Water Quality Changes Associated with New & Standard Domestic Distribution System Piping Materials

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The distribution system, including home plumbing materials, has been identified as a major contributor to deteriorated water quality and also taste and odor (T&O) issues in drinking water (Khiari *et al.*, 2004, Hem *et al.*, 2002, Dietrich *et al.*, 2004, Durand *et al.*, 2004). In evaluating the distribution system, work has focused mainly on materials that water contacts before it enters the consumer's home drinking water infrastructure, such as water mains, service pipes, and storage tanks (Rigal *et al.*, 1999 and Tomboulian *et al.*, 2004). The sustainability of materials for home plumbing systems, as they relate to T&O properties, has not been widely explored. The growing need for more detailed studies of common household plumbing materials is evident, based on limited data.

Studies have shown that many T&O episodes result after installation of new materials (Khiari *et al.*, 1999). A lack of understanding of the possibility that these materials may contribute odor could result in dissatisfied consumers or unnecessary panic in a community.

T&O problems in the distribution system and domestic plumbing infrastructure are caused by biological sources (fungi and bacteria), chemical sources, system design (dead ends), and system operation (blending chloraminated water with chlorinated). T&O problems are becoming more prevalent as utilities and homeowners use newer polymer materials for piping and as chloramines replace chlorine for residual disinfection (Seidel *et al.*, 2005). In order for utilities to advise on and deal with T&O issues, they must understand problems in both the public distribution systems and in domestic plumbing infrastructure.

Aesthetic qualities of drinking water reaching the consumer's tap can be significantly affected by the type of materials and disinfectant used in the domestic plumbing system (Rigal *et al.*, 1999; Khiari *et al.*, 1999). Studies have shown that the presence of residual chlorine can have deleterious effects on some pipe materials and subsequently affect the T&O properties of drinking water (Marchesan *et al.*, 2004).

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As more utilities convert to chloramines, there is a need to further evaluate interactions of piping materials and chloramines (Seidel *et al.*, 2005). Studies have shown that rubber gaskets deteriorate in the presence of chloramines, generating undesirable odors

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(Khiari *et al.*, 2002). Conflicting results from another study concluded that degradation of gaskets after exposure to chloramines is application specific and depends on the end-use of the material being contacted (Bonds, 2004). These conflicting results highlight the need for more complete evaluation of the T&O impacts of chloramines on other materials.

A pilot plumbing rig was used to simultaneously evaluate several plumbing materials to determine their effects on the aesthetic properties of drinking water in the presence of chlorine or chloramines disinfectant. Copper is the most commonly used metallic piping material in domestic plumbing systems in the U.S. To date, there are no reported studies of copper material imparting an odor to drinking water.

Stainless steel and galvanized iron are less frequently used in the U.S., although they have been used in Japan and European countries such as Germany. Khiari *et al.*, 2002, showed that water exposed to galvanized pipe could obtain a sour taste or astrin-gent feeling in the mouth due to the presence of zinc and aluminum salts.

The odor properties of metallic pipes used in distribution systems has not been extensively studied. Chlorinated polyvinyl chloride, polyethylene, and cross-linked poly-ethylene are rapidly replacing copper as preferred domestic plumbing materials worldwide.

Cross-linked polyethylene (PEX) is the most recent plastic material incorporated into the U.S. market (> 10 years). Currently it is estimated that 12 percent of residential homes in the U.S. use PEX plumbing material. Very few studies have examined the sustainability of PEX material when used in drinking water infrastructure.

Researchers in Norway showed that PEX contributes an odor of Threshold Odor Number (TON) ≥ 5 (Skjevrak *et al.*, 2003. According to standards in the United States, this is unacceptable based on a secondary Maximum Contaminant Level of TON = 3 (USEPA, 1979a). Chemical analysis identified the oxygenate methyl tert-butyl ether (MTBE) as the major VOC component in water exposed to the PEX pipes.

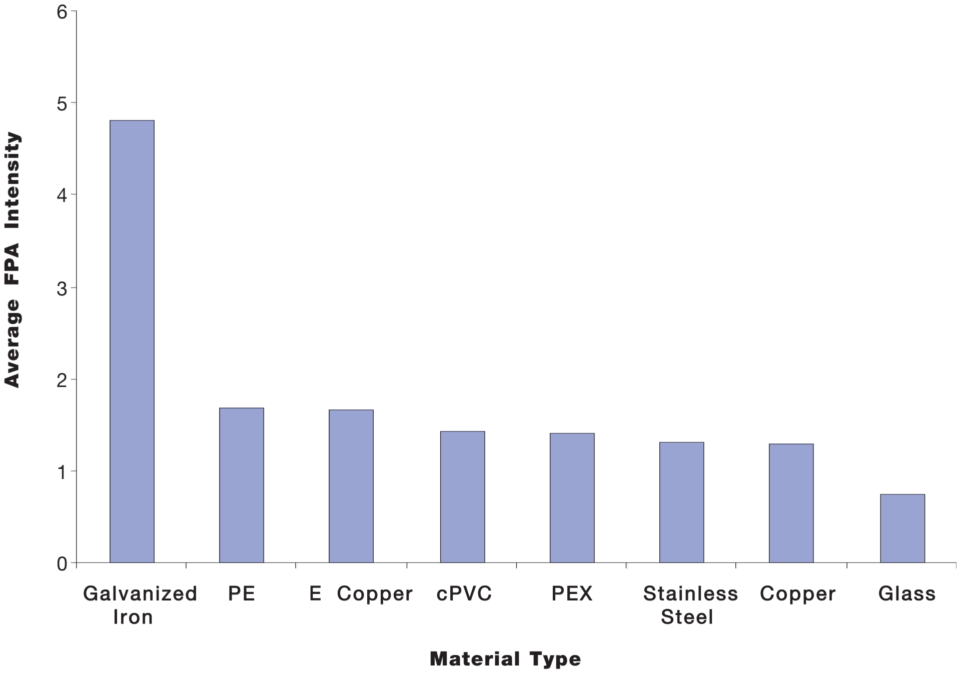

Figure 1: Overall ranking of plumbing materials in order of descending odor intensity in the absence of disinfectant.

These findings in Norway prompted the need to investigate the potential of newly installed PEX material to alter drinking water characteristics under varying water quality conditions. The primary purpose of these studies is to better understand the behavior of materials in affecting T&O of drinking water when exposed to varying water qualities in the United States.

Materials & Methods

Characteristics of Synthetic Experimental Water

For each experiment, synthetic tap water was prepared using nanopure water (Barnstead® Nanopure Filter) and mineral concentrations typical of drinking water in the Eastern United States. The following concentrations of ions were generated: 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 Si, 4 mg/L K^+, 1.4 mg/L NO_3^- as N, 10.0 mg/L Cl^-, 0.002 mg/L PO_4^- as P. The alkalinity of the experimental water was 34 mg/L as $CaCO_3$, and pH range 7.8 to 8.0.

No additional natural organic matter was added to the water. Initial TOC concen-trations in base synthetic water of 0.1 to 0.2 mg/L were recorded. All experiments were performed at room temperature and pressure.

Plumbing Rig

Three individual replicate plumbing rigs

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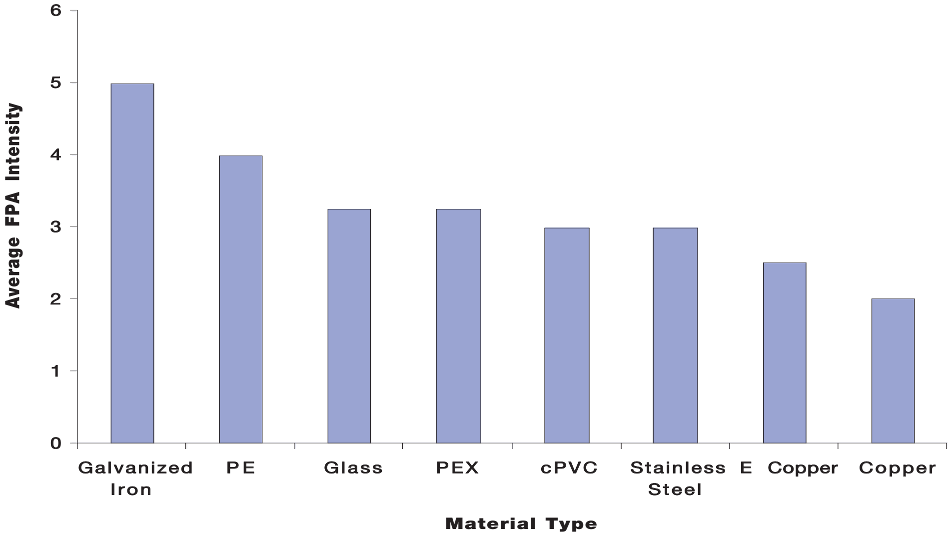

Figure 2. Overall ranking of plumbing materials in order of descending odor intensity in the presence of residual free chlorine based on average FPA intensities.

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were constructed of the same plumbing materials, but each differed in water circulating through the rig. All materials were approved for use in potable water systems by the National Sanitation Foundation (NSF 61) and purchased at a local home building supply company or ordered directly from the manufacturers.

The diameter of the pipes ranged from 3/8 inch to 3/4 inch, and all pipes were purchased in eight-foot lengths. The pipes were exposed to experimental water for eight-hour stagnation periods, three times each day.

Between each stagnation period, the pipes were flushed for two minutes and refilled with a fresh batch of experimental water. Water flowed into the pipes solely under the influence of gravity. The rigs were operated at room temperature.

After an eight-hour stagnation period, water was drawn from each pipe material and collected in clean, two-liter volume glass bottles. Water was collected from the storage tank to coincide with every rig sampling. One rig was sampled per day.

During the first month of operation of each rig, samples were collected every two weeks, then sampling tapered to once every month, then once every three months. Data were collected over a six-month period.

Flavor Profile Analysis was used to characterize the odors generated. The research protocol was approved according to the standards of the Virginia Tech Institutional Review Board for human subjects. The procedure for Flavor Profile Analysis was followed from Standard Methods 2170, and four to six members were present at all sampling times.

Migration/Leaching Protocol for Utility Quick Test

The Utility Quick Test (UQT) is a leaching/migration protocol recommended for use by utilities when evaluating T&O properties of materials prior to their installation in distribution systems (Schweitzer *et al.*, 2004). Separate experiments consisted of dosing the experimental water with no disinfectant, 2 mg/L free chlorine, or 4 mg/L monochloramine as chlorine.

Seven-foot lengths of PEX-b and five-foot lengths of PEX-a pipe were used to accommodate the required sample volume needed for sensory and chemical analysis. Each pipe length was flushed for three hours, disinfected with 50-mg/L free chlorine, and rinsed according to the leaching protocol of the UQT.

The PEX pipe material was filled completely with experimental water, sealed using Teflon-lined VOA vial stoppers and parafilm "M" paper, and left under static conditions for three consecutive periods. A fresh batch of experimental water was used to refill the pipe section after each stagnation period. The exposure time per flush varied between 72 hours (three days) and 96 hours (four days).

Controls for each experiment were performed by placing synthetic water in standard 500-mL glass Erlenmeyer flasks that were wrapped with aluminum foil paper to prevent exposure to light, and then sealed with glass stoppers. The water was stored in the flask headspace free, and the flasks were further protected by sealing the glass stoppers with parafilm paper. An individual control was set up for each experimental condition investigated.

Flavor Profile Analysis was used for sensory analysis, with the procedure followed from Standard Methods 2170.

Total Organic Carbon Analysis

Sample preparation and analysis was followed according to *Standard Methods for the Examination of Water and Wastewater Method 5310.*

Results & Discussion

Plumbing Rig

Aqueous Total Organic Carbon (TOC) concentrations increased as much as 1 mg/L for some materials during the first month of use. The increased TOC observed for many plumbing materials was consistent with the presence of a distinct odor or a high Flavor Profile analysis intensity rating, with the

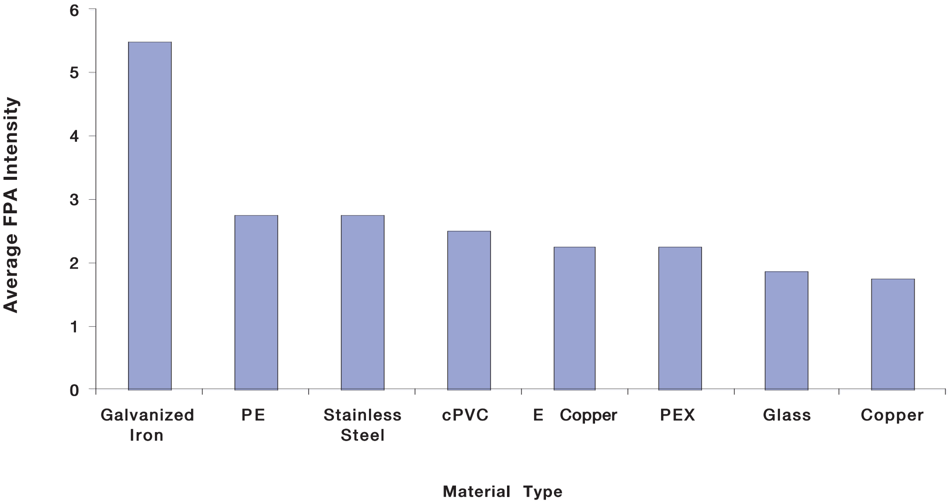

Figure 3. Ranking of plumbing materials in order of descending odor intensity in the presence of residual chloramines based on average FPA intensities.

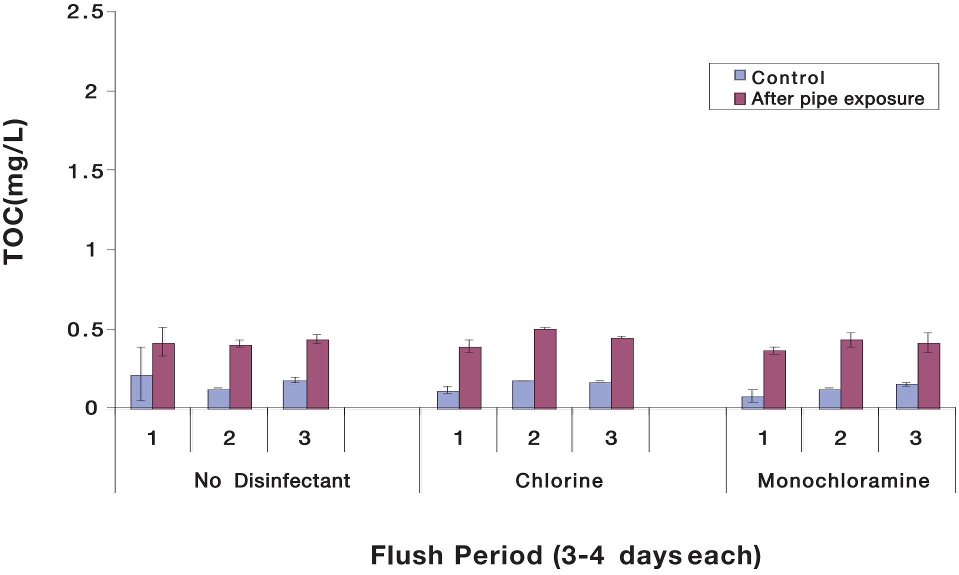

Figure 4: Variation in TOC of peroxide PEX (PEX-a) after exposure to water containing no disinfectant, 2 mg/L as Cl_2 and 4 mg/L monochloramine as Cl_2. The standard error of the value is shown

exception of galvanized iron. For galvanized iron, the high odor intensity persisted despite fluctuations in TOC concentrations.

The descriptors most consistently used to describe plumbing-associated odors from both plastic and metallic pipes were, "plastic", "oily", "chemical," and "solvent". In the presence of chlorine, samples were consistently described as "chlorinous" and rated at high Flavor Profile Analysis intensities.

Very little plumbing associated odor was detected in the presence of residual free chlorine. In the presence of residual chloramines, the "chlorinous" odor was not as potent nor as frequently detected as in the chlorine samples. Plumbing-associated odors such as "plastic" and "rubbery" were more easily detected.

A few of the materials displayed characteristic odors in the presence of chloramines. Stainless steel leachate was described as "sulphur" and "chalky" but not "chlorinous" when in contact with chloramines containing water, but had no previous such odor when contacted with water with no disinfectant or chlorine. Similarly, copper metal displayed increased odors in the presence of chloramines. Polyethylene and epoxy-lined copper also contributed distinct odors such as "rubbery" and "oily".

In summary, galvanized iron produced the worst odors that were consistently described as "motor oil" with Flavor Profile Analysis intensity ranging from 4 to 6. This material consistently generated the most intense odors. Polyethylene generated more intense plumbing-associated odors than PEX or cPVC plastic material. The least odorous materials were chlorinated polyvinyl chloride and copper.

Figures 1, 2, and 3 rank the overall odor produced by the materials when exposed to no disinfectant, free chlorine, and chloramines, respectively. Rankings are in descending order, based on an average Flavor Profile Analysis intensity calculated over the entire six months of rig operation.

<u>Utility Quick Test</u>

The difference in measured TOC from water exposed to PEX-a and PEX-b was substantial. Figures 4 and 5 show the increase in measured TOC after each flush period for PEX-a and PEX-b, respectively. There was an overall decline in measured TOC for PEX-b but no clear trend for PEX-a; concentrations were fairly consistent between flushes.

The maximum increase in TOC for water exposed to PEX-a, both in the presence and absence of disinfectant, was 0.4 mg/L. PEX-b showed a 1.4-mg/L increase as compared to a 0.1-mg/L increase for the control water (glass). This difference shows a direct correlation to the more intense odor that was observed for PEX-b leachate, and it also corresponds to the higher degradation properties of silane PEX-b (Celina *et al.*, 1995).

Figure 6 compares the odor properties from PEX-a and PEX-b leachate in the absence of residual disinfectant. Similar results were obtained in the presence of both residual chlorine and chloramines.

Panelists identified a "bitter plastic/oily" odor in water exposed to PEX-a. A more intense and complex odor was described in water that had been exposed to PEX-b. When compared to the Flavor Profile Analysis of the PEX-a leachate, the overall intensity of this odor was fairly consistent, both in the presence and absence of residual disinfectant. A wider range of descriptors were used by panelists to

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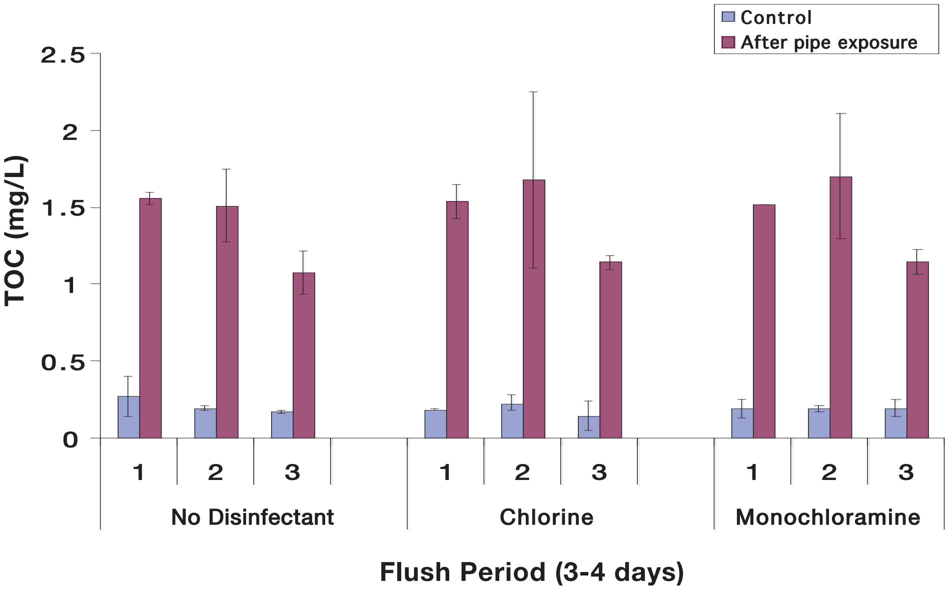

Figure 5: Variation in TOC after exposure of silane PEX (PEX-b) to water containing no disinfectant, 2 mg/L Cl2 and 4 mg/L monochloramine as Cl2. The standard error of the value is shown.

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describe this odor: "sweet chemical," "mechanical," "burning," "plastic," "solvent," "bitter."

In summary, the results showed that in the absence of disinfectant, peroxide PEX-a contributed fewer odors to the drinking water. Making a comparison using the Flavor Profile Analysis intensities in the presence of residual disinfectant was less valid since the presence of residual disinfectant chlorine or chloramines could have synergistic effects, enhancing odor intensity for water exposed to both PEX types.

The occurrence of a distinct odor, both in the presence and absence of residual disinfectant, eliminates any possibility of attributing the odors entirely to pipe degradation by chlorine or chloramines. Alternative explanations include: 1) leaching or dissolution of antioxidants and stabilizers and 2) leaching of byproducts of the manufacturing processes. Chemical analysis is necessary to identify the VOCs in the leachate waters.

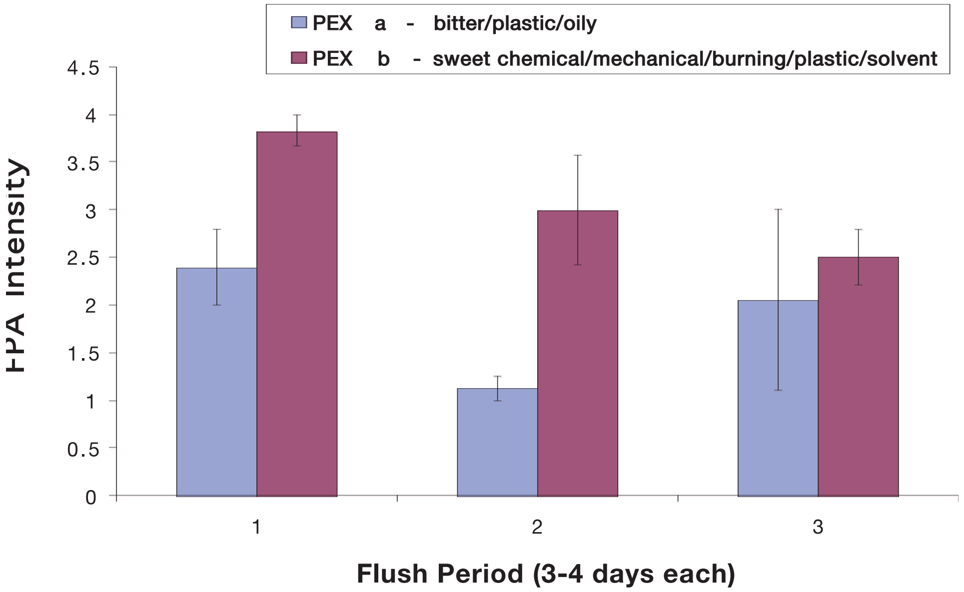

Figure 6: Compares the FPA intensity of silane (PEX-b) and peroxide PEX (PEX-a) in the absence of residual disinfectant over three flush periods.

Conclusion

Domestic plumbing materials have the potential to affect water-quality characteristics such as TOC concentrations, residual disinfectant, and odor when newly installed in homes—especially during the first weeks of service. Evaluating and understanding the potential of plumbing materials to impair the odor properties of drinking water will collectively benefit distribution and plumbing material manufacturers, utilities, and most im-portantly, the consumers.

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