PRE-TREATMENT ENHANCEMENTS TO IMPROVE SLOW SAND FILTRATION

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1.0 INTRODUCTION

While most of the larger urban centres in the Caribbean Region have upgraded their water treatment facilities over the last 25 years, many small communities (< 3,300 people) have inadequate water treatment facilities that jeopardize the health of their citizens. The next 25 years will see the continued development of water treatment infrastructure to smaller and smaller communities. The lessons learned in the development of small water systems in North America and elsewhere are well documented and are listed below:

- Source water protection programs are less likely to exist for small systems so that source water quality may be poor or highly variable,
- Small water system operators are poorly trained and often have many other municipal responsibilities,
- Local "in-house" or "staff" engineering expertise does not exist, and
- Per capita water costs are high.

Obviously, the criteria for selecting water treatment technologies for small systems are somewhat different than the criteria used for large systems. Some of the most significant criteria include:

- The system must be capable of treating a source water of varying quality without operator or engineering reaction to the changing source water quality,
- The water system must be very simple to operate, not involve complicated chemistry, hydraulics or controls, and require minimal operator attention so that operators can complete their other municipal tasks, and
- The life cycle costs of the system should be low. In particular, operating costs should be low and predictable and not involve any major ongoing capital costs for consumable and proprietary parts.

In many cases, these lessons have been learned the hard way where complicated mechanical and chemical systems were purchased and no local staff could maintain and operate efficiently. Unfortunately, today it appears that the principle of 'appropriate technology' has become a casualty of the headlong rush to 'high technology'.
Slow sand filtration offers significant benefits for small systems, and has long been recognized by organizations such as the World Health Organization (WHO) and the United States Environmental Protection Agency (USEPA) as an appropriate technology for small systems. Slow sand filtration is a passive filter that is simple to design and operate, uses no chemical pre-treatment, has low life-cycle costs and is very effective at removing microbial pathogens. The disadvantages of conventional slow sand filters are:

- Filter cleaning involved a manual scraping of the sand surface which was both labour intensive and costly (sand replacement costs),
- Since cleaning was labour intensive, low filtration rates were used in order to decrease the cleaning frequency, which resulted in filters with large area requirements, and
- While slow sand filtration was efficient at removing turbidity and microbial pathogens, it had low removal efficiencies for dissolved organics, metals, taste and odour and colour.

In recent years, much work has been devoted to improving slow sand filtration in order to eliminate these deficiencies. This paper will review recent enhancements to the basic slow sand filtration process including pre-treatment by ozonation and roughing filtration, and the development of a package treatment plant with the necessary hydraulic appurtenances to eliminate the need for surface scraping.

2.0 ‘CONVENTIONAL’ SLOW SAND FILTRATION

The traditional slow sand filter is basically a box full of sand. Figure 1 shows a cross section of a ‘conventional’ slow sand filter. Water enters the filter compartment above the media and flows down through the sand and in time will form a thin biological layer called a schmutzdecke.
The combination of physical straining and biological treatment will effectively remove turbidity, bacteria, viruses and will remove in excess of 99.99% of Giardia cysts (Bellamy et al. 1985) and Cryptosporidium oocysts (Ghosh et al. 1989). As the bed plugs up, the water level will rise over the sand. As it approaches an established upper level, usually the overflow, it must then be partially drained and the schmutzdecke scrapped off and discarded or stored for cleaning and recycling. Filter ‘runs’ of one to several months are typical. Over time the sand bed depth is reduced from the scrapings and new or re-cycled sand must be refilled into the box. Despite the limitations of conventional slow sand filters, the technology is widely used including major cities such as London, Zurich and Amsterdam as well as hundreds of small to mid-sized plants in North and South America. More importantly, slow sand filtration has been recognized by the USEPA as an appropriate technology for small systems (USEPA 1997), by the World Health Organization as an appropriate technology for developing countries (Pescod et al. 1986) and by the United Nations Environmental Program as technology applicable to Island States (UNEP 2002).

3.0 IMPROVING THE SLOW SAND PROCESS

A number of enhancements have been studied to improve the performance of slow sand filters both in their ability to remove naturally occurring organics and in extending their filter run times and/or simplifying the cleaning process. Two in particular have been investigated by the author and incorporated into a package Multi-Stage filter. These include pre-ozonation and roughing filtration ahead of the slow sand units. A sketch of the process is shown in Figure 2.
Pre-ozonation offers treatment for a number of common raw water issues such as, colour, disinfection byproduct pre-cursors, taste and odour, iron and manganese and last, but not least, microbial pathogens. Roughing filtration will remove a significant percentage of suspended material and protect the slow sand filter from premature clogging. In the Multi-Stage Filter process, the top layer of the roughing filter is activated carbon that protects the slow sand from pre-disinfectants such as ozone or chlorine. The hydraulic design of the Multi-Stage Filter package plant allows for the roughing filter to be cleaned by backwashing, while the surface of the slow sand filter is cleaned by a wet harrow process that does not involve scraping or removing sand.

4.0 APPLICATIONS

4.1 Sturgeon Lake, Ontario

To test the proposed roughing filter enhancement, a pilot study was carried out in 1993 at Sturgeon Lake, Ontario, approximately 120 km northeast of Toronto.

The raw water source is not suitable for a ‘conventional’ slow sand process due to high algae, moderate colour and moderate turbidity. The results of the pilot study with respect to turbidity and colour are presented in Figures 3 and 4.

The significant outcome of this study is the performance of the roughing filter. Despite the fluctuations in the raw water turbidity from 1.5 to 10 NTU, the roughing filter effluent remained consistently below 0.8 NTU. Due to the low turbidities from the roughing filter, the slow sand filter was allowed to operate at a filtration rate of 0.3 m/hr for the 4 month period of the study without requiring a cleaning. Colour was removed to below 5 TCU over the four month period of the study through absorption in an activated carbon filter with an empty bed contact time of 15 minutes. Subsequent studies however have shown carbon life to be an issue.
4.2 North Haven, Maine

The Multi-Stage process pilot study was carried out in 2000/2001 at North Haven, Maine, an island community located approximately 20 km off-shore in the Atlantic Ocean. The North Haven raw water quality is generally good. Turbidity is typically less than 1 NTU, although spikes to approximately 5 NTU have occasionally been observed. Colour has been measured as high as 60 TCU, although typically does not exceed 40 TCU. Total organic carbon (TOC) has been measured as high as 8 mg/L. Alkalinity is relatively low, approximately 15 to 20 mg/L at CaCO₃.

The raw water source was proven to be unsuitable for a ‘conventional’ slow sand process during a long-term pilot test conducted in 1998. Although that previous pilot test demonstrated effective removal of turbidity and bacteria, it did not significantly remove colour and total organic carbon, even after the filter beds had been amended with activated carbon. The Multi-Stage Filter pilot plant included pre-ozonation in order to reduce TOC concentrations.

**Test Conditions**

- Applied Ozone Dosage: 3.0 mg/L
- Roughing Filter Filtration Rate: 1.8 m/hr
- Slow Sand Filtration Rate: 0.3 m/hr

**Results**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Raw Water</th>
<th>Treated Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbidity</td>
<td>1.0 NTU to 5 NTU</td>
<td>0.2 NTU to 0.4 NTU</td>
</tr>
<tr>
<td>Colour</td>
<td>20 TCU to 40 TCU</td>
<td>&lt; 5 TCU</td>
</tr>
<tr>
<td>TOC</td>
<td>7.0 mg/L to 10.0 mg/L</td>
<td>5.0 mg/L to 6.5 mg/L</td>
</tr>
</tbody>
</table>

![North Haven Colour](figure5.png)

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Pre-Treatment Enhancements To Improve Slow Sand Filtration
TOC was reduced on average by 25% during the pilot study. In addition to TOC sampling, ultraviolet absorption was also measured and SUVA (the ratio of ultraviolet absorption to TOC) calculated to evaluate the disinfection by-product potential. During the pilot study, SUVA for the raw water ranged from 2.91 to 2.53 L/mg-m, and SUVA for the treated water ranged from 1.59 to 1.14 L/mg-m. Pre-ozonation in combination with biological filtration has well documented efficiencies for removal of organics in water. The result of lowering TOC in the North Haven water was a reduction in the chlorine demand and a reduction of trihalomethane byproduct formation.

4.3 White River, Ontario.

White River is a small community in Northern Canada. The community presently has a well field which is clearly under the influence of surface water and limited in quantity. The decision was made to go to a nearby lake where quantity was assured and quality was relatively good, with typical colour measurements of 20 to 40 NTU, typical TOC of 5.0 to 7.0 mg/L, and typical turbidity of 0.5 to 2.0 NTU.
**Test Conditions**

Applied Ozone Dosage: 2 to 4 mg/L  
Roughing Filter Filtration Rate: 1.8 m/hr  
Slow Sand Filtration Rate: 0.3 m/hr, increased to 0.4 m/hr for last two weeks and 0.62 m/hr for last three days  
GAC Contactor EBCT: 20 minutes

**Results**

<table>
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<tr>
<th>Parameter</th>
<th>Raw Water</th>
<th>Treated Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbidity</td>
<td>0.3 NTU to 2.0 NTU</td>
<td>0.2 NTU</td>
</tr>
<tr>
<td>Colour</td>
<td>10 TCU to 20 TCU</td>
<td>&lt; 5 TCU</td>
</tr>
<tr>
<td>TOC</td>
<td>5.0 mg/L</td>
<td>3.5 mg/L to 3.7 mg/L</td>
</tr>
</tbody>
</table>

The disinfection byproduct formation potential dropped across all stages of the process as shown in Figure 6. No turbidity removal was seen in the first three weeks due to the lack of a *schmutzedecke*. The pre-ozone was operated during this period but was turned off for a period of 4 days to allow the biological process to get ‘seeded’. Results improved almost immediately as can be seen in Figure 7.

![Figure 6. Byproduct Formation Potential](image-url)
Pre-Treatment Enhancements To Improve Slow Sand Filtration

Figure 7: Raw and Effluent Turbidity (NTU)

- Ozone off
- Turbidity Meters installed
- First Clean
- Decommissioning

NTU

Date

31-Jul-02 11-Aug-02 22-Aug-02 2-Sep-02 13-Sep-02 24-Sep-02 5-Oct-02 16-Oct-02 27-Oct-02

Plant Effluent Raw
4.4 Wabauskang First Nation
5.0 SUMMARY

The pre-ozonation and roughing filter enhancements to the slow sand process have significantly extended the range of raw water quality that can be treated with this technology without sacrificing the simplicity of operation.

Pilot testing and full-scale applications of the Multi-Stage Filter have demonstrated that the process is very flexible and forgiving of raw water quality. It produces a consistent, high-quality effluent regardless of any fluctuations in raw water quality and independent of any operator attention. Pre-ozonation provides effective treatment for colour, taste and odour, pathogens and iron and manganese. Ozone breaks down long chain organic molecules to smaller more biodegradable forms which are subsequently removed in the slow sand biological filtration.

The roughing filter is capable of removing high levels of turbidity and extends the filter runs, or alternatively allows higher filtration rates through the slow sand filter with little risk of pre-mature clogging. The roughing filter is washed similar to a rapid sand filter and on the same approximate frequency as the slow sand filter, i.e. once every 2 - 6 months. The slow sand filter can be cleaned using a hydraulic ‘wet harrow’ method that is simple and requires little time. Annual wastewater and sludge volumes from filter cleaning are minimal. Due to the low cleaning frequency, lack of moving parts or consumables or high technology, operator requirements are minimal.

Virtually no sand is lost during cleaning therefore there are no ongoing sand replacement costs. Labour costs are extremely low. There are no chemical costs, and power costs are low since there are no blowers, extra pumps mixers etc. Of the major conventional water treatment plant options, slow sand filtration has the lowest operating costs, by far.

World-wide experience has shown slow sand filtration to be an effective treatment technology. Pilot-scale studies and full-scale applications of the Multi-Stage Filter shown in this paper demonstrate that new advances have overcome the traditional limitations of conventional slow sand filters and that the Multi-Stage Filter is a very effective process for small systems.