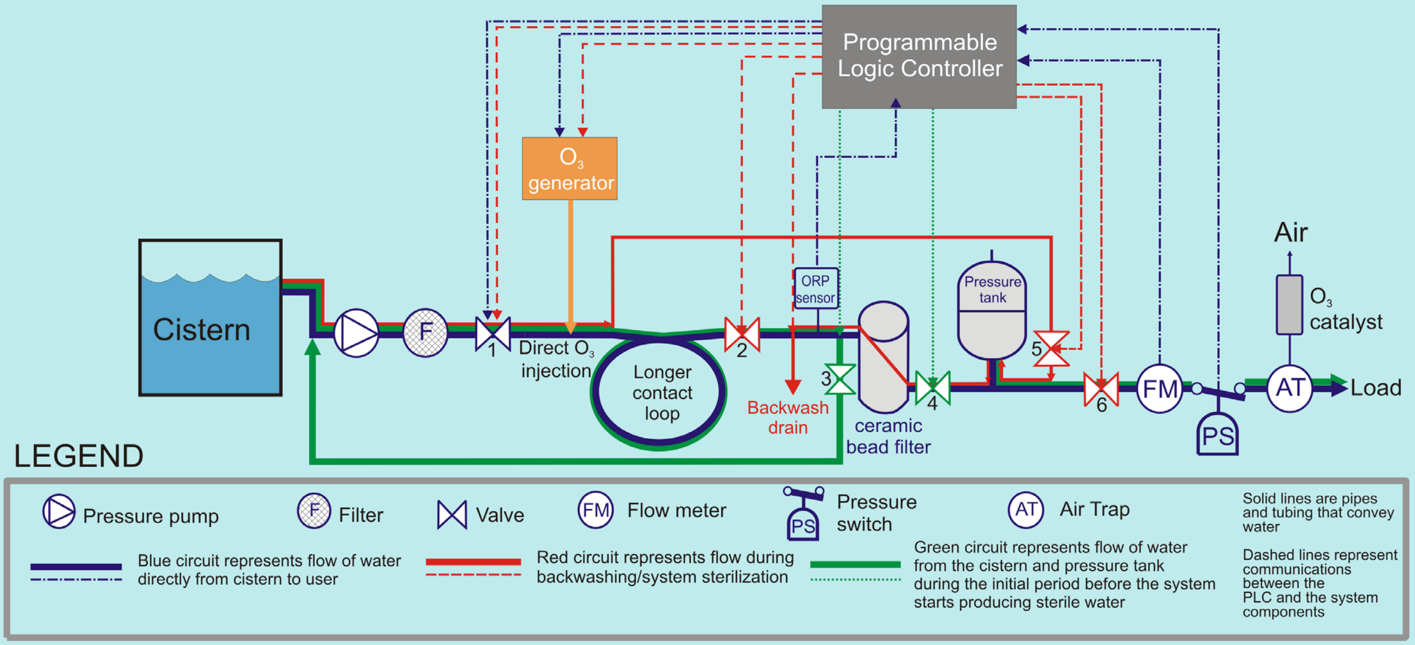
Assessment of the Use of Ozone for Rainwater Treatment

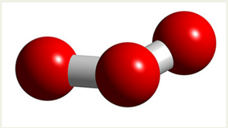
TECHNICAL BRIEF

Low Impact Development Series



Implementation of rainwater harvesting technologies has grown in recent years due to an increasing interest in Low Impact Development (LID) stormwater management technologies and a greater awareness of the importance of water conservation and reuse. . The practice addresses several elements of sustainable water management, including the conservation of municipal treated drinking water, reduction of stormwater runoff volumes, and reduction in costs, energy consumption and greenhouse gas emissions due to less demand for treated municipal water.

Residential rainwater harvesting systems are most often used to supply water for toilet flushing and outdoor uses such as irrigating landscaped areas or washing vehicles. If the collected water is treated to render it potable, it can be used to supply water for all other household uses, including laundry, showers, dishwashing and drinking water. An effective rainwater treatment system must be capable of (i) removing chemical and microbiological contaminants, (ii) providing safe, treated water at all points of use in the system, and (iii) providing enough water to meet household demands immediately when it is needed.



The first discovery of the presence of ozone was in 1839 by Christian Schonbein, who named it after the Greek word 'ozein,' meaning 'to smell.' The first full-scale industrial application of ozone for the disinfection of municipal drinking water took place at the village of Oudshoorn, Nethernalds in 1893 (AWWA, 1991).

This study was undertaken to better understand the suitability and feasibility of applying an ozone-based water treatment and disinfection system to render rainwater potable when collected through domestic rainwater harvesting systems. A prototype ozone treatment system was integrated into a pre-existing rainwater harvesting system located in House B of the Archetype Sustainable House at the Living City Campus in Vaughan, Ontario. Based on monitoring outcomes, system design modifications are proposed to improve its efficacy and functionality (Cover Photo). A review of alternative comparable disinfectants is also provided.

DISINFECTANT COMPARISON

There are several technologies on the market that are suitable for the treatment and disinfection of rainwater. The most common disinfection technologies suitable for treating rainwater from a domestic system - UV radiation, chlorination and ozonation - were compared based on effectiveness (Table 1), safety and operational considerations. Ozone demonstrates the highest efficacy across the different pathogen categories, while UV radiation is second, and chlorine is the least effective, since it cannot effectively inactivate Cryptosporidium and is only moderately effective against Giardia.

Ultimately, ozone was selected as the disinfectant for rainwater harvested at the Archetype House based on the following key factors:
• Disinfection capacity - Ozone is the most powerful of the disinfectants, and is highly effective against a range of pathogens.
• No need for a residual - It is unnecessary to maintain a disinfectant residual in a small domestic system like the one considered.
• Use of fewer consumables - Ozone based systems use less consumables than systems that apply UV radiation.
• Capacity to measure the disinfectant dose in the water - The dosing of ozone can be determined based on oxidation-reduction potential (ORP) levels in the water, which can provide certainty about the extent to which the water contains the disinfectant.

APPROACH

Description of Systems

Stormwater draining from the south side of the roof of Archetype House B and the roof of the in-law suite above the garage is conveyed to a 10,000 litre underground concrete cistern. The ozone generator that was integrated into the rainwater harvesting system

Table 1. Microorganism reduction ability for UV radiation, chlorine and ozone (adapted from: Earth Tech Canada, 2005).

Disinfectant	Microorganism Reduction Ability			
	E. Coli	Giardia	Cryptosporidium	Viruses
UV radiation	Very effective	Very effective	Very effective	Moderately effective
Chlorine	Very effective	Moderately effective	Not effective	Very effective
Ozone	Very effective	Very effective	Very effective	Very effective

was the DEL Ozone Eclipse™ -4 which produces ozone on demand. It is rated for delivery of 1 gram/hour, resulting in the generation of 1350 ppm of ozone gas. When there is a demand for water in the house, cistern water is pumped into the system, passes through a flow meter and then a JUDO PROFi mesh screen filter (Figure 1). Once filtered, it passes through another length of pipe and a venturi injector which sucks ozone into the water stream. The dosed water flows through a 76 ft long cross-linked polyethylene contact loop, after which it is filtered through an H2Flow Ceramic Bead filter, which uses Macrolite® engineered media to filter out suspended solids and other contaminants (e.g. iron, manganese). The treated water then flows past a pressure switch and out to meet the demand in the house.

Monitoring

The extent to which water was sterilized was measured by: (i) Measurement of oxidation-reduction potential (ORP) using an ORP sensor and (ii) Laboratory testing of water samples for microbiological and other contaminants for three scenarios. The measurement of ORP was used throughout the operation and monitoring of the system as an instantaneous gauge of the extent to which the ozone generator was delivering enough ozone to sterilize the water.

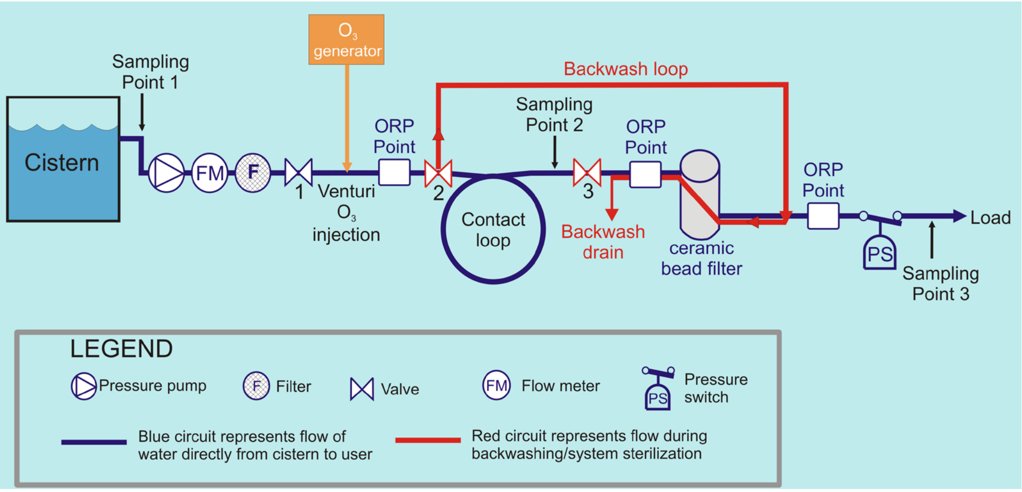


Figure 1. Schematic of the installed ozone treatment system.

Monitoring of the effectiveness of the system to provide adequate treatment of rainwater stored in the cistern was conducted for three scenarios: 1. normal operation; 2. after agitation to suspend accumulated sediments; and 3. after addition of wildlife (fox) feces.

FINDINGS

The prototype rainwater treatment system was not effective at inactivating all coliforms and E. coli, as is required for potable water as per the Canadian Guidelines for Drinking Water Quality. Coli-

Table 2. Microbiological contaminant levels in prototype rainwater treatment system. All values reported are in units of coliforms per 100 mL.

	CDWQG	Cistern water	Post contact loop	Treated water
Aug. 28, 2013		*Normal Operation*		
Total coliform	0	710	2300	**570**
Escherichia coli	0	20	12	**7**
Fecal streptococcus	n/a	680	430	**120**
Pseudomonas aeruginosa	n/a	150	110	**73**
Total suspended solids	500 mg/L	205	204	**205**
Tubidity	0.1 NTU	4.89	2.95	**1.42**
Sept. 11, 2013		*Normal Operation*		
Total coliform	0	1000	65	**69**
Escherichia coli	0	2	0	**0**
Fecal streptococcus	n/a	400	1	**28**
Pseudomonas aeruginosa	n/a	29	4	**6**
Total suspended solids	500 mg/L	140	137	**137**
Tubidity	0.1 NTU	3.28	0.73	**2.07**
Sept. 20, 2013		*Tank Agitation*		
Total coliform	0	1100	660	**290**
Escherichia coli	0	29	15	**2**
Fecal streptococcus	n/a	740	82	**55**
Pseudomonas aeruginosa	n/a	52	19	**5**
Total suspended solids	500 mg/L	131	133	**131**
Tubidity	0.1 NTU	16.40	8.27	**4.11**
Oct. 3, 2013		*Fox Fecal Matter Addition*		
Total coliform	0	2500	550	**300**
Escherichia coli	0	53	2	**2**
Fecal streptococcus	n/a	92	29	**28**
Pseudomonas aeruginosa	n/a	14	64	**48**
Total suspended solids	500 mg/L	90	91	**90**
Tubidity	0.1 NTU	25.20	4.64	**3.18**

Notes: Underlined values are in exceedance of Canadian Guidelines for Drinking Water Quality (CDWQG).

forms were detected in the treated water samples from all experiments, and E. coli was detected during all but one experiment (Table 2). If the system was performing effectively, a decrease in coliforms and E. coli would be expected between the cistern water sampling point and the post contact loop sampling point. This was observed during almost all experiments, with the exception of August 28, during which coliform levels increased – from 710 to 2300 c. This large increase was likely caused by contaminants being introduced within the system somewhere between the two sampling points, which would indicate that the process used to sterilize the system before the experiment was ineffective. Slight coliform levels also increased for samples collected on Sept. 11, which indicates that bacteria were introduced by the filter rather than removed.

Treated water met the general chemistry Guidelines for all parameters except for turbidity, which was elevated for all experiments. Although water was not sampled immediately after the initial filtration, the elevated turbidity of the water sampled after the contact loop suggests that the filter could not remove enough particulate matter to meet the thresholds in the Guideline and adequately prepare the water for ozonation. The insufficient filtration may be a result of a high proportion of fine particles in the cistern water which would be small enough to pass through the filter screen. While turbidity levels were elevated above the Guidelines, they generally followed the expected trend, decreasing as water traveled through the system, with the exception of the Sept. 11 experiment; this may provide further evidence that the backwashing and sterilization of the filter prior to the experiment did not adequately clean the filter.

Concentrations of metals were generally within guidelines for all samples, including treated and untreated water. Exceedances occurred only for metals that do not have a maximum acceptable concentration under the Guidelines. For aluminum (operating guideline) and iron (aesthetic objective), only raw cistern water samples exceeded the Guidelines. The only exceedance in a treated water sample was for manganese during the Aug. 28 experiment or 50.6 ug/L – slightly exceeded the aesthetic objective of 50 ug/L, which is based on the potential for manganese to affect the taste of the water.

The prototype rainwater treatment system could not provide safe and disinfected potable water. Although a process was in place to run highly ozonated water through the treatment system components, including the ceramic filter, the results suggested that this sterilization/backwashing process was inadequate during some of the experiments and that bacteria was introduced into the water by the system. Also, disinfection could have been enhanced if the contact time (35 seconds in the current system) was longer. The primary filtration was found to be inadequate, as turbidity levels were in exceedance of water quality guidelines and some of the ozone injected into the system would have reacted with these solids, leaving less ozone available to inactivate microorganisms.

The process of disinfecting the water could only be initiated once the demand occurred, resulting in a delay of more than 10 minutes before the system could deliver. ORP measurements taken at the point immediately after the injection of ozone by the venturi did not reach 800 mV (the level necessary for sterilization) until the system was running for at least 6 minutes. It is possible that a different venturi would need to be used in the existing system to create a lower pressure that would deliver ozone at a faster rate, that the flow rate would need to be adjusted, or that an active rather than passive injection system – like an ozone pump – should be used instead.

An alternative design for a domestic rainwater system capable of generating potable water would include: i) Improved filtration and disinfection; ii) A demand tank; iii) Safeguards to ensure that contaminated water never reaches the taps; and a means of keeping water disinfected until it reaches the end user (See Cover Photo). Other added features include: i) Addition of a programmable logic controller to automate system processes and improve ease of use; ii) Addition of a pressure tank used to store sterilized water so that any demand in the house can be met without delay; iii) Modification of ozone injection mechanism; iv) Longer contact loop; and v) Addition of an air trap to release gas from the pipe and an ozone catalyst to convert any gaseous ozone present to oxygen, which can then be safely vented from the system.

CONCLUSIONS AND RECOMMENDATIONS

Characteristics of a viable of ozone-based rainwater treatment

- A powerful disinfectant is required to ensure that bacteria, viruses or protozoa will not survive the disinfection process.
- Bromide levels in the source water should be low (< 0.10 mg/L) so that the by-product, bromate, will not exceed 0.01 mg/L (the maximum acceptable concentration in the Guidelines) in treated water from the rainwater harvesting system.
- Organic matter in the source water should be low or it should be easy and cost-effective to remove so that the potential for by-product formation is minimal.
- The system should be small and feature a distribution system with little potential for regrowth of microbiological contaminants, including a treatment option to improve the taste, odour and colour of the water is desirable.
- There should be other contaminants of concern in the source water that ozone can help remove (e.g iron, manganese, sulfides).
- The system must allow for real-time measurement of its disinfection capacity as water passes through (determined by ORP for ozone).

Considerations during system selection

- Particular attention should be paid to determining the concentrations of contaminants that will affect the success of disinfection, such as resilient pathogens, suspended solids and precursors to disinfection by-product formation, like bromide and organic matter.
- It is essential to be familiar with the applicable federal and/or provincial water quality standards for the intended use.
- It is important to consider potential environmental sources (e.g. overhanging trees, windblown dust, nearby sources of air pollution) as well as contamination that may come from the collection and storage system itself (e.g. rooftop, cistern, pipes).
- The system must be designed based on knowledge of household water use rates and the maximum capacity at which the system will be expected to deliver treated water.
- Regulations only apply to a system larger than those for individual private residence. Systems classified as 'small drinking water systems' are regulated by the Ministry of Health and Long Term Care under Ontario Regulations 318/08 (Transitional - Small Drinking Water Systems) and 319/08 (Small Drinking Water Systems).
- When considering whether the cost of the system can be accommodated within a given budget, it is important to consider all capital costs for purchase and installation, parts and labour associated with regular maintenance, and electricity requirement.

REFERENCES

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For more information on STEP's other Low Impact Development initiatives, or to access the full report for this study, entitled Evaluation of the Suitability of Ozone for the Treatment and Disinfection of Rainwater, visit us online at www.sustainabletechnologies.ca

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