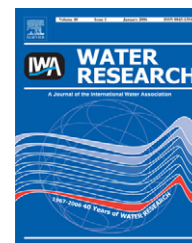


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Sensory aspects and water quality impacts of chlorinated and chloraminated drinking water in contact with HDPE and cPVC pipe

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ABSTRACT

Pipes constructed with high-density polyethylene (HDPE) or chlorinated polyvinyl chloride (cPVC) are commonly used in drinking water distribution systems and premise plumbing. In this comprehensive investigation, the effects on odor, organic chemical release, trihalomethane (THM) formation, free chlorine demand and monochloramine demand were determined for water exposed to HDPE and cPVC pipes. The study was conducted in accordance with the Utility Quick Test (UQT), a migration/leaching protocol for analysis of materials in contact with drinking water. The sensory panel consistently attributed a weak to moderate intensity of a “waxy/plastic/citrus” odor to the water from the HDPE pipes but not the cPVC-contacted water samples. The odor intensity generated by the HDPE pipe remained relatively constant for multiple water flushes, and the odor descriptors were affected by disinfectant type. Water samples stored in both types of pipe showed a significant increase in the leaching of organic compounds when compared to glass controls, with HDPE producing $0.14 \mu\text{g TOC}/\text{cm}^2$ pipe surface, which was significantly greater than the TOC release from cPVC. Water stored in both types of pipe showed disinfectant demands of $0.1\text{--}0.9 \mu\text{g disinfectant}/\text{cm}^2$ pipe surface, with HDPE exerting more demand than cPVC. No THMs were detected in chlorinated water exposed to the pipes. The results demonstrate the impact that synthetic plumbing materials can have on sensory and chemical water quality, as well as the significant variations in drinking water quality generated from different materials.

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1. Introduction

Recent decades have seen the advent of synthetic premise plumbing materials and a continuing trend of increased use in homes and distribution systems. Plastic pipes currently make up about 54% of the all pipes installed worldwide. Polyvinyl chloride (PVC) makes up 62% of this demand, and polyethylene (PE) in its various forms about 33.5% (Raynaud, 2004). Selected polymer pipes such as high-density polyethy-

lene (HDPE) and chlorinated polyvinyl chloride (cPVC) make durable, cost-effective replacements to traditional materials such as copper. Research has shown considerable impacts to taste and odor via the leaching of odorous organic compounds into water from distribution system materials such as pipes, liners, and storage tanks (Rigal and Danjou, 1999; Anselme et al., 1985; Khiari et al., 2002; USEPA, 2002; Skjevrak et al., 2003; Tombouljian et al., 2004; Marchesan and Morran, 2004). As distribution systems are continuously expanded and

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older metal pipes are replaced with synthetic materials, it is critical to consider the effects on taste, odor, and consumer perception that these changes will have (Dietrich, 2006).

Understanding the interaction and effect of distribution system materials is inherently important to maintaining a high-quality product at the tap and high consumer confidence. A 1989 AWWA USA study reported 65% of water utilities considered the distribution system responsible for their taste and odor problems; a recent report summarized odor problems associated with chemical leaching, chemical reactions and biological-mediated reactions in distribution systems and their materials (Khiari et al., 2002). These aesthetic issues have great significance to both utilities and the public, as consumer awareness of water quality is heavily influenced by taste and odor perception at the tap (McGuire, 1995; Whelton, 2003; Dietrich, 2006).

While the impact on drinking water aesthetics resulting from exposure to cPVC and HDPE has been investigated, little work has been done to simultaneously determine sensory and water quality effects of water with disinfectant species and concentrations comparable to those found in the actual distribution system. This knowledge is especially important in light of the widespread effects caused by the switch from chlorine to chloramine in North America and elsewhere that has exacerbated lead release (Edwards and Dudi, 2004).

The United States currently has no standard method to provide an evaluation of aesthetic effects from synthetic plumbing materials, such as those standards that exist in Europe and Australia. The NSF 61 Drinking Water System Components—Health Effects standard, from the US National Sanitation Foundation, is used only to evaluate for compliance with health requirements. The standard establishes the minimum health effects requirements for chemical contaminants and impurities that may be leached into drinking water (ANSI/NSFIS, 2000). HDPE is tested for volatile organic compounds (VOCs), metals and phenolics. cPVC is analyzed for VOCs, metals, phenolics, tin, antimony, and residual vinyl chloride monomer. Based on the findings of an international workshop of drinking water experts, the Utility Quick Test (UQT) was developed in 2001 to constitute the US equivalent of an organoleptic assessment tool for materials in contact with drinking water (Schweitzer et al., 2004). This protocol seeks to generate sensory data resulting from the leaching of volatile organics from the plumbing materials and predict the effects such materials might have on the distributed drinking water. Unlike most of the existing standard sensory protocols (e.g., Australia/New Zealand 4020, British Standard 6920-2.2.1:2000, French AFNOR Standard XP P41 250) that evaluate materials in one type of chlorinated or non-chlorinated water, the UQT can use a water representative of any tap water, and thus investigate chlorinate as well as chloraminated waters.

The ability of VOCs to leach directly from polyethylene pipe materials, manufactured by a variety of processes, and cause odors in drinking water has been demonstrated repeatedly. Organoleptic changes to water quality have been caused by defective polyethylene pipe, via both the leaching of the polymer additives and oxidation of the surface of the pipe during extrusion (Anselme et al., 1985). The main compounds identified included antioxidants (4-methyl-2,6-di-*t*-butylphenol, alkyl thiophene), several aldehydes and plasticizers

(phthalates and tributyl phosphate). The burnt plastic odor was found to be due to butylated hydroxytoluene. Studies done by the French Centre de Recherche et de Contrôle des Eaux showed that insufficiently controlled extrusion conditions can result in the formation of oxidation products such as aldehydes, ketones, or quinones which can convey burned-oil or sweet flavor to drinking water (Rigal, 1992). Further studies have confirmed the ability of VOCs to leach from pipes and pipe linings, and effect taste and odor (Skjevrak et al., 2003; Marchesan and Morran, 2004), and a number of the odor causing compounds have been specifically identified (Villberg et al., 1997; Brocca et al., 2002; Skjevrak et al., 2003). PVC has not been known to cause significant odor during migration tests (Skjevrak et al., 2003). Migration of chlorinated organics and organotin compounds have been reported however (Sadiki et al., 1996; Sadiki and Williams, 1999; Mallevalle and Suffet, 1987).

The intent of this research was to comprehensively evaluate changes in sensory and chemical water quality when cPVC and HDPE pipe contact with drinking water containing representative levels of chlorine and monochloramine. Specific objectives of this research were to: (1) determine if the polymers contributed odor(s) to the water and (2) examine the effects of HDPE and cPVC on TOC leaching, trihalomethane (THM) formation, and disinfectant residual.

2. Materials and methods

2.1. Utility quick test

cPVC and HDPE pipe with internal diameters of 19 mm were acquired from local building supply companies. Based on health effects for use in home plumbing systems in the United States, both materials were certified according to USA National Sanitation Foundation (NSF-61) standards.

To conduct the UQT, 2.13 m lengths of cPVC and HDPE pipe were flushed using distilled water for 1 h, filled with water containing 50 mg/l free chlorine for 3 h for disinfection, and flushed again with distilled water to eliminate any chlorine residual. "Reference" tap water was then prepared to simulate tap water typically found in the Eastern US. The reference tap water was synthesized using Nanopure (Barnstead® Nanopure Filter) water combined with salts equaling 8 mg/l Mg^{2+} , 46 mg/l SO_4^{2-} , 20 mg/l Na^+ , 0.05 mg/l Al^{3+} , 11 mg/l Ca^{2+} , 2.6 mg/L SiO_3^{2-} , 4 mg/l K^+ , 1.4 mg/l NO_3^- as N, and 0.002 mg/l PO_4^- as P. No additional natural organic matter was added to the water. Three separate batches of the water were prepared, one containing 2 mg/l free chlorine, one containing 4 mg/l monochloramine, and one containing no disinfectant. The pH was adjusted to between 7.7 and 7.9. The pipe lengths were filled to their entire volume to eliminate headspace and capped with Teflon-lined VOA vial caps and attached with Parafilm®. The pipes were stored undisturbed at room temperature and pressure for 72–96 h (3–4 days), after which the leachate water was removed for analysis. The fill and drain process was repeated 2 additional times for each UQT. The entire UQT was performed twice. Controls were prepared with the 3 types of disinfectant water and stored in

the dark separately in 500 ml glass Erlenmeyer flasks with ground-glass stoppers for identical time periods as the pipes. Controls in glass were conducted for each experimental condition investigated.

2.2. Flavor profile analysis (FPA)

FPA was conducted in accordance with the procedures found in Standard Method 2170 (APHA, 2005). Odor-free water was obtained from a Barnstead[®] Nanopure filter. All samples were prepared in 500 ml wide-mouth Erlenmeyer flasks with ground-glass stoppers and heated to 45 °C in a water bath for 15 min prior to testing. Five to seven panelists from a trained group of ten were presented with the flasks in random order at 2-min intervals, and asked to give a descriptor and intensity rating (0–12) of the odor of the water in the flasks in accordance with their FPA training. The intensity ratings are described as follows: 0 = odor free; 4 = weak; 8 = moderate; 12 = strong. The human subjects protocol was approved by the Virginia Tech Institutional Review Board.

2.3. Water quality analyses

2.3.1. TOC analysis

Analysis of total organic carbon (TOC) concentration content of water samples was performed using a Sievers[®] 800 Portable TOC analyzer, and the parameters described in Standard Method 5310C (APHA, 2005).

2.3.2. Disinfectant residual

Residual for free chlorine, total chlorine, and monochloramine were determined by measuring the concentration of these species before and after they were stored in the pipes and control flasks. Concentrations of the disinfectant species were determined using appropriate powder pillows (DPD for free chlorine and indophenol for monochloramine) and a HACH[®] Pocket Colorimeter II and HACH[®] DR/2400 Portable Spectrophotometer.

2.3.3. Trihalomethane analysis

THM content of water samples was performed according to USEPA Method 502.2 or Standard Method 6232D (APHA, 2005). The instrument was a Tremetrics 9001 gas chromatograph with a Hall 1000 detector, Tekmar 3000 purge trap and concentrator and Tekmar 2016 Purge Trap autosampler.

2.3.4. Formation and sorption of THMs

The fate of THMs in water exposed to HDPE pipe was investigated by examining whether or not THMs could form from leached TOC and chlorine during the UQT and then sorbed into the polymer pipe. To investigate THM formation from leached TOC, reference tap water with no disinfectant was used to fill sections of HDPE pipe as well as glass control flasks and allowed to remain under static conditions for 72 h. The water was then drained from the pipes and controls into 40 ml amber vials with Teflon-lined caps. Hypochlorous acid was added at 2 mg/l as Cl₂. Sodium thiosulfate was subsequently added to quench the THM formation reaction at 0, 24 and 72 h. The samples were then analyzed for concentration of THMs and TOCs.

An investigation into the sorption of trichloromethane into the HDPE pipe wall itself was conducted by filling 1 ft lengths of HDPE pipe and amber glass VOA vials with reference tap water to which 60 µg/l trichloromethane was added. The glass vials and pipes were filled to eliminate headspace and sealed with PTFE caps and allowed to rest horizontally for 72 h. Following the contact period, pipes and vials were sampled through the PTFE caps using 5 ml glass single-use syringe needles to prevent exposure to air. Following needle extraction, samples were injected into purge trap samples ports for analysis conducted by correlation with a five-point standard curve.

2.3.5. SPME/GC–MS analysis

Solid phase microextraction holder and 75 µm Carboxen[™]-PDMS coating fibers were purchased from Supelco (Bellfonte, PA, USA) for analysis of VOCs. The SPME conditions were optimized by the addition of 2 g of NaCl to 20 ml of sample water placed in a 40 ml VOA vial. The sample was stirred using Teflon-coated magnetic stir bars at 45 °C for 20 min during which time the fiber was injected into the 10 ml sample headspace for sorption. Samples were allowed to desorb for 3 min. An Agilent 6890 Series GC system connected to Agilent 5973 network mass selective detector was operated in splitless mode with a 0.75 mm i.d. injection sleeve (Supelco), total helium flow of 24 ml/min, inlet temperature of 220 °C, and 80 kPa pressure. The mass selective detector was operated in the mass range from 45 to 500; library matching to the NIST-98 (rev. 0.02.00) mass spectral library was used for tentative identification of compounds. All samples were analyzed within 2 days of collection.

2.3.6. Statistical analysis

Data were analyzed using SAS statistical software or Excel with type I error (α) of 0.05. The t-test or ANOVA were applied as the data were normally distributed.

3. Results and discussion

3.1. Odor assessment by trained panelists

The cPVC pipes did not contribute significant odor different from the glass controls, consistent with results reported previously (Skjevrak et al., 2003). When a “chlorinous” odor was detected in both controls and cPVC samples, it coincided with the presence of disinfectant in the UQT water, with more intense odors attributed to the presence of chlorine than monochloramine (FPA \geq 2).

HDPE pipe was found to contribute substantial odor. The FPA ratings varied between 4 and 8, which represent a ‘weak’ to ‘moderate’ odor intensity. The data indicate a strong correlation between water stored in the HDPE pipes and a ‘waxy/plastic/citrus’ odor, as described by panelists (Fig. 1). This odor is comparable with the ‘plastic/sweet/glue/solvent’ odor detected from HDPE (Villberg et al., 1998) which was attributed to one of the alkylphenols, esters, aldehydes and ketones found in other studies (Brocca et al., 2002; Skjevrak et al., 2003). Low-density PE was also shown to produce off-flavors in water due to carbonyls and alcohols (Andersson

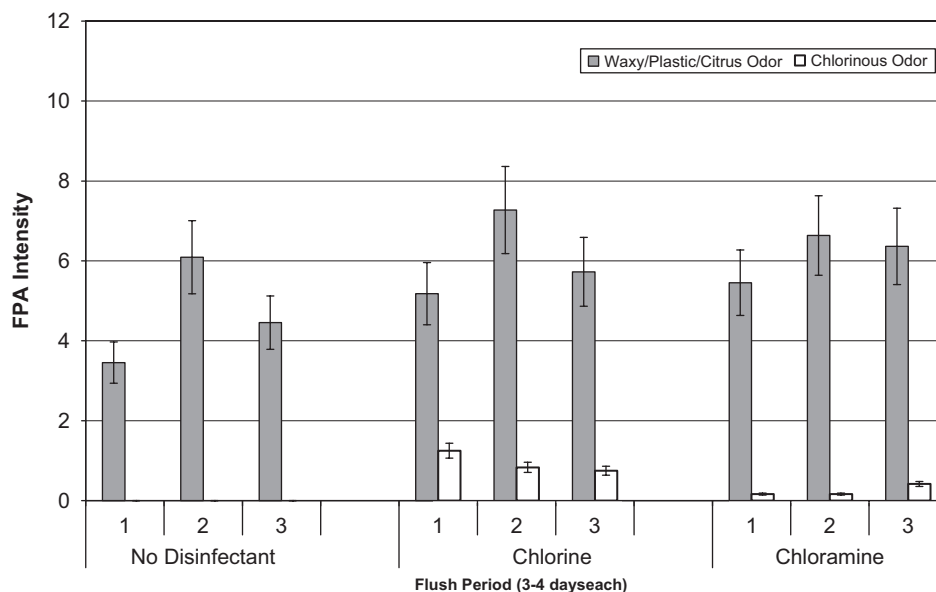


Fig. 1 – Average odor intensity for two replicate UQT experiments utilizing HDPE in the absence of disinfectant and the presence of 2 mg/l free Cl_2 or 4 mg/l monochloramine as Cl_2 . In the presence of free chlorine, “chemical/plastic” was given as the descriptor while in the presence of monochloramine, a “waxy-crayon/plastic” descriptor was used by panelists. The standard error of FPA intensity between replicates is shown.

et al., 2005). Additives used in the manufacture of PE pipes have been shown to have the potential to impart odors to water (Rogers et al., 2004).

When the UQT was replicated, odor intensity remained relatively constant for each flush and the three types of water tested for the HDPE pipe (Fig. 1). Thus, presence of chlorinous odors from disinfectants did not mask the odor leached from the HDPE pipe. This is similar to previous reports where the presence of chlorine or chloramines did not alter the intensity of a chemical/solvent odor from silane cross-linked polyethylene pipe (PEX-b) (Durand and Dietrich, 2007), but different from research that demonstrated that free chlorine masks earthy-musty odors (Worley et al., 2003; Bruchet et al., 2004). While the odor descriptor for HDPE was ‘waxy/plastic/citrus’ overall, the ‘plastic’ odor tended to vary with disinfectant type. The descriptors given by the panelists varied slightly with disinfectant type, with ‘chemical/plastic’ given as the descriptor for water with chlorine and ‘waxy-crayon/plastic’ given as the descriptor for water with monochloramine. The change in odor descriptor in the presence of different disinfectants could be due to either changes in human sensory perception in the presence of mixtures or chemical reaction of a leached compound with the disinfectant. Such disinfectant-related reactions are known to occur, with production of intensely odorous halophenols from reaction of phenols during chlorination and distribution being a classic example (Bruchet et al., 2004).

3.2. Leaching of organic compounds

Leaching of organic compounds, measured as TOC, occurred in the water exposed to both types of pipe and all disinfectant conditions. The amount of TOC leached to the water when exposed to cPVC pipe was about 75 $\mu\text{g/l}$ or 0.08 $\mu\text{g TOC/cm}^2$

pipe surface (Fig. 2 and Table 1), which was significantly higher than in water exposed to glass controls ($p < 0.001$). An even greater degree of organic carbon leaching occurred from the HDPE pipe (Fig. 3 and Table 1) which was also significantly different than the TOC measured in the glass controls ($p < 0.001$). The amount of TOC leached to the water when exposed to HDPE pipe was about 150–200 $\mu\text{g/l}$ with an average of 0.14 $\mu\text{g TOC/cm}^2$ pipe surface. The amount of TOC leached from either the HDPE or cPVC pipes did not change with subsequent flushes and was not affected by the presence of a disinfectant (Figs. 2 and 3). As odors were detected in the water exposed to the HDPE pipe, but not the cPVC pipe, the compounds leaching from the HDPE did cause detectable odor.

Leaching of organic compounds from pipe materials to water has been demonstrated in previous studies. PVC and HDPE pipes of 51.4 mm diameter were shown to leach VOCs and odorous organic compounds in a migration study that used ultra-pure water as the matrix (Skjevrak et al., 2003). That research also measured TOC but the amount leached was below their instrumental detection limit of 400 $\mu\text{g/l}$. PVC pipe is known to leach vinyl chloride monomer when contacted with water (Al-Malack et al., 2000). The ability of HDPE pipe to contribute odor causing compounds as TOC was demonstrated in a study which linked specific volatiles leached from HDPE to the odors they caused (Villberg et al., 1997; Skjevrak et al., 2003).

3.3. Consumption of disinfectant

Water exposed to both HDPE and cPVC pipes demonstrated a significantly lower disinfectant residual than did the glass controls. Both HDPE and cPVC consumed significantly more chlorine than the control ($p < 0.05$). Table 1 compares leached

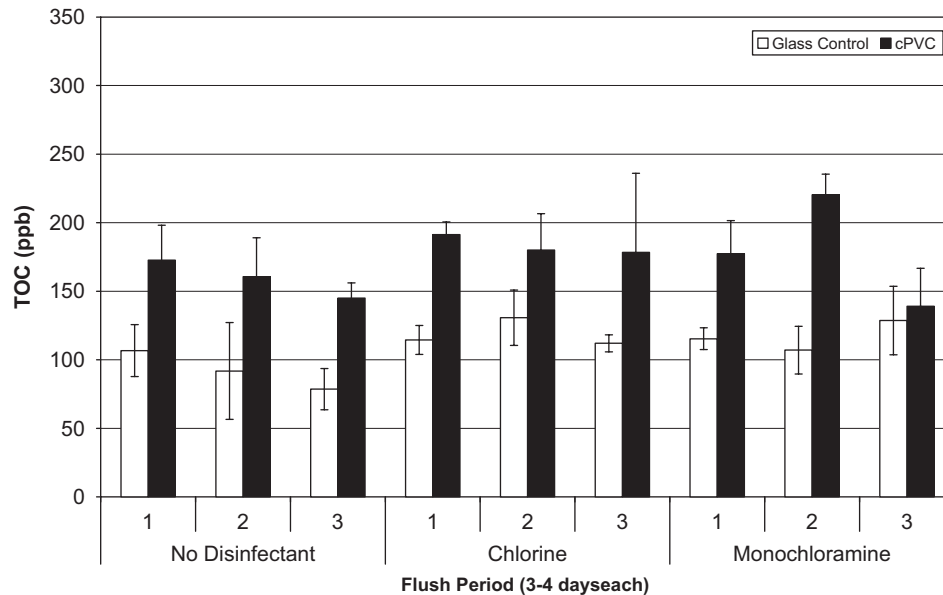


Fig. 2 – Average TOC concentrations for two replicate UQT experiments utilizing cPVC in the absence of disinfectant and the presence of 2 mg/l free Cl_2 or 4 mg/l monochloramine as Cl_2 . The standard deviation of TOC concentrations between replicates is shown.

Table 1 – Mean leached TOC and disinfectant demand, above that of the glass controls, as a function of inner pipe wall surface area, in $\mu\text{g}/\text{cm}^2$

Parameter	cPVC pipe ^a			HDPE pipe ^a		
	TOC leached	Cl_2 demand	NH_2Cl demand	TOC leached	Cl_2 demand	NH_2Cl demand
Flush 1	0.086 ± 0.00	0.5 ± 0.0	0.1 ± 0.1	0.139 ± 0.00	0.9 ± 0.0	0.5 ± 0.3
Flush 2	0.089 ± 0.01	0.4 ± 0.0	0.1 ± 0.0	0.142 ± 0.01	0.5 ± 0.0	0.5 ± 0.1
Flush 3	0.073 ± 0.01	0.3 ± 0.0	0.2 ± 0.1	0.141 ± 0.02	0.5 ± 0.0	0.1 ± 0.0

Values are means \pm standard deviation for $n = 9$.

^a Unit: $\mu\text{g}/\text{cm}^2$ pipe surface.

TOC and free chlorine demand as a function of pipe surface area. During the first flush, HDPE pipe consumed nearly twice as much chlorine as the cPVC pipe (0.9 vs. $0.5 \mu\text{g}$ chlorine/ cm^2 pipe surface). The chlorine demand decreased with subsequent flushes for both pipe types. A study of PCV and medium density PE pipes in distributions system (100 mm diameter and larger) also found that both materials consumed free chlorine (Hallam et al., 2002). The statistical analysis for monochloramine residual showed HDPE and cPVC had significantly more monochloramine demand than controls ($p < 0.05$). As shown in Table 1, the HDPE pipe exerted five times the disinfectant demand for monochloramine as did the cPVC pipe, with values of $0.5 \mu\text{g}$ monochloramine/ cm^2 for HDPE compared to $0.1 \mu\text{g}$ monochloramine/ cm^2 for cPVC.

3.4. Sorption and formation of THMs

Although low $\mu\text{g}/\text{l}$ trichloromethane concentrations were measured in the chlorinated leachates of cPVC and HDPE pipes, the concentrations measured in the leachates were not

significantly different that those measured in the glass controls. Trichloromethane was the only THM detected. Following the UQT, THM values in water exposed to HDPE pipe had a mean value of $0.71 \mu\text{g}/\text{l}$ ($n = 18$), compared to a mean control value of $0.92 \mu\text{g}/\text{l}$ ($n = 18$). There was no significant difference between THM concentrations in the HDPE and control ($p > 0.71$). Values in water exposed to cPVC pipe had a mean value of $0.48 \mu\text{g}/\text{l}$ ($n = 18$), compared to a mean control value of $0.23 \mu\text{g}/\text{l}$ ($n = 18$), values were not statistically different ($p > 0.47$).

Because the HDPE produced a significant amount of TOC and consumed significant chlorine, an experiment was designed to determine if the TOC from the HDPE was capable of forming THMs, and if the THMs were capable of sorbing back into the HDPE. Previous research demonstrated that epoxy-lining for distributions system pipes leached significant TOC that reacted with free chlorine to form trichloromethane that was subsequently sorbed into the epoxy-liner (Heim and Dietrich, 2007). Reference tap water with no disinfectant was exposed to the HDPE pipe for 72 h, drained,

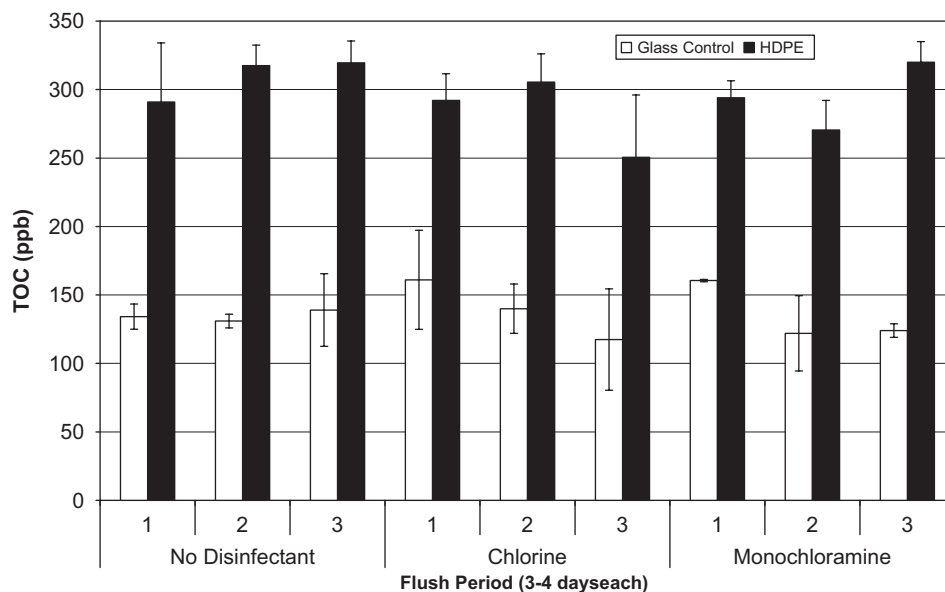


Fig. 3 – Average TOC concentrations for two replicate UQT experiments utilizing HDPE in the absence of disinfectant and the presence of 2 mg/l free Cl_2 or 4 mg/l monochloramine as Cl_2 . The standard deviation of TOC concentrations between replicates is shown.

chlorinated at 2 mg/l as Cl_2 , and then analyzed at 1, 24, and 48 h for TOC and THM formation. Results showed the leached organic matter did not form THMs. THM concentrations for all glass controls and HDPE samples were less than $1 \mu\text{g/l}$ for all contact times. The levels of TOC in the chlorinated pipe leachate decrease with time and averages for three replicate pipes were $450 \pm 96 \mu\text{g/l}$ at 0 h, $320 \pm 8 \mu\text{g/l}$ after 24 h, and $305 \pm 19 \mu\text{g/l}$ after 48 h. Although trihalomethanes did not form from the leached TOC, other disinfection by-products may have formed but they were not investigated.

Although THMs were not detected in the UQT flushes, or from reaction of the leached TOC with chlorine, the potential of trichloromethane to sorb to the pipes was investigated. After a contact time of 72 h in HDPE pipe, water which initially contained $60 \mu\text{g/l}$ trichloromethane only had a concentration of $33.5 \mu\text{g/l}$ trichloromethane, which was significantly lower than the controls ($p < 0.01$), indicating that HDPE pipes sorb trichloromethane.

3.5. Volatile organic compounds (VOCs) detected by SPME/GC-MS analysis

SPME followed by GC-MS analysis detected several organic compounds with the potential to cause odor. Table 2 lists compounds detected in the water exposed to pipe material and not in the water exposed to glass controls along with corresponding odor descriptors. The results show a higher number of organic compounds leached from the HDPE pipes when compared to the cPVC pipes. This correlates to the increased odor detected from HDPE by FPA panelists who analyzed the water, and demonstrates a link between increased leaching of VOCs and potential odor problems. Likely candidates for the “waxy/plastic/citrus” attributed by panelists to HDPE include some combination of higher weight alkanes (related to paraffin), phenolic compounds, and ketones.

Some of the compounds reported in Table 2 were identified in previous studies of synthetic plumbing materials and their interaction with drinking water, including alkanes (Villberg et al., 1997), ketones (Skjevrak et al., 2003, Villberg et al., 1997), and phenolic compounds (Brocca et al., 2002, Skjevrak et al., 2003). A study of low-density polyethylene (LDPE) packaging for food and water demonstrated that production of migatable and odorous aldehydes, ketones, and alcohols occurred during polymer manufacturing and was related to extrusion temperature and oxygen contact time (Andersson et al., 2005). If the source of the oxygenated organic compounds in HDPE pipe for drinking water is similar to their source in LDPE for foods, then controlling the manufacturing process could provide a means to limit their production and off-flavored water.

4. Conclusions

The research demonstrates the impact that different types of premise plumbing materials can have on water quality aesthetics. This is important knowledge for utilities and consumers as associating the presence and intensity of the odor and linking it with a specific plumbing material can help identify problems and suggest solutions.

- Water exposed to the either HDPE or cPVC pipe for 72–96 h stagnation times showed increases in TOC and decreases in disinfectant residual. Water samples contacted with HDPE produced $0.14 \mu\text{g TOC}/\text{cm}^2$ pipe surface, which was significantly greater than the TOC increase from cPVC. The chemical compounds identified in the leachate from HDPE pipes included specific ketones, phenols and hydrocarbons detectable by solid phase microextraction.
- Water stored in both types of pipe showed disinfectant demands of $0.1\text{--}0.9 \mu\text{g disinfectant}/\text{cm}^2$ pipe surface, with

Table 2 – Compounds and their associated odors (Merck, 2001) detected in water in contact with cPVC or HDPE but not detected in controls

cPVC		HDPE	
Compound	Odor descriptor	Compound	Odor descriptor
1-3 butadiene	“Gasoline-like”	Phenol	“Sweet-tarry”
Titanium dioxide	None	Bisphenol	“Phenol-like”
		Cyclotetradecane	“Hydrocarbon”
		Tetradecane	“Hydrocarbon”
		Cyclohexadiene	“Gasoline/terpentine”
		Cyclohexanone	“Solvent-acetone”
		Cyclopentanone	“Solvent-acetone”

Identifications are tentative based on SPME-GC/MS analysis with library matching.

HDPE exerting more demand than cPVC. The disinfectant consumption can likely be attributed to the interaction of oxidizing disinfectant species with either antioxidants from the manufacturing process or the polymer itself.

- Sensory data indicated that the HDPE pipe leached compounds that contributed a “waxy/plastic/citrus” odor to drinking water at levels that would result in weak to moderate odor intensities that would be readily detected by consumers. The odor was present in water exposed to the pipe material, and its intensity did not diminish during subsequent flushing and stagnation periods within the approximately 10-day timeframe of the UQT.
- Sensory panelists tended to describe the “plastic” odor of HDPE leachate as “chemical/plastic” in the presence of chlorine, and “waxy-crayon/plastic” in water with monochloramine. The presence of disinfectants did not alter the intensity of the odors. Several odorous ketones, alkanes, and phenols were detected in headspace and likely contributed to the perceived odor.
- This research confirms the ability of synthetic plumbing materials to affect water quality and reinforces the value of sensory testing to determine the effects of new materials on consumer perception of water quality.

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