometer for purposes of ensuring mechanical seal and its use by small system operators
- Refinement of recommendations for credit for bag and cartridge filtration for purposes of complying with the LT2SWTR.

Keywords

Water quality
Turbidity
Filtration
Bag filters
Cartridge filters

ABSTRACT

As part of the rule making process for the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR), the USEPA is in the process of determining the appropriate level of log removal credits to be given to cartridge and bag filters. An experimental study was conducted to evaluate the effectiveness of two bag filters and one cartridge filter to meet turbidity requirements expected in the LT2ESWTR. The tests were conducted at the St. Louis (City) Howard Bend Water Treatment Plant in St. Louis County, Missouri. Both turbidity removal and particle count reduction (in the 2 to 10 µm range) were evaluated.

The scope of the present study was preliminary and the focus was on evaluating performance of bag and cartridge filters when used in the field. A single pass of chemically conditioned and settled water through either bag was not sufficient to produce a filtered effluent with turbidity less than 0.3 NTU. However, both bags could effectively reduce turbidity levels and particle counts for a short time. The results show that the bags are susceptible to short-circuiting and such incidents are not easily detected. The cartridge filter produced an effluent with turbidities averaging less than 0.07 NTU, but clogged after a short time and limited flow. Thus, the cartridge filter may meet the technical goals of the study but may not be economical.

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1
INTRODUCTION

1.1 Background

Drinking water regulations implemented in the past 20 years present a challenge to all U.S. water utilities, but especially to small ones where resources and funding are limited. Thus, many small water utilities, and the U.S. Environmental Protection Agency (USEPA) regional offices that support them, are interested in evaluating low-cost technologies that can produce drinking water that meets the many stringent requirements of the new regulations, with particular emphasis on the stringent turbidity requirements of the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). One such possible technology is the disposable bag or cartridge filter, which has found widespread use especially in small-scale industrial applications. With this technology, water is pumped under pressure through a woven fabric that filters the particles from the water. While the USEPA has conducted several detailed assessments of a variety of filters and cartridges in a laboratory setting, there is little field data available. This study was initiated to provide the USEPA with some field data in order to assess the performance of these units in a "real-world" setting.

1.2 Study Objectives and Scope

Bag or cartridge filter systems have traditionally been used in small-scale wastewater treatment applications, such as with metal finishers or printed circuit board manufacturers to meet pretreatment requirements, or as a treatment step in high purity water, such as the quality needed in manufacturing printed circuit boards. Given the large market and vast number of potential users of this equipment in industrial applications, there are numerous suppliers of housings, replacement bags and replacement cartridges.

More recently, managers of smaller water treatment facilities are considering these systems as a low-cost alternative to meeting the turbidity requirements of LT2ESWTR, which require that even very small systems produce finished water with turbidity less than 0.3 NTU in at least 95 percent of all samples. Given the intense level of interest in this equipment, the USEPA Office of Research & Development (EPA ORD) has conducted detailed laboratory studies of these systems to determine how effectively they can reduce turbidity and remove particles in the size range of *Cryptosporidium* (EPA, 2001). Yet, as the National Small Flows Clearinghouse states in their Tech Brief on filtration, the use of bag or cartridge filters in potable water treatment must be considered an emerging technology (NSFC, 1996). The uncertainty reflected by the NSFC publication has made it challenging for the USEPA to determine an appropriate level of log removal credit for these devices under the terms of the LT2ESWTR.

The USEPA laboratory tests have been conducted under carefully controlled conditions using tap water spiked with polystyrene beads (EPA, 2001). In addition, at least one manufacturer has conducted Environmental Technology Verification of their system through NSF International (NSF International, 2001). However, many of these assessments were not focused on how these systems perform under "real-life" conditions. The present study was initiated to evaluate the effectiveness of a small sampling of two bags and one cartridge under "normal" water treatment plant conditions. The bags and cartridges were chosen to represent a range of expected performance and costs; their listed performance characteristics are described in detail in Chapter 2.

The study was conducted at the St. Louis Howard Bend Water Treatment Facility located in St. Louis County, Missouri. The plant is a lime-softening plant treating water from the Missouri River, and has a capacity over 200 million gallons per day. Currently, water treated at the facility is pumped to St. Louis City, St. Louis County, and neighboring St. Charles County. The study was conducted by pumping settled water (i.e. effluent from the settling basin after lime-softening) through the bag and cartridges, so the influent water for the study is already chemically conditioned and has passed through the sedimentation stage. Influent water turbidities were always less than 1.0 NTU. Typical particle counts (in the size range from 2 to 10 micrometers) in the influent ranged from 500 to 1000 particles per mL.

1.3 Previous USEPA Assessments

The EPA ORD has conducted a number of studies with bag and cartridges in an effort to determine an appropriate level of log removal credit the devices should receive for the removal of pathogens. This effort is partly to satisfy the requirements expected under the LT2SWTR, which is expected to be finalized by July, 2005. The effort is also partly in response to the numerous inquiries about the potential use of these devices by rural water utilities in a number of USEPA regions (Goodrich, 2004).

The EPA ORD has conducted more than 10 assessments of bag and cartridge combinations from a variety of manufacturers using tap water spiked with 3 micrometer-diameter polystyrene latex beads to simulate *Cryptosporidium* removal (EPA, 2004). The EPA ORD has tested a number of combinations of bags and cartridges and found wide variation in the outcome. The USEPA researchers report the following observations that are pertinent to the present field investigation:

- certain cartridges fouled quickly--within 30 minutes--even when preceded by a bag filter and low turbidity influent (< 1 NTU);
- runs were performed with low turbidity influent (less than 0.1-0.2 NTU); yet, such low turbidities do not reflect typical drinking water plant conditions;
- turbidity removal was not evident;
- certain bag and cartridge combinations in series achieved long filter runs capable of processing as much as 1.5 million gallons total from an individual bag;
- some of the bags were prone to splitting.

The principal dilemma for EPA regulators, whose responsibility it is to use the ORD investigations to award appropriate treatment credit to bags and cartridges, has been a lack of field verification, where the bag and cartridge filters were operated under actual treatment plant conditions. Thus, this present study was designed to provide such information.

1.4 Technology Summary

Bag and cartridge filters are used in a wide number of industrial filtration applications, from filtering white water in a paper mill to filtering corn syrup at a processing plant. They come in a nearly limitless range of sizes, from coarse wire screens to fabrics capable of filtering particles with sizes less than one µm. In this study, the focus was exclusively on bags and cartridges made of fabric and rated for filtration of particles in the size range of 2-10 µm in diameter.

Bag and cartridge filter technology is simple and straightforward. The bags and cartridges are made of woven materials, usually a polymer, which serves to filter the particles from the water. The bags are cone-shaped and hung inside a cylindrical canister. Typically, a metal mesh strainer provides support to the bag so that during operation the fabric is pushed against the strainer. The cartridges are woven over a perforated plastic or metal core, which provides the rigidity needed to hold fabric up against typical operating pressures. The fabric can be Dynel, acetate, porous stone or carbon filters, but these sophisticated materials are most often used only in unique, industrial settings. The more common materials, principally cotton and polypropylene, are inexpensive and most often recommended by the manufacturers for use in potable water applications.

Both bags and cartridges are rated to some particle size—known as the filtration rating—expressed either nominally or absolute. A nominal rating means that the bag or cartridge removes a certain percentage of particles (usually 95 percent) down to its rating. An absolute rating means the item will remove greater than 99 percent of the particles sized at or above its rated value.

2
MATERIALS AND METHODS

The field study was designed to evaluate the performance of two types of bag filters and one cartridge filter under "real-world" situations. Previous EPA ORD assessments of this equipment have used tap water spiked with polystyrene latex beads (EPA, 2001; EPA, 2004). These assessments are designed to provide the information needed to calculate appropriate log removal values for specific filters, and were conducted under controlled laboratory conditions. However, they do not address the question of performance or effectiveness under circumstances likely to be encountered in operating drinking water facilities.

The present study was intended to represent actual usage by water treatment facility staff. Thus, the staff at the St. Louis Howard Bend Water Treatment facility operated the units during the long-term assessments and collected the samples for study of the performance parameters for this study.

2.1 Experimental Design

The filter assemblies were supplied by the USEPA Water Supply Water Resources Division (WSWRD) located in Cincinnati, Ohio. The equipment was shipped to the Howard Bend plant and assembled by plant staff on a skid located within the treatment plant's filter gallery. A schematic of the experimental set-up is shown in Figure 2-1.

Influent for the filters was taken from a point in the treatment plant that was after sedimentation but prior to dual-media filtration. Two sump pumps (Little Giant WGP-90 supplied by Grainger, Inc.) were used to pump water through the filters; the pumps were lowered into one of the treatment plant's active gravity filters, in order to use water before plant filtration. During the initial assessment period it was determined that flow rates remained relatively constant regardless of fluctuations in the depth of the water within the filter.

The photograph of the experimental set-up is shown on Figure 2-2. Pressure gauges (manufactured by US GAUGE, Grainger Part no. 1X597, capable of measuring from 0 to 50 psig, were installed immediately upstream of the unit being tested. In Figure 2.2 the pressure gauges are installed upstream of the two filter bag housings as, at the time this picture was taken, the cartridge filter was not being used. Effluent from all housings was discharged to a drain to avoid any chance of cross-contamination. Howard Bend plant staff also installed sampling ports in both the influent and effluent lines of the housings. Clear plastic tubing was used for the sample lines. Flow through the housings was controlled by using a gate valve on the housing effluent, as shown in the schematic on Figure 2-1.

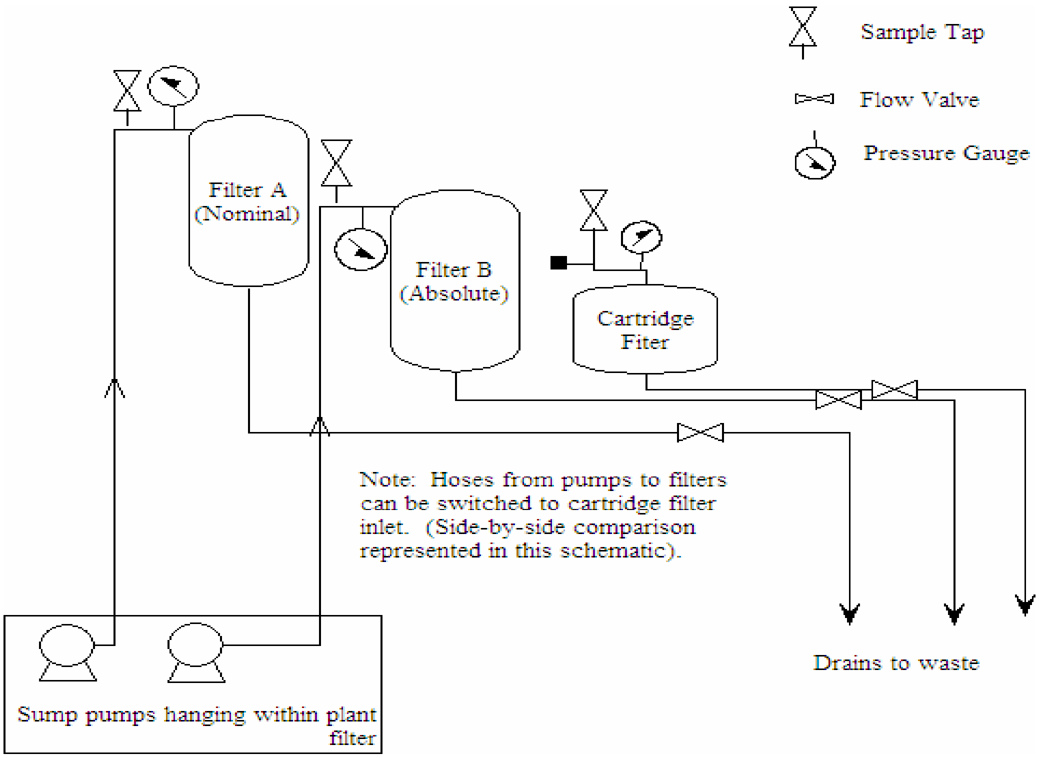

Figure 2-1
Experiment Schematic

Figure 2-2
Experiment Showing Two Filter Bag Housings (Silver Units) and Single Cartridge Housing (White Unit between Bag Housings)

Flow through the two bag housings differs. As shown in Figure 2-3, flow through one of the housings enters on the side and must turn 90 degrees before existing at the bottom. While the differences seemed minor, the differences proved significant from the standpoint of testing various bags. Both types of filter bags fit one of the housings (the housing in Figure 2-2 on the right), but only the thinner, nominal bag fit the housing on the left in Figure 2-2. Thus, this study was able to assess both types of filter bags; however, it points to a potential field operation issue in that filter bags must be carefully selected for both treatment capability (i.e. filtration rating) and with the ability to fit into the filter housing.

Two bags and one cartridge filter were evaluated in this study. The properties, as specified by the manufacturers, are summarized in Table 2-1. The three filters represent a range of performance characteristics. The first bag filter, named B-1, has a graduated filter design and is claimed by the manufacturer as a "high-performance" bag. The bag consists of multiple layers with successively tighter ratings so that smaller particles are removed as the fluid travels through each layer. According to company literature, this bag had the most consistent performance of any bag tested by the US EPA team in Cincinnati. The second filter, designated B-2 in this study, is a standard single-ply bag designed to be a cheap filtration alternative for a variety of filtration applications. Selection of the cartridge filter was driven by the type of housing supplied by EPA WSWRD. Cartridge filters are made specifically for a particular make, so interchanging is not possible. In this case, a rating of 1 µm was chosen because that rating was the largest available below the expected size of *Cryptosporidium*.

Table 2-1
Properties of Filters Tested in this Study

Filter No.	Test Filter Designation	Clean Pressure drop, psi	Max Pressure drop, psi	Particle size rating, µm	Efficiency	Retail Cost ($)
1	B-1	.5 - .35 at 20 gpm	25	5 – 15, absolute	>99 %	48
2	B-2	unknown	unknown	1, nominal	96.8 % @ 7 µm	3.50
3	C-1	2.5 at 20 gpm	25	1. absolute	> 95	75

Information on for Bag B-2 was obtained from the equipment supplier. Pressure drop information was not available from the manufacturer.
Based on the results from this study, clean pressure drop was less than 1 psi.

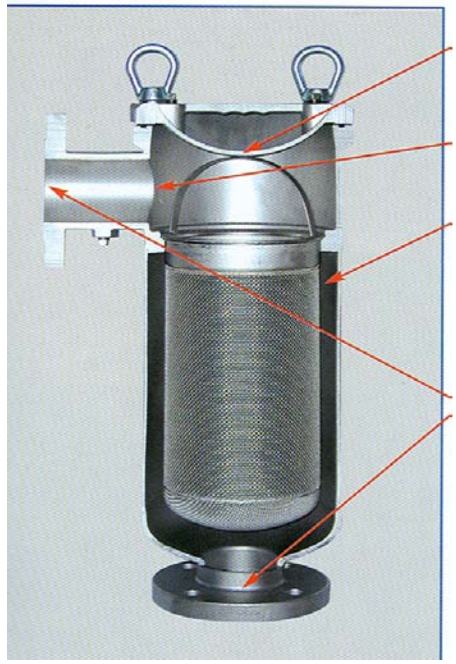

Figure 2-3
Typical Bag Housing with Side Influent

2.2 Sample Collection and Analysis

Experimental operation, along with sample collection and analysis, are described in detail as the Field Study Protocol, which is included as an Appendix to this report. The protocol includes the Quality Assurance Project Plan (QAPP), as required by EPA-funded projects where data are collected. The following is a brief description of the efforts used in operating the experimental matrix.

Testing was divided into two phases. During the first phase, three runs lasting about eight hours each were conducted as preliminary runs. These tests served to identify the range of experimental parameters needed for this study. The initial runs showed the pumps could deliver as much as 20 gpm through the filter bags, and about 1 gpm through the cartridge filter. However, more steady flow control was obtained by operating the filters at approximately 10 gpm. The cartridge filter, which has a higher clean pressure drop, was operated at peak flow of 1 gpm for the duration of the study. During the second phase, the filters were continuously operated until one of the following occurred: terminal headloss was achieved, the effluent turbidity equaled influent turbidity (i.e., turbidity removal was no longer evident), or no more flow passed through the filter. Operating parameters for the eight runs conducted are summarized in Table 2-2.

Engineers from the EPRI Community Environmental Center collected samples and measured turbidity during the initial 4 to 8 hours of operation during each test; thereafter, Howard Bend treatment plant staff collected samples and measured turbidity. Turbidity measurements of the influent and effluent from any operating filters were taken on an hourly basis for the first six hours, and every 8 hours thereafter. In addition, experiment operating data including pressure and total flow were recorded. Samples were also collected at the same time intervals for analysis by optical particle counter (size-specific particle number concentration) and turbidity at the Aerosol and Air Quality Laboratory in the Washington University School of Engineering and Applied Science.

Table 2-2
Summary of Test Parameters for Individual Runs

Run No.	Filter Tested	Flow rate		Total Hours Operated	Volume of Water Treated, gallons	Reason for Stopping Run
		Initial, gpm	End, gpm			
PHASE 1 (Preliminary)						
1	B-2	26.4	25.6	8.8	13,800	preliminary
2	B-1	25.8	24.9	8.8	13,380	preliminary
3	B-2	26.8	26.2	6.0	9,500	preliminary
4	B-1	25.5	25.5	6.0	9,180	preliminary
PHASE 2						
5	B-2	27.1	25.9	83.6	136,251	turbidity
6	B-2	14.6	6.5	147	75,429	turbidity
7	B-1	13.6	8.0	147	80,887	turbidity
8	C-1	1.2	0	141	2,400	flow

preliminary = preliminary run targeted for 8 hours to determine test parameters
turbidity = effluent turbidity exceeded influent turbidity
flow = effluent flow was too low to gather sufficient data

3
FIELD TEST STUDY RESULTS AND DISCUSSION

The experiment was operated in two phases, including a preliminary assessment (which included a number of different short-term tests), and long-term tests with bag filters and a cartridge filter. Unlike the EPA ORD studies referred to in this report, this pilot study was an evaluation of a single pass through the three filters evaluated. Both bag filters fit into the housings provided, but were not manufactured by the same manufacturer of the housing.

3.1 Preliminary Assessments

The preliminary assessments include the calibration procedure, along with turbidity and particle count analysis of short-term filtration tests to establish operating procedures.

3.1.1 Calibration Procedure

Particle counts and turbidity measurements were carried out for samples from the treatment plant. The Washington University School of Engineering conducted a preliminary dilution calibration in order to establish a turbidity/particle count relationship. The calibration procedure has two purposes. First, the procedure can be used to determine if a linear relationship exists between particle counts and turbidity. Second, the procedure enabled researchers to assess ‘typical’ particle counts for turbidity values expected during the study. The results of that calibration procedure are presented on Figure 3-1.

The graphs in Figure 3-1 showed that turbidity and particle counts have a linear relationship within the expected range of turbidity when plotted on log-log paper. While the exact nature of the relationship is not germane to the study, it enables the researchers to validate the performance of the filters during the long-term testing. The performance verification procedure is described in more detail in the results section on the long term tests. The information developed for Figure 3-1 shows that the particle counter used in this study counted around 1,000 particles (with diameters in the 2 to 10 μm range) for turbidities around 0.1 NTU.

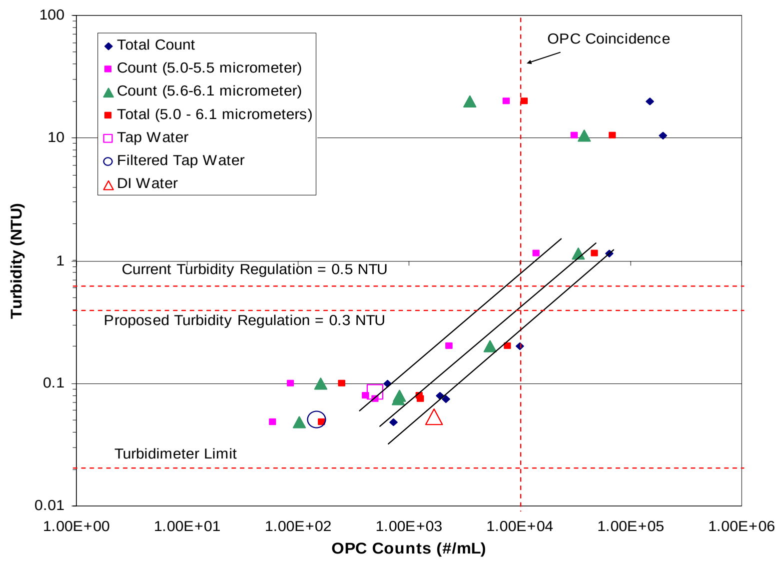

Figure 3-1
Turbidity versus Optical Partical Counts for Influent Water from the Howard Bend Water Treatment Plant

The initial particle count evaluations also revealed that, in general, in both the influent and effluent samples, most of the particles were smaller than 6.1 µm. The percentage of the total particles smaller than 6.1 µm varied, but typically ranged from 80 to 90 percent. When properly operating, both the bags and cartridge removed the same proportions of both the larger particles (i.e. those ranging from 6.1 to 10 µm) and smaller particles. Therefore, in the reporting and discussing these results only total particle counts (from 2 to 10 µm) are given.

3.1.2 Phase 1 Evaluations

The bag filters were operated for four different tests, each lasting about 8 hours to provide a shakedown of the experimental set-up and to identify the most appropriate parameters for use in the bag and cartridge filter assessments. These preliminary assessments enabled the research team to assess their equipment and the process used to collect and analyze test samples.

Samples were analyzed for particle counts by WU and for turbidity at the plant. At the conclusion of these tests it was determined that the field turbidity measurements should be replaced by laboratory turbidity measurements, as calibration conditions and other details on the field turbidimeter were not known. So, field turbidity measurements are not reported here, except for the single cartridge trial run when an error with the laboratory turbidimeter prevented collecting that data.

Results from the four tests, listed in Table 2-2 as Phase 1, are summarized in Tables 3-1 and 3-2.

Table 3-1
Summary of Particle Counts for B-2 Bag Filter (Rated 1 μm Nominal)

Time	Run No. 1* (#/mL)				Run No. 3* (#/mL)			
	Influent	Effluent	Removal %	Removal log	Influent	Effluent	Removal %	Removal log
2 hours	1318	1222	7.2	0.03	568	115	79.8	0.69
4 hours	1328	485	65.0	0.44	565	78	85.9	0.86
6 hours	501	1273	(154.0)**	NA	710	242	65.8	0.47
8 hours	381	218	42.8	0.24	921	658	28.5	0.15

* Refer to Table 2-2 for experimental conditions

**The particle removal data at the 6 hour time interval was NOT included in developing average removal for the Hayward bag filter.

It should be noted that at certain times, especially for the longer duration runs in Phase 2, the effluent concentrations were higher than the influent concentrations. This could be due to the comprising of the seal of the bag unit in the housing; and a re-entrainment of the particles already collected. Re-entrainment of particles is an important issue and relates to operational details such as either replacement of the bag filter or backwashing of the filter. If either is not done in a timely manner, there could be a burst of particles in the effluent, resulting in compromising of water quality.

Table 3-2
Summary of Particle Counts for B-1 Bag Filter (Rated 5 μm Absolute)

Time	Trial No. 2* (#/mL)				Trial No. 4* (#/mL)			
	Influent	Effluent	Removal %	Removal log	Influent	Effluent	Removal %	Removal log
2 hours	2109	82	96.1	1.41	671	343	48.9	0.29
4 hours	936	434	53.7	0.33	1318	389	70.5	0.53
6 hours	1029	253	75.4	0.61	690	393	43.1	0.24
8 hours	945	182	80.7	0.72	1054	916	13.0	0.06

* Refer to Table 2.2 for experimental conditions

Influent turbidity during these runs fluctuated around 1.0 NTU. Turbidity measurements were seen to match with the particle count measurements, as also demonstrated in the initial NTU-OPC validation plot shown on Figure 3.1 and discussed earlier.

Removal of particles by the bag filters during the 8 hour preliminary tests was even more varied than the turbidity removal data. During the first day of tests (i.e. Runs 1 and 2), the nominal bag (i.e. Bag B-2) performed inconsistently, with one sample where total particles exceeding those in the influent and another where removal was under 10 percent. During this initial test, total particle removal from the absolute bag was more consistent, and ranged from 53.7 to 96.1 percent removal for all particles from 2 to 10 μm.

During the second set of tests, which were Runs 3 and 4, the filter performance fared better and the nominal bag (Bag B-2) outperformed the absolute bag (Bag B-1). Particle removal ranged from 28 to 86 percent removal for the nominal bag, but from only 13 to 70 percent for the absolute bag. Typical influent particle counts were between 500 and 1000 counts per ml and fluctuated considerably; however, fluctuation within this range of particles is common and well within expected performance. Further, turbidity measurements match with the particle count measurements as demonstrated in the calibration curve on Figure 3-1.

3.2 Phase 2 Evaluations

3.2.1 Bag Filter Results

The long-term assessments were successful in demonstrating both how well the bag filters can work and in exposing potential flaws in their operation. This section summarizes the results and points to both the successes and flaws. Two separate tests were conducted of a single pass through an individual bag. The first long-term run was a single-pass assessment of B-2 bag filter, which is nominally rated at 1 μm (Run No. 5 in Table 2-2). The second long-term run was a side-by side comparison of this bag with Bag B-1, with an absolute rating of 5 μm (Runs 6 and 7 in Table 2-2). Effectiveness of turbidity removal and particle removal are presented for the initial single-pass test (Run No. 5) on Figures 3-2 and 3-3.

In general, the results from Run No. 5 suggest that the bag filters can effect removal of both particles and turbidity. However, they may not be sufficient alone to achieve the turbidity requirements of the LT2ESWTR. With the exception of the first six hours, particle removal averaged about 35 to 40 percent until about 50 hours of runtime, which also corresponds to the point where turbidity removal percentages dropped dramatically. Turbidity removal averaged about 15 percent for the entire run, as shown in Figure 3-2, effluent turbidity exceeded influent turbidity at several times during the test. Further, effluent turbidity (as measured in the WU lab) averaged 0.49 NTU for the entire test, which is not sufficient to meet the turbidity requirements of the LT2ESWTR.

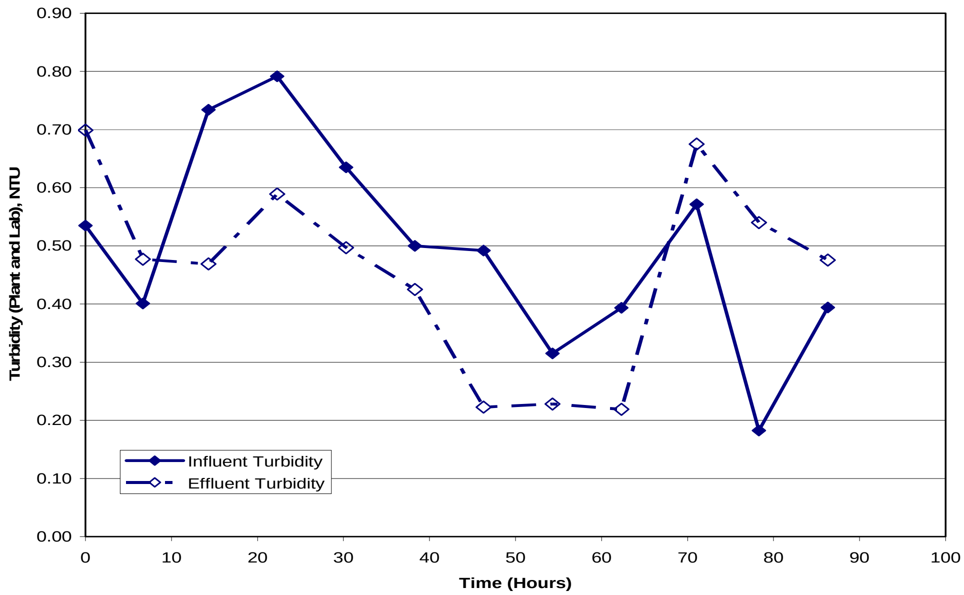

Figure 3-2
Turbidity Measurements for Long Run for Bag B-1 (Run 5)

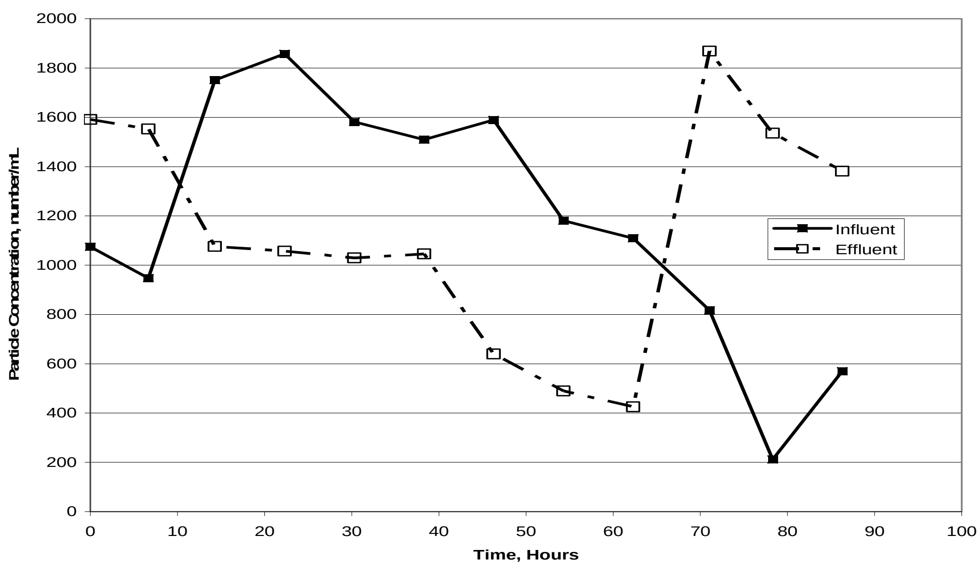

Figure 3-3
Particle Count Measurements for Long Run for Bag Filter B-1 during Run5

As Figure 3-3 clearly shows, the nominal bag was effective at reducing particles in treated water by about 50 percent. The particle reduction was for particles in the size range of 2 to 10 µm, which brackets the range for *Cryptosporidium.*

These initial results were quite promising, and demonstrated that the bag filtration system has potential as a viable and inexpensive treatment technique. Using these results as a basis, another long-term test was conducted where bags B-1 and B-2 were operated side-by-side to compare the performance of each with the same influent water quality (Runs 6 and 7).

The turbidity removal performance and particle count reduction performance are shown in Figures 3-4 and 3-5, respectively.

The results from the side-by-side comparison, summarized by the data presented on Figures 3-4 and 3-5, show highly variable turbidity removal and particle count reduction. In many cases, effluent values exceed influent values from both bags. Unlike the initial run, there is no period of time during the entire operation that either bag showed consistent turbidity removal performance or the ability to reduce particle count. A post-run assessment of the filters suggests a possible explanation.

Upon completion of the side-by-side comparison, the bags were removed and inspected. A picture of the absolute bag after the run next to a virgin (i.e. unused) bag is shown on Figure 3-6. Stains from the floc in the settled water are evident on the outside of the bag, particularly near the top, suggesting that water may have worked its way around the outside of the bag during filtration.

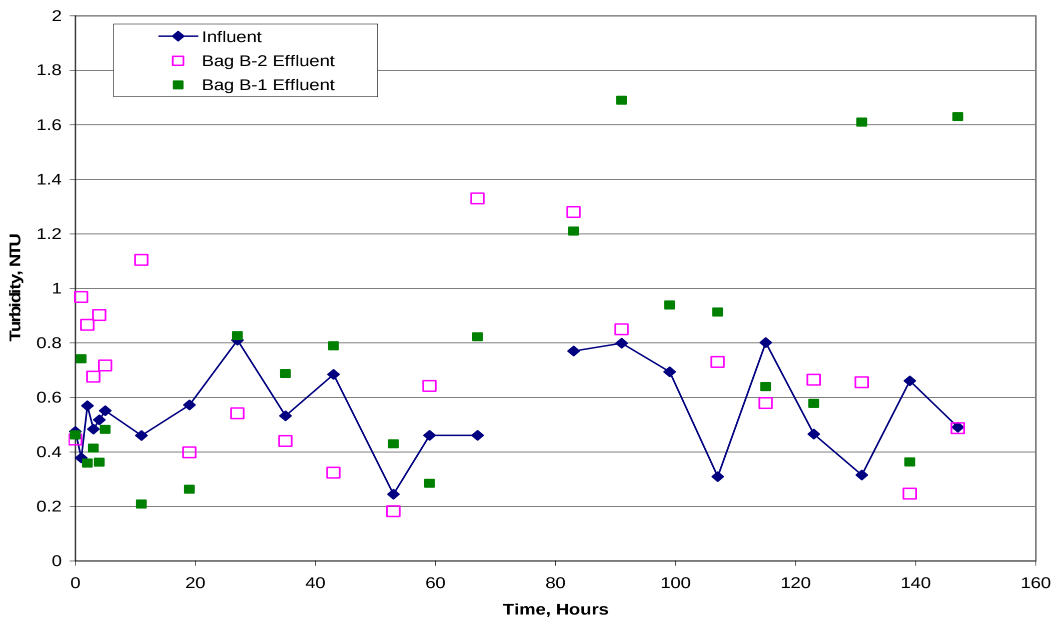

Figure 3-4
Turbidity Measurements for Long Run Comparison of Bag Filters B-1 and B-2 (Runs 6 and 7)

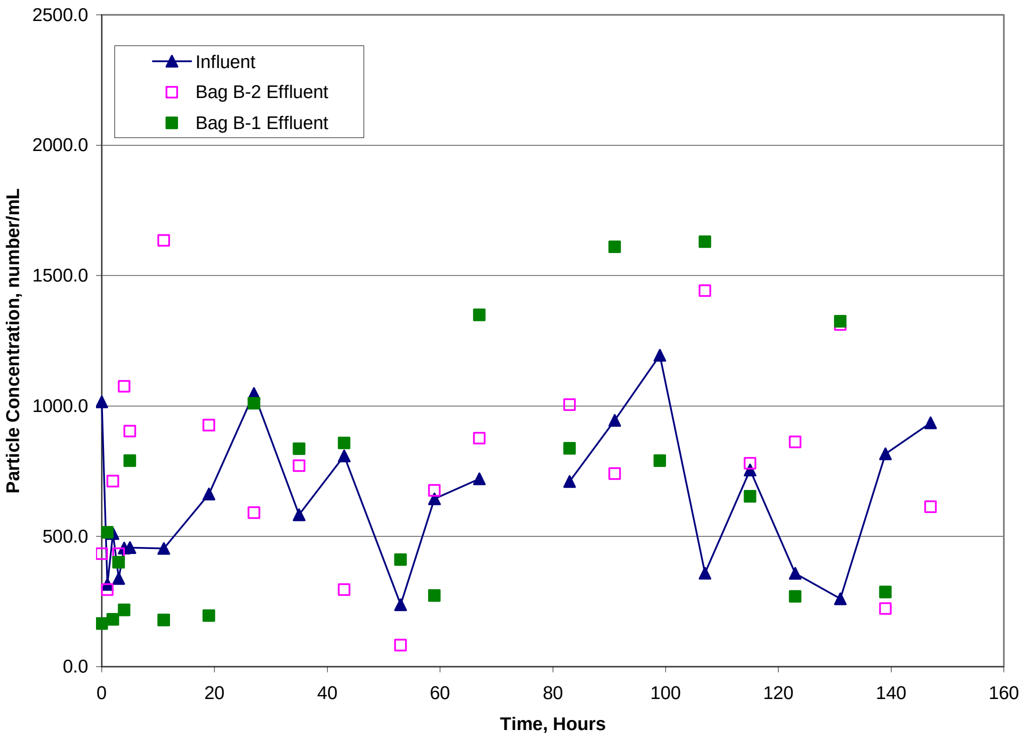

Figure 3-5
Particle Count Measurements for Long Run Comparison for Bag Filters B-1 and B-2 (Runs 6 and 7)

Figure 3-6
Comparison of Absolute Bag used in Side-By-Side Comparison to Unused Bag

The promising results from the initial run combined with the poor performance exhibited in the side-by-side comparison point to two critical and related issues with using the bags for potable water filtration. First, while the bags can effectively filter potable water and remove particles in the size range expected for *Cryptosporidium*, short-circuiting can occur. The bags used in this study were not made by the same manufacturer of the filter housings. In a real world application, a certain amount of swapping of bags and housing should be expected, so the potential of short-circuiting due to a mismatch of the filter bag and the housing seal surfaces must be considered when developing guidelines for the use of this equipment.

The second issue when using the bags for filtration is that a poor mechanical seal is not readily and immediately obvious. This presents significant problems for the actual operation of these units in the field, because when operating on water with the low turbidity observed in this study, it can be difficult to distinguish between instrument variability and the poor performance indicative of short-circuiting. Pressure drop could serve as a simple indicator of a well-sealed bag-housing assembly. The pressure gauges commonly used in bag/cartridge filter assemblies (such as the one used in this study) may not be sensitive enough to indicate a short-circuit leak. An alternative method has been proposed for operational testing in the next phase of testing, and is described in detail Chapter 4.

3.3 Cartridge Filter Results

Cartridge filtration offers the promise of more consistent results than what can be obtained with bag filtration alone. Both the EPA Office of Research and Development and independent results by other researchers suggest that the cartridges can remove turbidity more consistently and effectively than bags (EPA, 2001; NDWC, 1996; Cheremisinoff, 2002). The EPA's own research at their Cincinnati test facility confirmed this conclusion; however, their approach has focused on preceding the cartridge with a bag to serve as a roughing filter. Given the low turbidity (less than 1.0 NTU) and the chemical conditioning of the influent used for this field study, the cartridge was tested by itself for both turbidity and particle removal.

The cartridge filter operated at a higher pressure but significantly lower flow than the bag filters (Run 8 in Table 2-2), so head loss through the cartridge filter is much greater than head loss through a bag filter. Whereas the flow through the bag filters was throttled to attain the target flow, there was no need to do so with the cartridge filter. Thus, the throughput using the cartridge filter was significantly less than the throughput from either bag filter when operated for the same amount of time. Visual inspection of the cartridge at the conclusion of the run shows that it was quite dirty (see Figure 3-7).

Figure 3-7
Visual Comparison of a Virgin Cartridge (Left) Versus the Test Cartridge after Filtering 2,400 Gallons of Water (Right)

Total water filtered by the cartridge filter was only slightly over 2,400 gallons total after more than 140 hours of continuous operation. By the final 8 to 12 hours of the run, the filter was sufficiently clogged that the sump pump could no longer push water through the filter, and virtually no water was filtered. A larger pump will be needed increase throughput through the cartridge filter, or some sort of cleaning procedure should be adopted based on the measured pressure drop. Given that the cartridges are disposable, the larger pump is most likely the preferable option.

The visual inspection suggests that the cartridge filter is quite effective in straining turbidity and particles from the influent; the test results verify this hypothesis. However, the paltry amount of water that can be filtered may make the performance of the cartridge filter alone uneconomical. While the cartridge did perform better than either bag filter, the cartridges are quite expensive; thus, it must be capable of producing more water to become economical. The data is discussed in more detail below.

3.3.1 Turbidity Removal Performance

Turbidity removal performance during the initial stage of Run 8 was acceptable. After an initial ripening period, effluent turbidity from Cartridge filter C-1 was below the expected turbidity limit of 0.3 NTU in 11 of the 16 samples collected, representing 69 percent of the samples. While this is below the 95 percent required by turbidity standards, it was felt that after some optimization, performance should improve. Turbidity removal seems to be related to the influent turbidity, as evident in Figure 3-8. When influent turbidity rose, effluent turbidity seems to follow. Performance decreased significantly after about 98 hours of runtime, which corresponds to the period where the filtration rate dropped nearly to zero. Thus, it is apparent that the filter began sloughing off particles after about 100 hours of operation.

The design of the cartridge and cartridge housing shows that the hydraulic fit is much tighter than is the case with the bag filters. Thus, the cartridges are probably less prone to short-circuiting. In addition, housing designs for the cartridge filters are unique enough that swapping of cartridges with housings not specifically designed to take them would not be possible. This lack of versatility can affect the cost of the cartridges by tying a water utility into a single manufacturer for replacement modules, but also provides a measure of safety to the process not provided by bag filtration.

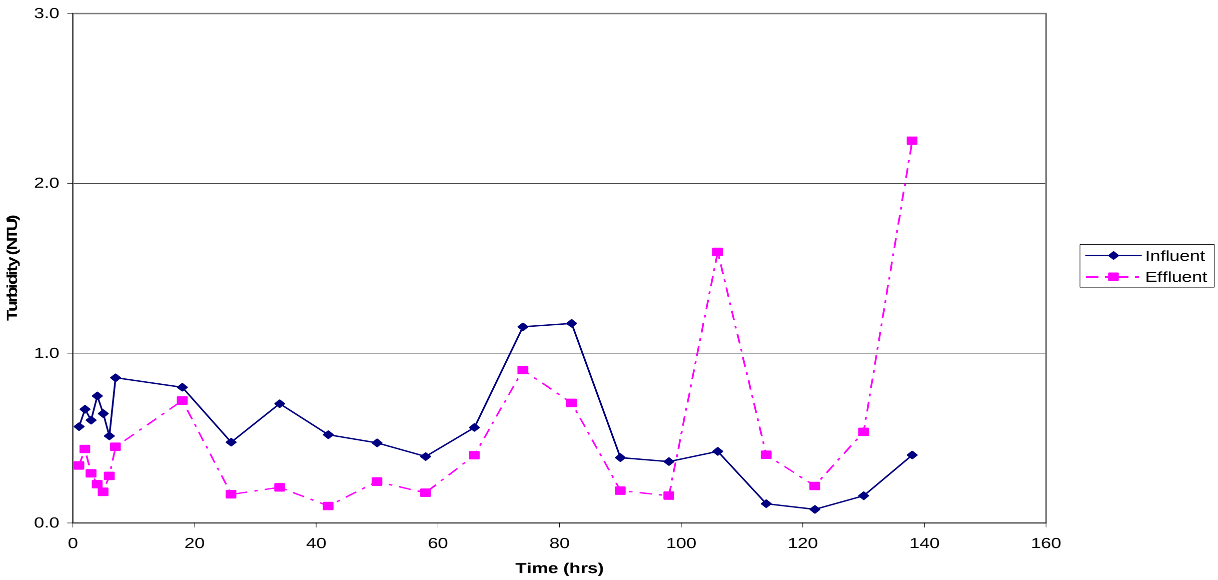

Figure 3-8
Turbidity Measurements from Long Run for Cartridge Filter C-1 (Run 8)

3.3.2 Particle Removal

Particle reduction mirrored turbidity removal, with a brief rise around 80 hours of operation and a couple of high effluent readings after 100 hours of operation. Particle removal during Run 8 is presented on Figure 3-9. The cartridge filter was able to effect a clear reduction in the small particles. In fact, if the four outliers are excluded, the average reduction in particle count was 63 percent from influent to effluent. Total particle counts in the effluent rarely exceeded 500 per ml.

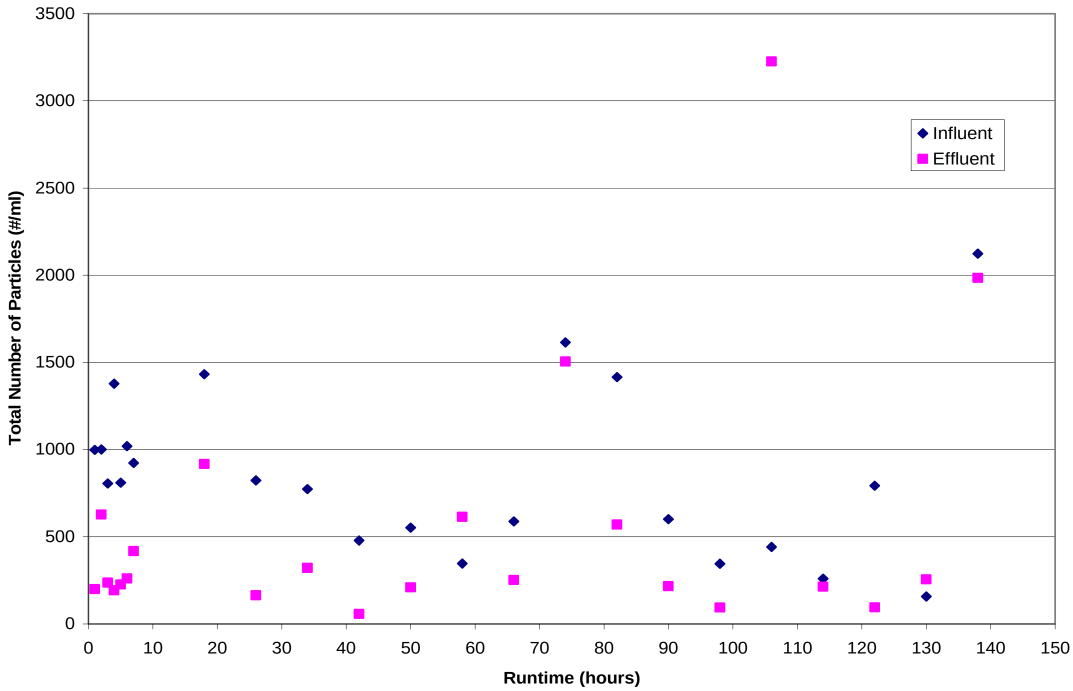

Figure 3-9
Total Particle Count Measurements for Long Run through Cartridge Filter C-1 (Run 8)

The outliers are of concern, particularly when assessing if the cartridge filter is an effective device in removing *Cryptosporidium* from potable water supplies. However, only one data point on Figure 3-9 shows effluent particle counts in excess of influent particle counts. The particle counts measured in the influent and effluent are very low, so an incident where sloughing occurs would cause a marked change in a graph, as is seen in Figure 3-8. Thus, it can be concluded that the cartridge is an effective device by itself at removing particles in the size range of *Cryptosporidium*. It is less clear whether the cartridge can produce sufficient quantities of potable water to be economical. A cartridge filter operated in series with a bag filter may be a more economical way to achieve water quality goals while assuring adequate filtration. While there is not sufficient data to estimate appropriate removal credits for these filters, the cartridge filter by itself achieved approximately 1 log removal under the conditions in this study. It is hoped that a cartridge filter in tandem with a bag filter could achieve 1.5 to 2 log removal performance. However, such verification is proposed for the next phase of testing of this work.

4
CONCLUSIONS AND RECOMMENDATIONS

The evaluation of the bags and cartridge filter was limited in this study to a handful of runs; so sweeping generalizations about the potential performance of these units are limited by the scope of the study. However, the data collected in this study combined with research efforts conducted by the EPA (2001) and NSF (2001) can lead to broader statements than what is possible from an examination of the evidence in this study alone. This section summarizes that evidence to lead to potential conclusions about the performance of these filters and possible recommendations, both for policy purposes and for future research directions.

4.1 Performance of Filters in Field Study

This study was an assessment of two types of bag filters and one cartridge filter in a real-world setting. Water conditioned within a conventional water treatment plant was pumped in a single pass through one of the three types of filters tested, in order to establish the potential for these treatment units to serve as filters for small, rural water utilities throughout the United States.

In many ways, the performance of the filters in this situation is a best-case scenario. The filters tested in this study replaced the dual media filtration practiced at the St. Louis water treatment plant. That plant is operated by an experienced group of professionals who routinely keep filtered water turbidity well below 0.1 NTU. In order to achieve that consistency, the water must be properly conditioned before filtration by constant adjustment of the coagulant dose and proper operation of any settling basins. Bag and cartridge filters offer an inexpensive and low-tech method of filtering water, so it is probably safe to assume that any water utility seriously considering using such a method would be less sophisticated, and most likely less vigilant, in their water conditioning than are the staff at the St. Louis treatment plant. So, it can be concluded that the bag and cartridge filters operated as close to a best-case scenario as possible during this test.

Assuming that is true, the performance of the bag filters was inadequate in meeting the new turbidity requirements as set down by the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). In both short- and long-term testing, neither bag filter tested could produce water with turbidity less than 0.3 NTU for more than a few hours. No attempt was made to optimize the type of bag used in this evaluation; further study could examine this issue, but it is readily apparent that bag filters are not adequate protection against *Cryptosporidium* as a filtering system in and of themselves. This conclusion concurs with many of the experiments by the EPA ORD, which seems to limit their experiments to using the bags in combination with other bags or a more robust filter, such as a cartridge filter.

These results square with those obtained in the environmental verification test conducted by NSF International (NSF, 2001) for LaPoint Industries. That study assessed the performance of an inexpensive prefilter bag followed by the same model B-1 bag used in this study to remove microspheres with sizes of 3.7 and 6.0 μm. Influent turbidity of the well water used in that study averaged 0.75 NTU. Effluent turbidities from the filters averaged between 0.30 and 0.35 NTU for the first 10 days, but climbed up into the range of influent turbidities in the second 10 days of tests. Without the benefit of a prefilter, the poorer performance of the bag in this study is justified.

Another, potentially more significant conclusion from the study pertains to the potential for short-circuiting. Even under the attentive care provided by the staff at the St. Louis plant, significant short-circuiting occurred. A simple measurement is crucial to using this equipment in the field to ensure leak-proof fitting. One potential measurement, which could be examined in more detail in the next phase of testing, is explained in the following section.

The cartridge filter, on the other hand, has better potential under the single-pass scenario. While only one run was attempted, the water quality of the applied water was fairly typical for the treatment plan (i.e. there were no unusual spikes or changes in water quality), so the researchers have confidence in the repeatability of this test. Turbidity readings were lower than those achieved from bag filters B-1 and B-2. As a barrier to *Cryptosporidium*-sized particles, the particle count data suggests that the filter could consistently provide about 50 percent removal of even very small particles, less than 6.1 μm in diameter. Some sloughing may have occurred, but the sudden rise in particles was just as likely due to fabric tearing loose from the cartridge. On a technical basis, it is possible that the cartridge filter could be used as a filter for potable water.

However, on a practical basis changes are needed. The run length for the cartridge filter was simply too short. This observation concurs with a similar one made by the EPA on C-1 cartridge filter, which has also observed problems with that cartridge plugging prematurely even when using a prefilter. Given that the operating pressure used in Run 8 was only 11 psig, which is well below the manufacturer's upper limit of 25 psig, a larger pump could improve throughput. However, as other research has shown, total water treated would probably remain unchanged. Thus, either the run length would be shortened or filtration performance would suffer. While the cartridge filter would work from a technical standpoint, it may be economically infeasible. No attempt was made to optimize the selection of the treatment cartridge, but those interested in using this technology should be warned that a careful consideration of several cartridges would be necessary before a potable water supplier selects the best one.

4.2 Recommendations for the Next Phase of Work

Single-pass filtration of water using either the nominally-sized or absolutely-sized bag filters does not produce water capable of meeting either turbidity limits or removal *Cryptosporidium*-sized particles. The cartridge filter results are more promising, particularly as pertains to turbidity removal, but greater pressures may be necessary to ensure that the filter can be used to treat water economically. The results show that the bag filters assessed in this study cannot produce potable water alone with a quality sufficient to meet the turbidity requirements of the LT2ESWTR. The cartridge filter shows more promise as a filtration device, but its economic feasibility is uncertain. A combination of bag filters and cartridge filters seems more likely to produce the quality water needed at a more affordable price.

An adjustment should also be made to the field filtration unit for further work as well as operational convenience. Pressure measuring devices are needed to measure pressure drop across the filter. This measurement will help in the daily operation of the unit.

Based on the results from this study, it is recommended that two concepts be investigated. First, a protocol for verifying the expected operating parameters should be followed and verified during each run to ensure the integrity of the bags and the mechanical seals. This protocol, described below, will be easy to complete and can be used to ensure that the run is quickly ended if short-circuiting occurs. Second, the bag filters should be tested in series with each other and with the cartridge filter to determine performance. The cartridge filters are expensive, so it may be more economical to use some combination of filters. Perhaps the most appropriate assessment would be to filter water through the nominal bag filter first followed by the absolute rated bag filter. Results from this assessment could be compared to the results of using the cartridge filter alone and the nominally-sized bag filter in series with the cartridge filter. This range of results would enable the EPA to accurately determine the most acceptable configuration of bag and cartridge filters to achieve water quality goals.

Operating parameters will be determined using a two-step evaluation. First, an inclined U-tube manometer will be installed on the filter systems at the treatment plant to more accurately gauge pressure drop across the bag filters. Given the excellent performance of the cartridge filter and after an examination of the mechanical seal, such control may not be necessary for the cartridge filter; however, this will be verified in the second phase of tests. A schematic drawing of the proposed U-tube manometer installation is shown on Figure 4-1.

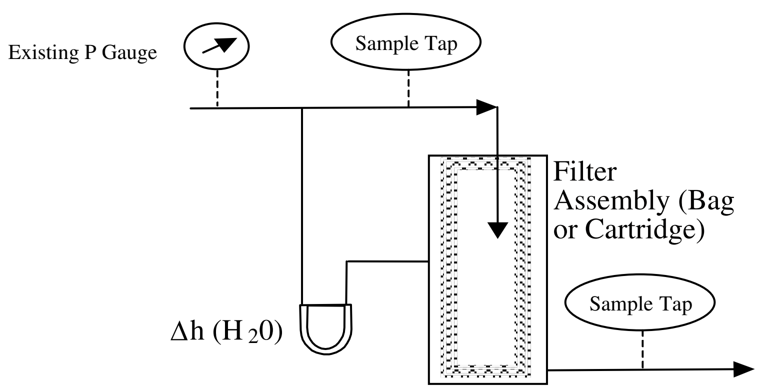

Figure 4-1
Suggested Change for Δp Measurement

Concurrent with installing the U-tube manometer, a laboratory evaluation of the filter materials is proposed. This evaluation will provide information for the expected pressure drop across the filter as a function of face velocity. A schematic of that experimental set-up is given on Figure

4-2. Increase in headloss with continuous filtration could also be studied for specific sized particles or simulated natural sediment matter.

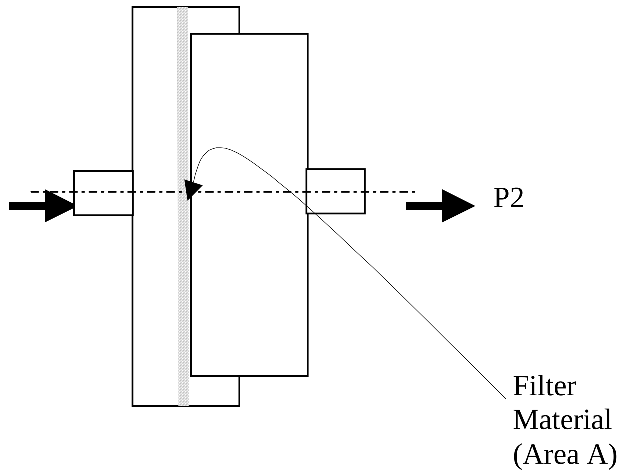

Figure 4-2
Testing of Filter Material for Particle Removal Efficiency

The information gathered from these preliminary tests will be used to assess performance of the bag and cartridge filters. In summary, the next phase of testing will focus on the following:

- verification of filter material integrity and expected pressure drop at controlled face velocities;
- long-term operation of a nominal bag followed by an absolute bag operated in series;
- long-term operation of a nominal bag followed by a cartridge filter operated in series;
- evaluation of using a simple, inclined tube manometer for purposes of ensuring mechanical seal and its use by small system operators;
- refine recommendation for credit for bag and cartridge filtration for purposes of complying with the LT2SWTR.

A
REFERENCES

Cheremisinoff, Nicholas P. 2002. Handbook of water and wastewater treatment technologies. Boston, Butterworth-Heinemann. Chapter 6.

EPA, 2001. Small Drinking Water Systems Handbook: A Guide to "Packaged" Filtration and Disinfection Technologies with Remote Monitoring and Control Tools. EPA Water Supply and Water Resources Division, Cincinnati, Ohio.

EPA, 2004. Status of Experimental Runs for Bag and Cartridge Filters in Series, March 11, 2004, USEPA, Cincinnati, Ohio.

Goodrich, J. 2004. Personal communication on April 24.

Goodrich, J. et. al., 1995. "Cost and Performance Evaluations of Alternate Filtration Technologies for Small Systems", *Proceedings of the 1995 American Water Works Association Annual Convention*.

National Drinking Water Clearinghouse. 1996. Tech Brief: Filtration. Item No. DWBRPE47, West Virginia University, September, 1996.

NSF International, 2001. Physical Removal of Giardia- and *Cryptosporidium*-sized Particles in Drinking Water: LaPoint Industries Aqua-Rite Potable Water Filtration System. Environmental Technology Verification Report NSF 01/24/EPADW395.

B
PILOT STUDY PROTOCOL

B.1 Introduction & Purpose

The EPRI Community Environmental Center and Washington University are collaborating in conducting a short-term pilot evaluation of bag and cartridge filters for the U.S. EPA. The EPA considers these filters a realistic alternative for small water treatment systems struggling to meet the turbidity removal and pathogen removal requirements of the Enhanced Surface Water Treatment Rule. This pilot evaluation will be conducted at an operating water treatment plant to simulate the use of the system in real world applications.

The pilot system includes two bag filters and one cartridge filter. Both bag filters and the cartridge filter are placed into stainless steel housings fitted with gaskets to contain pressure. Under normal operation the filters strain contaminants as the water is pumped through them, so the housings are under pressure. Operating pressures depend on the particular filter or cartridge in use, and run length is largely determined by a preset pressure differential.

This document summarizes the operation of the pilot system, goals of the study, and testing program. This document will be used by the EPRI Community Environmental Center and Washington University as guidance in all phases of conducting this evaluation.

B.2 Experiment Description

There are a number of bag and cartridge filter manufacturers. This pilot facility will use three systems from representative manufacturers that have been evaluated at EPA's research facility in Cincinnati, Ohio. The bag filter housings are manufactured by Strainrite, Inc. of Auburn, ME and Hayward Industrial Products, Inc. of Elizabeth, NJ. The cartridge filter system is manufactured by CyCron of Carson, CA. All three manufacturers build both the housings and the disposable filters (or cartridges). However, there are a number of companies making knock-off filters. In order to maintain quality control, during this study only the manufacturers' own filters and cartridges will be used.

The three systems will be installed in the basement of the filter building at the Howard Bend water purification plant in St. Louis, Missouri. The Howard Bend plant is a lime-softening plant treating up to 250 mgd of water from the Missouri River for the City of St. Louis. Water from the filter influent (which typically has a turbidity of around 1.0 NTU), will be used as the raw water to the pilot system. Using this water has the advantage of eliminating preconditioning needs, as the water has already passed through softening basins where lime and coagulants have been added.

The layout of the pilot system is presented as a schematic in Figure 2-1. There is no scale on the figure. It is anticipated that additional testing may be conducted at the conclusion of this study. However, during this evaluation, only two of the three filters will be operated at any one time. Thus, the schematic shows only two sets of pumps, piping, valves and other appurtenances. If additional tests are funded, a third, identical set of pumps and piping can be added.

Briefly, the water will be pumped via a submersible pump suspended into the influent of one of the plant's filters, into the filters housing. A ball valve will be installed upstream of the filter housing to control flow. Operating pressure will be monitored in each of the filter housings. A flow meter/totalizer will record flow in filter housing effluent pipe.

B.3 Pilot Study Test Parameters and Sampling

The pilot evaluation is based on a three-phased approach, with each phase building upon the results of the previous work. The initial study will focus on the first phase; subsequent phases will be completed if the systems prove robust enough to meet treatment goals and additional funding is secured. During Phase I, the investigation will assess whether the bag and cartridge filters are suitable for meeting ESWTR turbidity regulations (i.e. achieving less than 0.3 NTU). The investigation will focus on operational questions, such as the throughput that can be achieved using the bags and cartridges, optimum operating pressures, and the general level of attention required by the pilot facility.

During Phase I, samples will be collected to assess particle removal using sensitive particle counting techniques used by the Department of Environmental Engineering at Washington University. Of particular interest will be particles around the 5 μm size, which is about the size of cyst of the pathogen *Cryptosporidium*. In the second phase, *Cryptosporidium* and endospore challenges will be completed; most likely, this will be completed using plastic beads or a similar surrogate. The third phase will assess performance of various bags and cartridges in series, assess a variety of commercially-available bags and cartridges (including off-market ones), and investigate the performance of the system under various scenarios simulating abuse or neglect of the facility.

B.3.1 Operating Procedure

The pilot facility will be operated according to the manufactures' recommendations. Start up of both the bag and cartridge filters is a simple process, which includes inserting a new bag or cartridge into the unit, ensuring that the bag or cartridge is properly set, and ensuring that any 'o' rings or gaskets are properly placed. Once the operator is assured the bag or cartridge and gaskets are properly set, the lid is secured and the plant can be started. Under all circumstances, the plant will be allowed to operate for 15 minutes in order to reach steady state before any samples are collected.

These initial runs will be conducted to assess the short-term performance of the systems and to determine anticipated runtimes. According to the manufacturers, the bags and cartridges should be replaced once the pressure differential (i.e. the difference between starting and ending operating pressure) exceeds 25 psi. It is unlikely that that pressure differential would be exceeded during the initial runs. The operator shall measure and record all data on the data recording sheet. A sample sheet is attached to the end of this document.

B.3.2 Sampling Procedures and Protocol

A limited number of short runs will be intensively sampled at the beginning of the pilot study. The results of these runs will be used to estimate the long-term performance of the bags and cartridge so that the operators can better gauge the sampling frequency needed to accurately characterize the pilot system performance.

During initial runs, samples will be collected hourly and the total run length will be only 8 to 10 hours. During subsequent, long-term runs samples shall be collected once per shift (i.e. every 8 hours) and measured for turbidity and particle number. During these runs the pilot facility will be operated continuously 24 hours per day. During these tests, flow adjustments will be made manually once each day. The target flow through all filters will be 20 gpm. As pressure in the vessels increases, flow will decrease so the operator must increase the flow to 20 gpm and record the subsequent increase in pressure.

The scope of the first phase of the pilot study is focused, so samples will be taken only for analysis of turbidity and particle count. Under all circumstances, samples will be taken from the water both before and after the filtration devices. These samples will be termed raw water samples (i.e. before filtration) and treated water sample (i.e. after filtration). Neither turbidity nor particle count sampling requires preservatives or any special handling precautions. However, in all cases the pilot facility operator will collect samples in the following order: collect a raw water sample, then the corresponding treated water sample, followed by a second raw water sample from the sampling port upstream of the other filtration device, followed by the corresponding treated water sample.

Prior to collecting the sample, the operator shall rinse the sample bottle with the intended water stream. In addition, the operator shall wear polyethylene gloves when collecting the sample.

B.3.3 Sample Analysis

Analysis of turbidity and particle count shall be performed by the Department of Environmental Engineering at Washington University. Sample bottles shall be prepared and supplied by the department. A new set of sample bottles will be provided for each pilot facility run. Each set will include both a trip blank and a set blank. The trip blank contains particle free (i.e. deionized water) from the department laboratory. The set blank will be empty and filled with distilled water collected at the Howard Bend purification plant.

The instruments to be used for these analyses are an Ultrasonic Cleaner (Fisher Scientific Model No. FS30H), a Turbidimeter (HACH Model No. 2100AN), and an Optical Particle Counter (Particle Measuring Systems Model No. AAPS 200).

Upon receipt at the Department's laboratory and immediately prior to sample analysis, the sample vials will be placed in an ultrasonic cleaner for five minutes in order to evenly disperse the particles in the sample. The ultrasonic treatment serves to suspend particles settled between the time the sample was collected and the time it is tested.

Approximately 30 mL of the stirred sample will be removed from the vial and used for the turbidity analysis. The remaining portion of the sample will be used for the particle count analysis. Each sample will be analyzed for particle counts six times. Results from the first three replications of each sample are used to clean out the particle counter system and thus will not be reported. The outer part of the tubing transferring the samples to the OPC will be wiped with particle free (PF) water between each sample’s particle count analysis to prevent the cross contamination.

B.4 Data Collection Sheet

Data Collection Sheet
Bag & Cartridge Challenge Start Date:

Filters Operating(circle): Bag Filter B-1 Bag Filter B-2 Cartridge Filter C-1

Date	Time (2400 format)	Pressure (psig)		Total Flow (gals)		Field Turbidity (NTU)		
			Filter B-2	Filter B-1	Filter B-2	Influent	Filter B-1	Filter B-2

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