Attachment R.4 –
Testing of Point-of-Use Filters at Seattle Schools Drinking Fountains. Presentation at AWWA Water Quality Technology Conference, November 2005.

Testing of Point-of-Use Filters at Seattle Schools Drinking Fountains

Glen R. Boyd, Gregory J. Kirmeyer, Gregory L. Pierson,
Sidney L. Hendrickson, David Kreider, and Ron English*

HDR Engineering, Inc., Bellevue, WA
*Seattle Public Schools, Seattle, WA

Accepted for Presentation

American Water Works Association
Water Quality Technology Conference and Exposition

Quebec City, Quebec, Canada
November 6-10, 2005

Testing of Point-of-Use Filters at Seattle Schools Drinking Fountains

Glen R. Boyd, Gregory J. Kirmeyer, Gregory L. Pierson,
Sidney L. Hendrickson, David Kreider, and Ron English*

HDR Engineering, Inc., Bellevue, WA
*Seattle Public Schools, Seattle, WA

Abstract

Preliminary field and laboratory testing were conducted to determine the effectiveness of point-of-use (POU) filters in removing Pb and other corrosion by-products from drinking water at bubbler fountains and other potable water sources in Seattle Public Schools. POU filter installations and sampling at 9 schools indicated that the filters were highly effective for removing lead (Pb), cadmium (Cd), iron (Fe), and turbidity. The principal operating concern was that the filters would plug pre-maturely with iron particulates in buildings with older galvanized steel piping causing reduced flow rates. Results of field sampling were used to develop laboratory bench-top testing of the filter system. Testing was conducted on a filter system that consisted of a 5µm pre-filter and cartridge carbon filter. Preliminary bench-top testing results indicate that the filter system removed Pb to levels typically less than or equal to 10 ppb before exhausting its capacity for Pb. Results also indicate that the pre-filter provided significant removal of Pb. Pre-conditioning (e.g., soaking) of the filter system prior to installation or operating the filter system with intermittent (ON/OFF) flows did not appear to affect Pb removal efficiency. Additional laboratory testing results showed that elevated iron levels in the influent water stream caused reduced flow rates and reduced total throughput capacity of the filter system.

Background

Seattle Public Schools (SPS) purchases water from Seattle Public Utilities for drinking water, other potable uses, and fire protection service. SPS provides educational opportunities to 47,000 students in over 100 schools and administrative buildings. More than 60% of these structures are plumbed primarily with galvanized steel piping, which is over 40 years old and moderately tuberculated. A comprehensive water quality monitoring program of more than 2,000 water sources was conducted in 2004. Chemical analyses included lead (Pb), cadmium (Cd), zinc, copper, iron (Fe), turbidity, color, and coliform bacteria.

Results indicated that 513 samples out of 2,604 samples (19.7%) exceeded the USEPA's guideline of 20 µg/L Pb in schools based on 250-mL samples that had been standing overnight in the fountain and connective piping system. Because of the high variability noted in the Pb sampling results, the School Board decided to establish a more stringent criterion for Pb at less than or equal to 10 µg/L (ppb) for Seattle schools. In addition, Cd exceeded 5 ppb in 35 out of

1,657 samples (2.1%). Iron was found to exceed 0.3 mg/L (ppm) Fe in almost 30% of the samples collected from the piping systems.

Seattle Public Schools has investigated several water quality mitigation measures including piping replacement, fixture replacement, epoxy lining of pipes, and granular media-based point-of-use (POU) filters, which is the focus of this paper. POU filters were investigated because they offer a means of mitigating water quality concerns in some schools for an interim period until more extensive piping improvements could be made.

Objective

The objective of this study was to determine the effectiveness of point-of-use filters in removing Pb and other corrosion by-products from drinking water in Seattle schools at bubbler fountains and other potable water sources.

Approach

The project approach consisted of a field study and laboratory testing as described below.

Field Study

Seventeen POU filtration units were installed in 9 different Seattle schools and tested in an accelerated testing mode in November 2004 to determine if the units were effective in removing Pb from drinking water fountains. Fifteen of these filters were NFS certified for Pb and particulates removal and two were NSF certified for particulates removal only. The filters were packed with activated carbon filtration media with rated capacities of between 3780 L to 7560 L and flow rates of 0.9 to 2.1 L/min. Water quality samples were evaluated for Pb, Cu, Cd, Fe, turbidity, and coliform. Flow and pressure were measured periodically for periods up to 48 hours. During testing, the filters were subjected to a fixed pressure from the supply line and operated continuously. A photograph of a typical filter system installed under a classroom sink is shown in Figure 1.

Figure 1. Typical filter installation under a classroom sink, which includes a pre-filter and charcoal cartridge filter connected from the service line to fountain bubbler head (not shown).

Laboratory Testing

Laboratory testing was conducted in August 2005 to determine if elevated Pb levels in samples collected from school fountains after installation of POU filters could be attributed to early Pb breakthrough. A test rig apparatus was assembled at the HDR Water Quality Laboratory in Bellevue, Washington to study Pb removal and the effects of installation, operation, and iron interference on the efficiency of Pb removal by the filter system.

(a) 

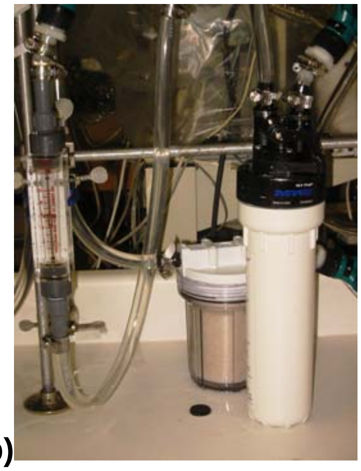
(b) 

Figure 2. (a) Laboratory bench-top test rig apparatus and (b) close-up of flow meter and filter system consisting of a 5µm pre-filter and a carbon filter connected in series.

The test rig consisted of 5 filter systems secured in-place and staged side-by-side on a laboratory bench (Figure 2). Each filter system consisted of a 5µm pre-filter (CUNO Inc., Meriden, CT, model UST-38M Undersink Water Filter) and a carbon filter (Hydro Life, Inc., Bristol, IN, model HLFS 950AD) connected by Tygon tubing. As the lead remediation strategy evolved, the District installed filters with higher capacity ratings (HLFS 950AD) in an attempt to extend filter life. These filters were NSF certified for chlorine reduction and taste and odor reduction, but not NSF-certified for lead reduction. Nevertheless, since these filters were in use, they were selected for the laboratory portion of testing.

Local municipal drinking water was used as the feed water, which is essentially the same as water delivered to Seattle schools. Typical water quality is characterized by pH 7.8-8.7, total alkalinity of 20 mg/L as $CaCO_3$, hardness of 29-30 mg/L as $CaCO_3$, TOC of 0.7-1.5 mg/L, and free chlorine residual of 0.9 mg/L (Seattle Public Utilities, Drinking Water Quality Annual Report, 2004). Background water quality samples were collected daily at the inlet to the test rig and characterized for pH, temperature, conductivity, TOC, and HPC. Flow was controlled by adjusting ball valves and metered at the inlet to each filter system. Flow was maintained at a constant rate of 0.5 gpm for the duration of the experiment into the three filter trains that were fed Pb only (Filters #1, #2 and #3). For the two filter trains fed iron (Filters #4 and #5), flow was controlled initially at 0.5 gpm but it then declined with time in as a result of filter clogging.

Four of the filter trains (Filters #1, #3, #4, and #5) were pre-conditioned in-place by assembling the filters in the test rig and running tap water through the system for several hours while laboratory personnel checked for leaks in the test rig. Immediately before initiating chemical feeding, a fresh pre-filter and a fresh filter were installed in one filter train (Filter #2) to simulate the effects of an "immediate-use" filter installation. A lead nitrate solution was fed to the inlet water line using a peristaltic pump at varying rates yielding varying inlet concentrations to each filter train ranging from an average of 1-8 µg/L Pb up to approximately 72-136 µg/L Pb. A second peristaltic pump was used to feed a ferric chloride solution to two of the filter systems providing concentrations of up to approximately 2.5 mg/L Fe to simulate iron corrosion associated with stagnant water in galvanized steel piping in older schools. Two of the filter systems were operated intermittently (one fed Pb only, Filter #3, and one fed both Pb and Fe solutions, Filter #4) to simulate hydraulic effects of ON/OFF flow through the filter system. Intermittent flow was performed by bypassing the filter during most of the time, switching valves to allow flow through Filters #3 and #4 for approximately 30-45 minutes prior to sampling, and then switching the valves to bypass the filters after collecting samples. This procedure was followed for each sampling event during the 5-day experiment. A process flow diagram of the test rig apparatus is shown in Figure 3.

Samples were collected at the inlet to the pre-filter, between the pre-filter and filter, and downstream of the filter along each filter train. Background samples also were collected at the tap water source. All samples were collected in 250-ml polypropylene bottles, stored on ice, transported with chain-of-custody forms to Laucks Testing Laboratories, Inc. in Seattle, Washington, and analyzed for metals (total Pb and Fe) within 7-14 days.

Preliminary Findings and Discussion

Preliminary findings from the field study provided insight regarding installation and operation of filters in the schools and results were used to design laboratory bench-scale testing. Preliminary findings of both the field study and laboratory testing are discussed below.

Field Study

Preliminary findings of the field study demonstrated that the filters were effective for removing Pb, Cu, Cd, Fe, and turbidity, after a brief break-in period. Measured Pb concentrations entering the filters during testing ranged from 1 to as high as 93 µg/L, but levels typically were not more than approximately 10 µg/L. Pb concentrations in filtered water were all less than 1 µg/L (the detection limit) with the exception of two readings in water from the initial flush of the filter that were 2 µg/L. When copper, cadmium, and/or iron were present in the incoming water, the metals were consistently removed to very low levels, usually to detection limits.

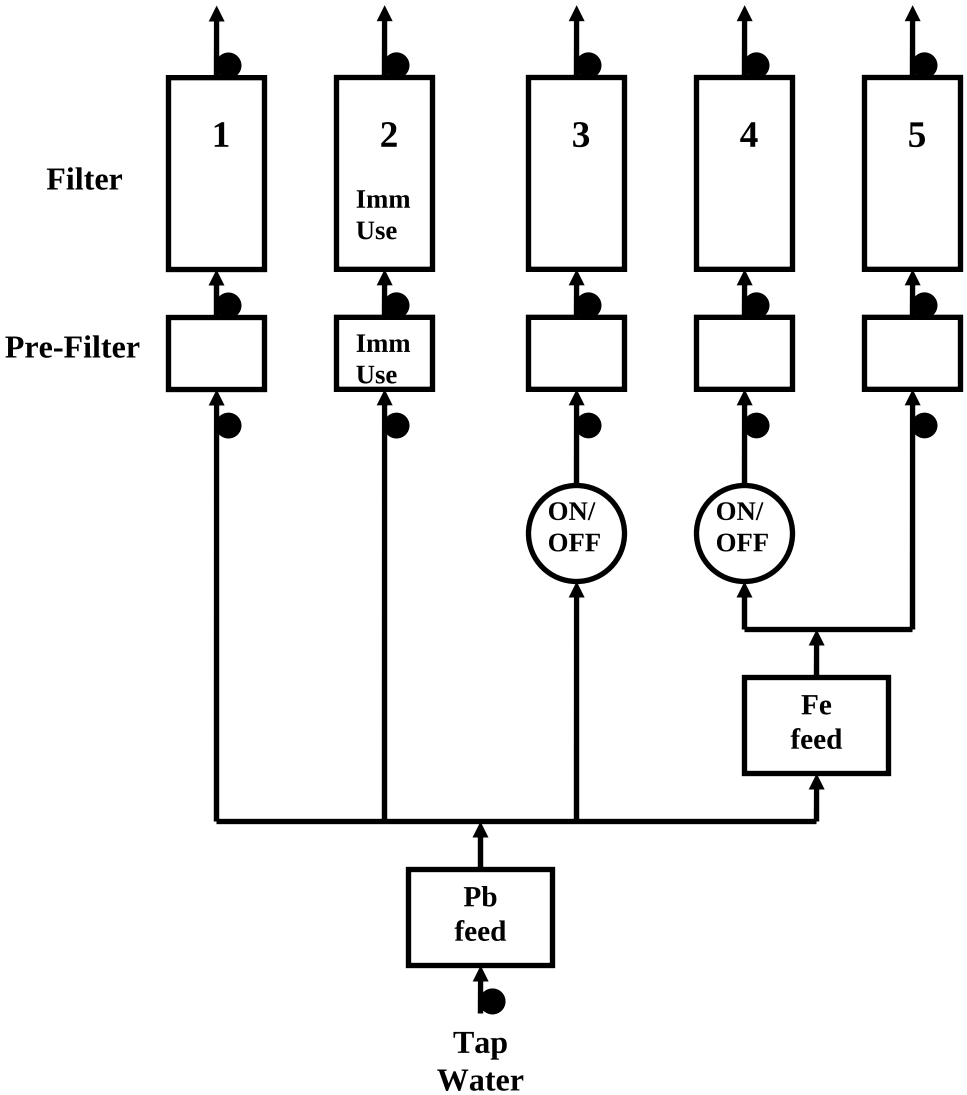


Figure 3. Process flow diagram of laboratory test rig apparatus for filter testing (● represents sampling locations).

The main operating issue was that the filters would plug prematurely with iron particulates in buildings with older galvanized steel piping, resulting in reduced flow rates and reduced filter capacity. For example, the measured incoming iron levels were as high as 28 mg/L Fe for three filters installed at one school with known iron problems, resulting in a significant load of iron on the filters. These three filters were NSF certified for Pb and particulates removal to 1000 gallons capacity, but stopped flow after only 300 – 400 gallons. However, Pb removal performance at terminal flow conditions was still good, i.e., to below detection limits, so Pb was not breaking through even when iron particulates prematurely reduced the filter's flow capacity. The implication of this premature plugging was that the cartridges in the filters would need to be changed two or maybe three times per year under typical operating conditions, which becomes a maintenance issue.

Laboratory Testing

The laboratory testing program was developed based on the findings of the field study to test the efficiency of the filter system for removing Pb. The following conditions were studied (Table I):

- A filter system was placed in service immediately (immediate-use filter) for comparison to a pre-conditioned (soaked) filter system,
- Elevated Fe levels were added to the influent water stream for comparison to a filter system receiving only Pb in the influent, and
- Two filter systems were operated with intermittent (ON/OFF) flow for comparison to continuous flow operation.

Table I – Experimental Test Scenarios

Test Scenario	Filters
Compare effects of pre-conditioning	Filters #1 and #2
Compare effects of continuous use to intermittent (ON/OFF) use	Filters #1 and #3
Compare effects of elevated iron (Fe) during continuous use	Filters #1 and #5
Compare effects of iron (Fe) during with intermittent (ON/OFF) cycles	Filters # 3 and #4

Influent Pb levels used in this study can be categorized into three phases based on inlet feed concentrations for Filters #1, #2, #3 and #5 - moderate levels at an average feed of approximately 23-34 μg/L Pb during the first phase of flow (0-12 h), low levels at an average feed of approximately 1-8 μg/L Pb during the second phase of flow (24-72 h), and high levels at an average feed of approximately 72-136 μg/L Pb during the third phase of flow (84-120 h). These three phases of influent Pb levels are highlighted in Figure 4 as illustrated for Filter #1. Note that Filter #4 exhibited greater variability in inlet lead concentrations compared to the other four filter trains.

Pre-Conditioned vs. Immediate-Use Filters

Testing results for Filter #1 (pre-conditioned filter system, continuous feed, Pb only) and Filter #2 (immediate-use filter system, continuous feed, Pb only) are shown in Figures 4 and 5, respectively. Both of these filter systems were fed only Pb solutions. Results indicate that the pre-filter and the filter both removed Pb from the inlet water stream. During initial operation of Filter #1 up to approximately 12 h of cumulative flow, experimental data showed that most of the Pb was removed by the carbon filter (52-68% of total Pb was removed from the inlet stream by the carbon filter). Thereafter, experimental data showed that Pb was removed primarily by the pre-filter (50-75% of total Pb was removed from the inlet stream by the carbon filter). Similar Pb-removal behavior was observed in data collected for Filter #2. These data therefore suggest that the pre-filter can play an important role in removing Pb from tap water for a point-of-use filter system.

Experimental results also indicate that filter breakthrough (Pb > 10 µg/L) was observed after 84 h of cumulative flow. At a constant influent flow rate of 0.5 gpm, the total volume of throughput after 84 h of continuous flow was 2,520 gal. The mass of Pb removed from the influent by the pre-filter and by the filter were calculated based on the concentration of Pb measured in samples collected at the three sampling points for each filter train (Figure 3) during each sampling event. After 84 h of flow through Filter #1, the cumulative mass of Pb removed by both the pre-filter and the filter was determined to be 130,500 µg Pb (Figure 6). Assuming a daily fountain usage of 100 drinks per day, each drink lasting 3 sec and water flowing from the fountain at 0.5 gpm, it was estimated that the daily usage of each fountain is approximately 2.5 gal per day.

Daily fountain usage $$\frac{100 \cdot drinks}{day}\left(\frac{3\sec}{drink}\right)\left(\frac{0.5gal}{\min}\right)\left(\frac{\min}{60\sec}\right)=\frac{2.5gal}{day}$$

Further assuming that the influent water contains 50 µg/L Pb and that the filter has a capacity to remove 130,500 µg of Pb, then the service life of the filter system can be estimated to be 275 days, which is equivalent to approximately 1.5 school years.

Daily mass of Pb removed by filter $$\frac{2.5gal}{day}\left(\frac{50\mu g \cdot Pb}{L}\right)\left(\frac{3.785L}{gal}\right)=\frac{473\mu g \cdot Pb}{day}$$

Service life $$130500\mu g \cdot Pb\left(\frac{day}{473\mu g \cdot Pb}\right)=$$ 275 school days ≈ 1.5 school years.

For Filter #2, the cumulative mass of Pb removed from the influent water stream was 166,350 µg Pb after 84 h of cumulative flow, which equates to a filter service life of approximately 1.9 school years.

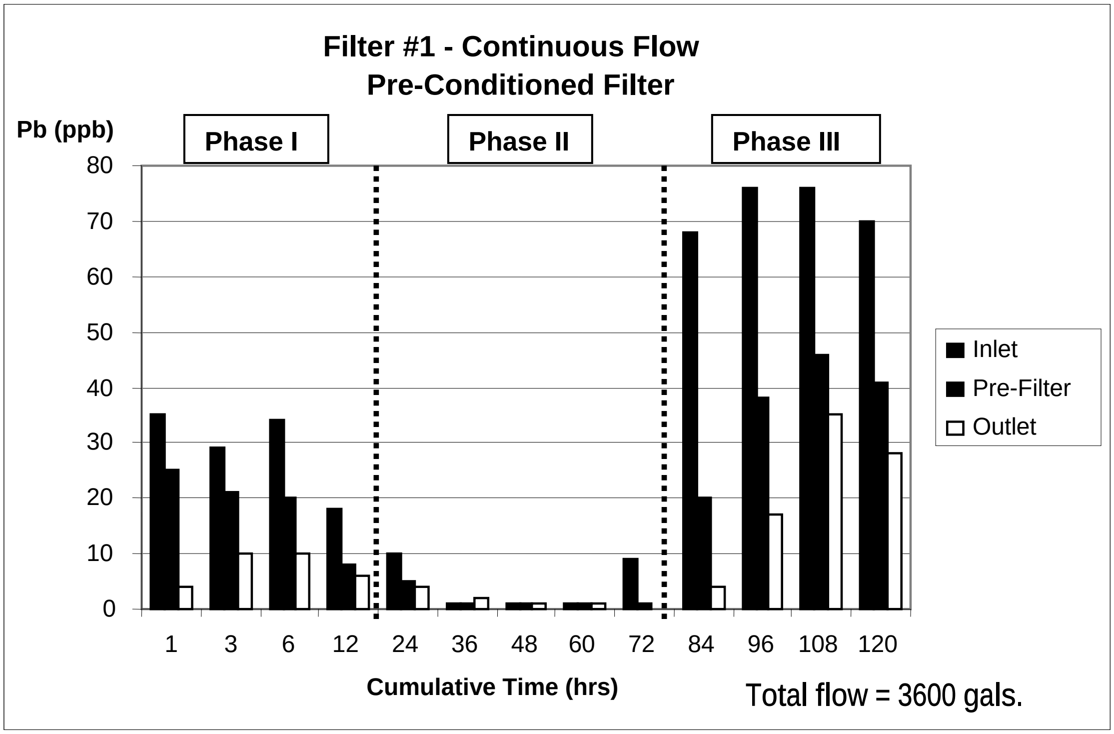


Figure 4. Pb concentration in Filter #1 as a function of cumulative time of flow.

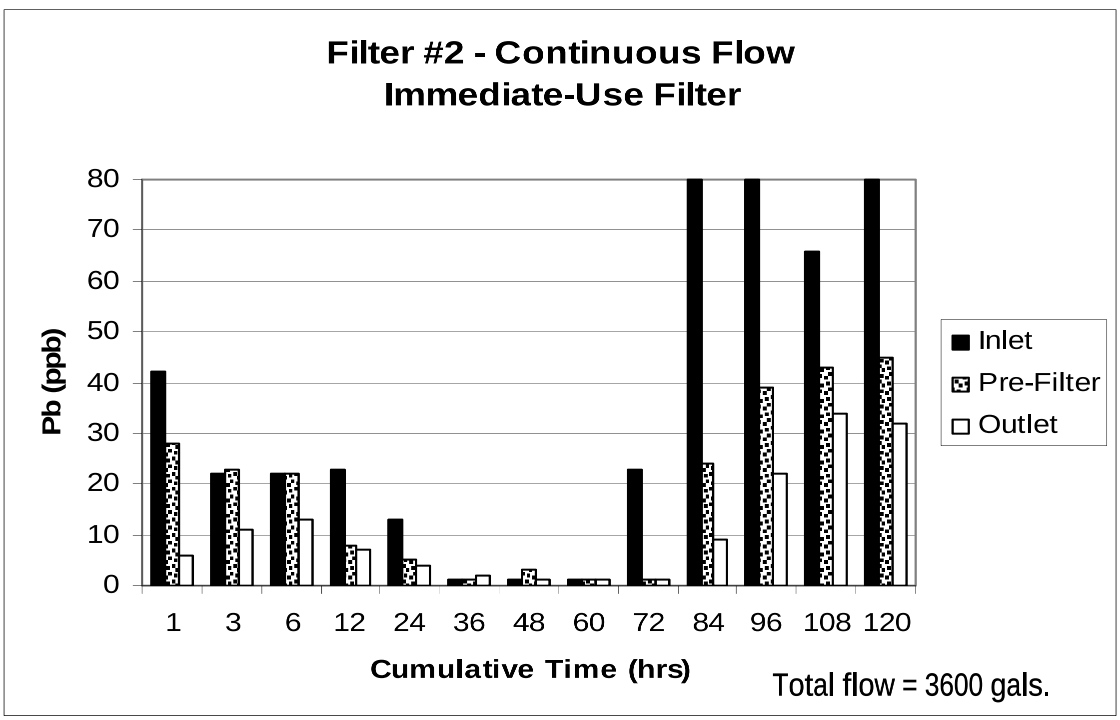


Figure 5. Pb concentration in Filter #2 as a function of cumulative time of flow.

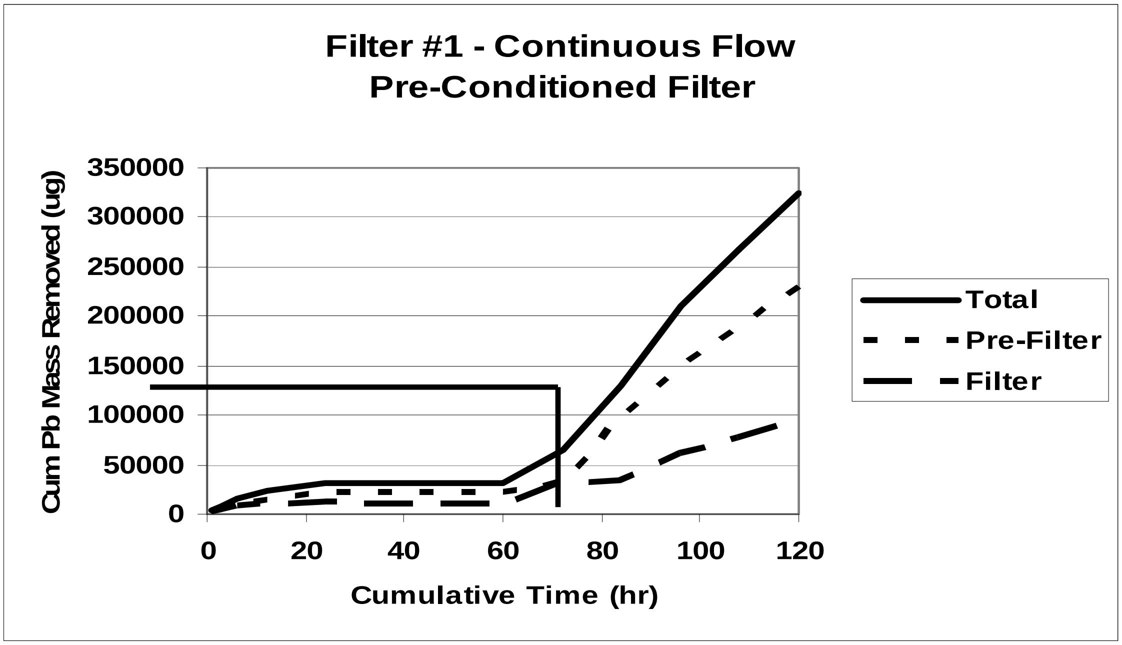


Figure 6. Cumulative mass of Pb removed by Filter #1 (pre-filter, filter and total) as a function of cumulative time of flow.

Elevated Iron (Fe) in Water

Testing results for Filter #1 (pre-conditioned filter system, continuous flow, and only fed Pb) and Filter #5 (pre-conditioned filter system, continuous flow, and fed both Pb and Fe) were compared to determine the effect of elevated Fe on the performance of Pb removal by the filter system. In addition to Pb, Filter #5 was fed varying levels of iron ranging from 0.8 to 2.4 mg/L Fe. Experimental data for Pb in Filter #5 is shown in Figure 7. Experimental data for Fe in Filter #5 are shown in Figure 8.

Results indicate that the filter system removed both Pb and Fe from the influent water stream. Similar to Filter #1 and Filter #2, results indicate that the pre-filter contributed to the removal of Pb, and in this case, also contributed to the removal of Fe from the influent stream. However, results also indicate that the presence of Fe adversely affected the flow rate and throughput capacity of the filter system. During the 120-h test period, the flow declined from an initial rate of 0.5 gpm to 0.25 gpm after 12 h, and then declined further to a rate of 0.05 gpm and lower after a cumulative flow of 72 h until no more flow was possible near the end of the experiment. As a consequence, the total throughput capacity of the filter system was reduced to 20% of original capacity based on a total flow of 690 gal. for Filter #5 compared to 3,600 gal. for Filters #1 and #2. It should be noted that there was no Pb breakthrough from Filter #5 during this test period. Thus, although the presence of Fe has the effect of reducing flow capacity, the filter system successfully removed Pb from the influent water stream during early flow testing. More study is needed to determine if accumulated Pb potentially can be released from the filter system during later flow for elevated levels of Fe in the influent water stream.

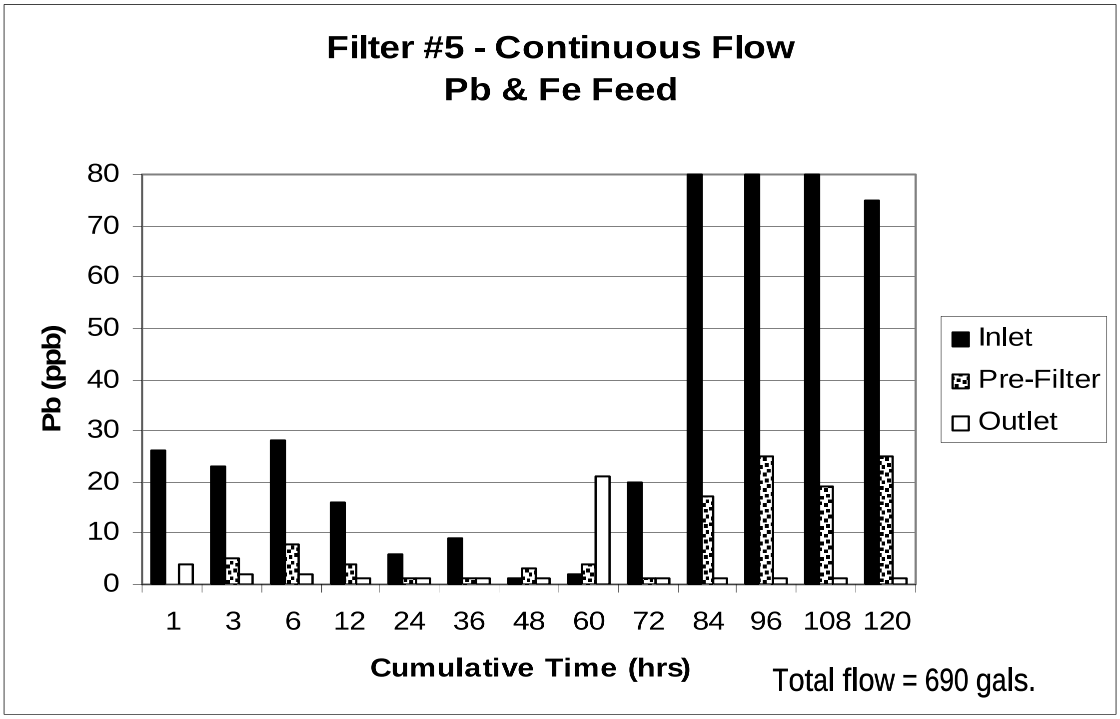
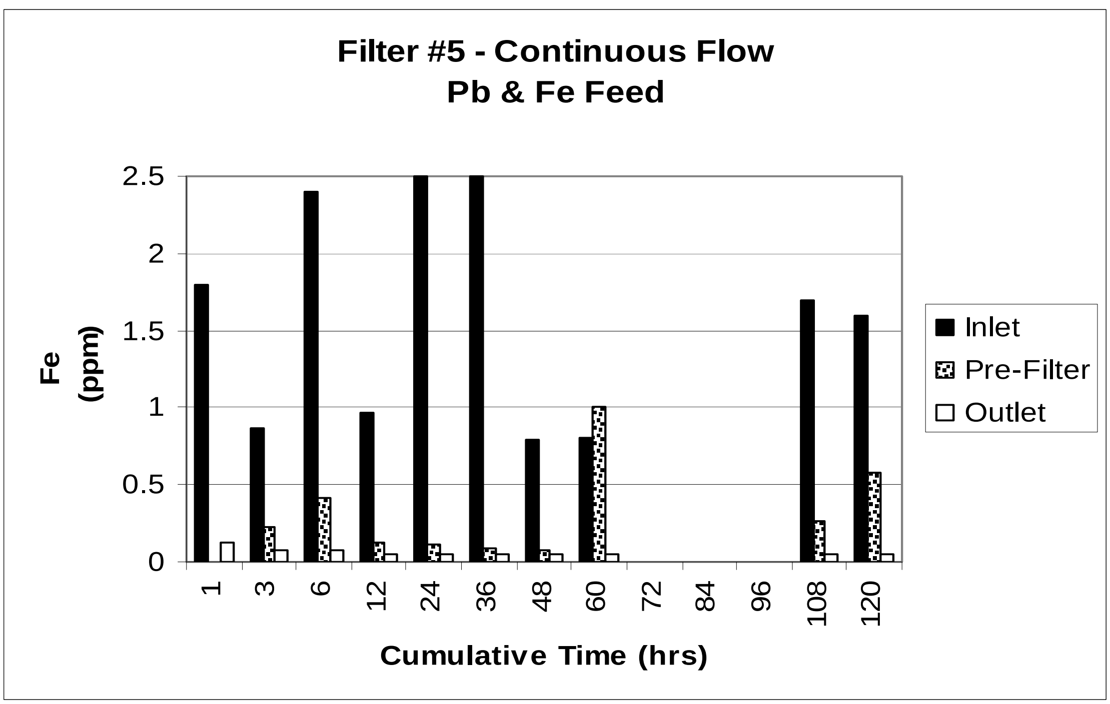


Figure 7. Pb concentration in Filter #5 as a function of cumulative time of flow.



Ir

Figure 8. Fe concentration in Filter #1 as a function of cumulative time of flow.

Experimental results for Filter #3 (pre-conditioned filter system, intermittent flow, and fed Pb only) and Filter #4 (pre-conditioned filter system, intermittent flow, and fed both Pb and Fe) were compared to determine the effect of intermittent (ON/OFF) flow on the performance of the filter system for removal of Pb. Intermittent flow was used in this study to mimic daily fountain usage in the schools. Both Filters #3 and #4 were operated intermittently - one filter train was fed only Pb (Filter #3) while the other filter train was fed both Pb and Fe solutions (Filter #4). Experimental data for Pb levels in Filters #3 and #4 are shown in Figures 9 and 10, respectively. Experimental data for Fe levels in Filter #4 are shown in Figure 11.

Results indicate that intermittent flow did not adversely affect filter performance during early flow of the test period. As a consequence of ON/OFF filter operations used for this study, a total of 390 gals. flowed through Filter #3. Less total flow passed through Filter #4 (250 gals.), which was attributed to filter clogging associated with the presence of Fe in the influent water stream. For both Filters #3 and #4, the filter system removed Pb with intermittent flow operation. For Filter #4, the filter system also removed Fe with these operating conditions. More study should be conducted by operating the test rig for a longer cumulative time period to determine the capacity (both flow rate and total throughput capacity) of these filter systems when operated intermittently.

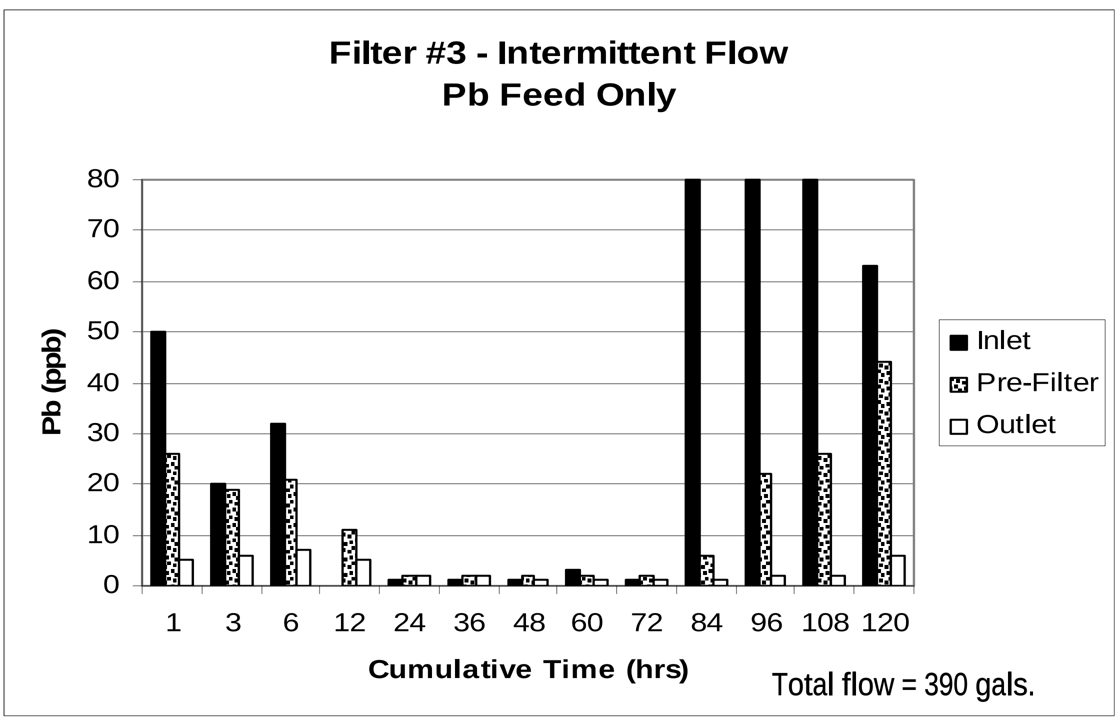


Figure 9. Pb concentration in Filter #3 as a function of cumulative time of flow.

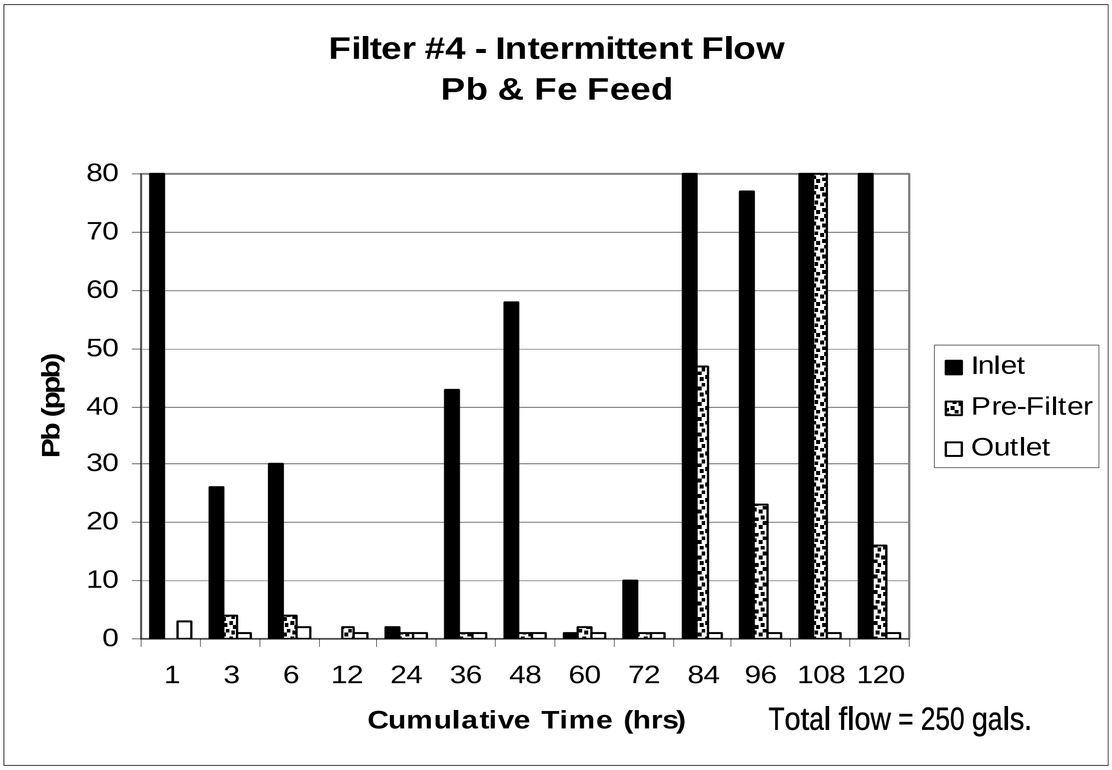


Figure 10. Pb concentration in Filter #4 as a function of cumulative time of flow.

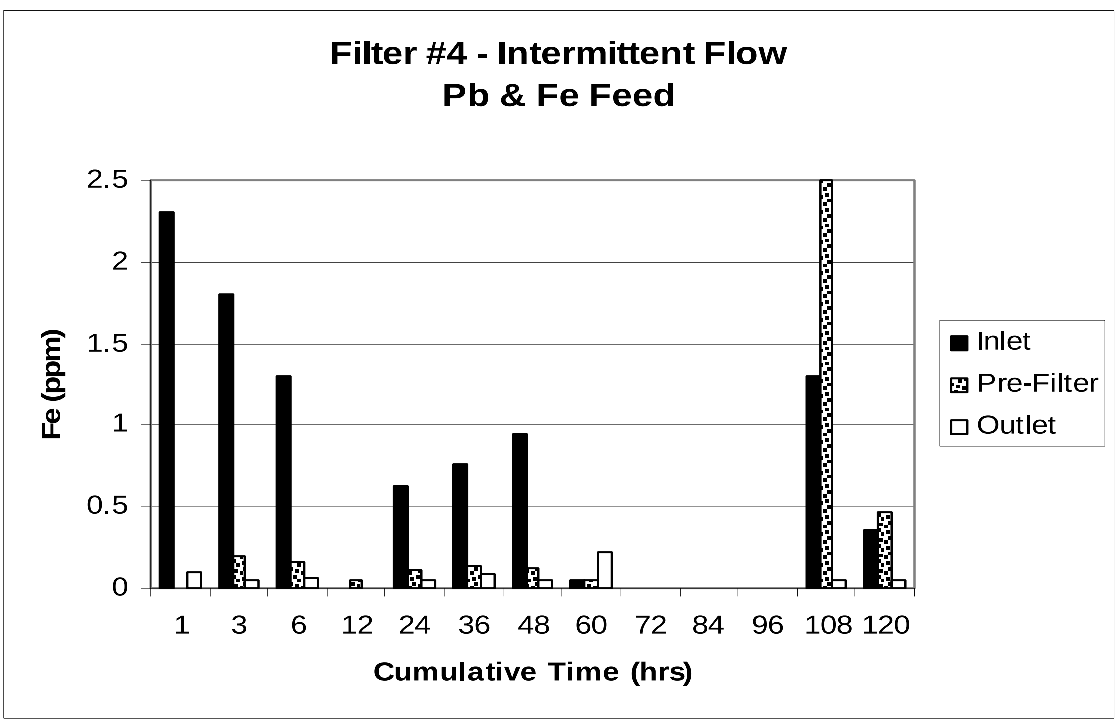


Figure 11. Fe concentration in Filter #4 as a function of cumulative time of flow.

Preliminary Conclusions

Preliminary sampling in Seattle schools indicated the following:

- POU filter systems were effective in removing Pb, Cd, Fe, and turbidity from influent water streams.
- The principal concern was that filters could plug prematurely with elevated iron levels in the influent stream associated with corrosion of galvanized steel piping in the schools.

Preliminary results of laboratory bench-top testing indicate the following:

- The filter system typically removed Pb to levels less than 10 ppb before reaching its Pb-removal capacity.
- The pre-filter contributed significantly to both Pb and Fe removal from the inlet water stream.
- Pb removal appeared to be unaffected by simulated scenarios of immediate-use of the filter system and intermittent (ON/OFF) flow through the filter system.
- Elevated iron levels caused reduced flow rates and reduced total throughput capacity of the filter system.

More study should be conducted to determine the capacity of filters for greater cumulative intermittent flows and lower iron levels in the influent stream. More study also should be conducted to determine if accumulated Pb potentially can be released from the filter system during later flow periods.

Acknowledgement

The authors wish to acknowledge technical laboratory assistance provided by Michael Britton of HDR/EES, Inc.