GF Piping Systems

Disinfectant Effects on Piping Materials in Potable Water Distribution Systems Inside Buildings

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***Have you considered the** disinfectants used by your local water service provider when selecting a potable water distribution piping system?*

***In the U.S. we utilize an array** of disinfectant practices which can impact the integrity of most commonly used piping materials.*

***With the introduction of products** developed for other markets, it is absolutely critical to ensure piping materials selected for hot and cold domestic water will be compatible, here in the U.S., over the life of the plumbing system.*

Overview

Today we work in a global economy where international manufacturers see opportunities further afield. This leads to the injection of products not necessarily developed for the U.S. market but which are currently being specified for use in the U.S. market. Without a thorough understanding of each market it's easy for manufacturers to adopt a one size fits all approach resulting in piping systems that don't perform the same as they did in their home market.

When the piping system is not fit for a particular application, or when something changes with the application, failures occur. The subtle differences in water chemistry from region to region can spell the difference between trouble free and costly liability.

Here in the US, public water utilities are required to provide safe and clean drinking water. However, disinfection methods vary from one utility to the next. It is also important to emphasize the fact that the disinfectant methods can change over time based on the needs of the utility. Insurance companies, plumbing engineers, and contractors must ensure the specified piping products are compatible with existing disinfectants and disinfectants that may be utilized during the life of any piping system.

No one is more familiar with the capabilities of these materials than the Engineers and Scientists at Georg Fischer Piping Systems. Our experience spans more than 200 years of developing materials for piping applications in markets around the world for the safe and reliable transport of liquids and gases. Our success is attributed to our understanding of the materials, applications and markets we serve.

Problem Definition

Currently there are more than 151,000 public water systems throughout the US. (EPA, n.d.)

More than 97% of them are considered small public water systems. Each faces unique financial and operational challenges while consistently providing drinking water that meets EPA standards and requirements. Understandably, each water system, large and small, will determine what works best for their system. Solutions differ and utilities can disinfect water in different ways. Disinfection agents include chlorine, chlorine dioxide, chloramines, ozone, and ultraviolet light.

“Water supply companies are responsible for the cleanliness of the water they supply up to the point at which it is delivered to the facility using the water. Once delivered, it is up to the facility to ensure that the water remains bacteria-free. Since chlorine dioxide generators are relatively simple and cost-effective to use and maintain, many hospitals, SPA facilities and hotels are now equipped with their own chlorine dioxide generators” (Swerea, 2011)

Understandably, a utility/ water supply company cannot jeopardize the health of the public solely for the survival of a piping material that should never have been introduced to the U.S. market.

“One of the consequences of the Flint crisis -- as well as widespread publicity of Legionella, lead, and cyanotoxin events across the United States -- is increased scrutiny of drinking water system operations.” (Espinola, 2017)

In the United States, water treatment utilizes a higher concentration of Chlorine (ppm) in the municipal water supply than in the EU. This is mandated by the Safe Drinking Water Act of 1974 and was further refined by Stage I and Stage II Disinfectant / Disinfectant Byproducts Standard established by the EPA in 1998 as shown in the table below.

Table 1. Maximum Residual Concentrations of Disinfectants and Disinfection byproducts according to Stage I and II Disinfectants and Disinfectant Byproduct Rules (Lenntech BV, n.d.)

Table 1: maximum concentrations of disinfectants and disinfection byproducts according to Stage I and II Disinfectants and Disinfectant Byproducts rules.

		Stage I	Stage II
Disinfectant	Chlorine	4 ppm	
	Chloramines	4 ppm	
	Chlorine dioxide	0.8 ppm	
Byproducts	Total trihalomethanes	80 ppb	40 ppb
	Halogenic acetic acids	60 ppb	30 ppb
	Bromate	10 ppb	5 ppb
	Chlorite	1 ppm	

(EPA 2001)

Concentrations of Chlorine, Chloramine, and Chlorine Dioxide in drinking water in the EU are controlled and verified by each member nation or municipal. There is an EU Directive (EU 98/83 EC) which puts a high upper limit on Chlorine, however, typical residual concentrations of Chlorine and Chlorine Dioxide in tap water are 0.3-0.6ppm and 0.1-2.0ppm, respectively. (Michael Herrmann, 2003)

Table 6: Default values for disinfectant residuals in tap water

"free available chlorine"	0.3 – (0.6) mg.l^{1}
chlorine dioxide	0.1 – 2.0 mg.l^{1}
Ozone	0.05 mg.l^{1}

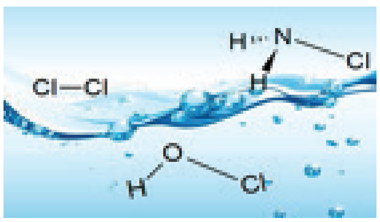
Disinfectants and Failure Mechanism

Today, different thermoplastic piping systems are specified for the transportation of drinking water inside buildings. These are not all alike and some perform poorly with the disinfectants used to keep our water safe. First, let us identify the common disinfectants that are used throughout the US.

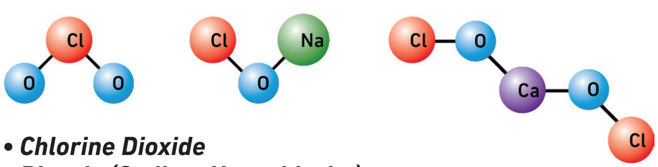
“In Canada and Europe the use of ozone and ultraviolet disinfectant is common, but because neither of these processes leaves a chemical residual in the water, there is no protection against bacteria growing in the pipes that deliver water to our homes. In the U.S., most cities use either chlorine or chloramines to disinfect public water supplies” (NSF, n.d.)

Chlorine, Chlorine Dioxide & Chloramines

"Chlorination is the process of adding chlorine to drinking water to disinfect it and kill germs. Different processes can be used to achieve safe levels of chlorine in drinking water. Chlorine is available as compressed elemental gas, sodium hypochlorite solution (NaOCl) or solid calcium hypochlorite (Ca(OCl)2 1. While the chemicals could be harmful in high doses, when they are added to water, they all mix in and spread out, resulting in low levels that kill germs but are still safe to drink" (EPA, 2013)



Chlorine is the most common disinfectant (oxidizing agent) used in the U.S. Free chlorine is a strong oxidizer which decays faster in the water stream. It is added to drinking water in following forms: Chlorine gas, Bleach (Sodium Hypochlorite), Chlorine Powder Ca(OCl)2. Another common chlorine based disinfectant is Chlorine Dioxide. Other than chlorine it does not hydrolyze in water to form hypochlorous acid but remains as dissolved gas. Amongst the chlorine based disinfectants, Chlorine Dioxide is the most powerful.



- ***Chlorine Dioxide***
- ***Bleach (Sodium Hypochlorite)***
- ***Chlorine Powder Ca(OCl)2***

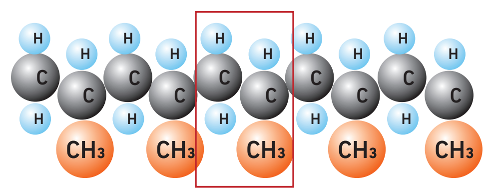
"Chloramines, another type of water additive, used to disinfect public drinking water at supplies. It is formed when ammonia is added to water that has first been treated with chlorine. The use of chloramines has become more widespread in the US as concerns about the creation of disinfection by-products from chlorine treatment alone have increased in recent years. Another reason for the increased use of chloramines for disinfection is that the compound will remain effective in warm water supplies for a longer period of time, which can provide better protection against bacterial growth in water distribution pipes in warmer climates." (EPA, 2013)

Amongst all Chloramines, the monochloramine is considered the best disinfectant. The Chloramines are weaker oxidants, more stable and decay relatively slower than free chlorine. **This means they reside in buildings, in greater concentrations, for longer period of time when compared to chlorine.**

All of these disinfectants will adversely affect Polyolefin thermoplastics mainly by oxidation.

Effects on thermoplastic pipe materials

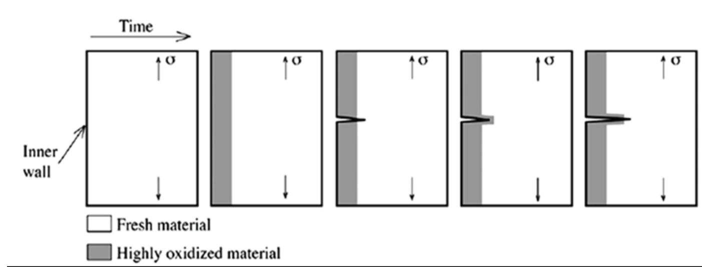
The disinfectant oxidants normally attack the non-polar polyolefin materials, especially tertiary carbon atoms, which are sensitive to oxidation. To slow down this oxidative degradation, polyolefin manufacturers add antioxidants to their pipe compounds. Unfortunately, over time, during continuous contact, the oxidants generated by common disinfectants consume the antioxidants from the polyolefin compounds and then the piping material degrades as the oxidation protection is used up. How well a specific polyolefin compound is able to perform in a strongly oxidative environment mainly depends on the quality of its stabilization additives.

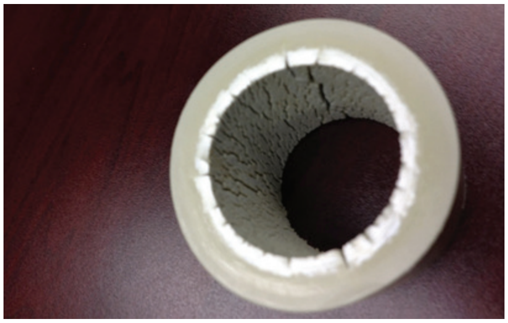


Polypropylene

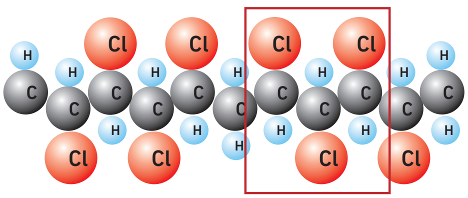
The mechanics of a chemical attack on pipe material consists of:

- **Oxidation of the inner layer.**
- **Micro cracking of the inner layer.**
- **Crack propagation through the wall with oxidation in advance of the crack front.**
- **Final rupture of the remaining pipe.**



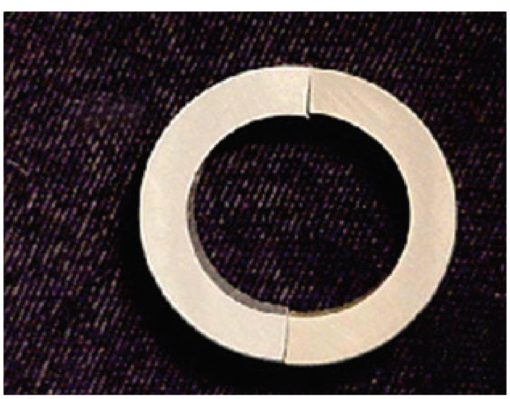


In contrast to polyolefins, the CPVC material consists of strong C-Cl polar bonds which are more stable against oxidation by disinfectants. Therefore the polymer itself is intrinsically protected against attack and oxidation by the common water disinfectants and does not rely on the availability of additives regarding this aspect.



CPVC Molecule

Moreover, the CPVC material can operate 100% of the time at 140°F. In fact, multiple manufactures rate their CPVC systems up to 160°F continuous use in hot water recirculation systems.



The key to a suitable material selection is its ability to operate in the intended service for the life of the system. For this reason we must not only assess an offshore piping manufacturers "Fit for Use" statements. We must also ensure it is "Fit for USA" and our water chemistry.

ASTM Standards

ASTM F2023 is the Standard Test Method for Evaluating the Oxidative Resistance of Crosslinked Polyethylene (PEX) Tubing and Systems to Hot Chlorinated Water. This standard is also used for PP-R, PP-RCT and PE-RT. The standard utilizes 4.0 ppm chlorine, ORP 850mV, pH 6.8, 80psi, 73.4°F and 140°F. These parameters represent more or less a worst case scenario. However, this standard is intended to predict a time to failure. Accordingly, ASTM F2023 does not prove immunity to chlorine; in contrast, it predicts an extrapolated time-to-failure.

"Frequent or continuous exposure to water conditions beyond those used in ASTM Test Method F2023 (i.e., aggressive water quality, pressures or temperatures) may cause premature oxidation and eventual brittleness of the PEX material, reducing ability to meet long-term requirements." (Institute, 2017)

ASTM F876 contains actual performance requirements. Section 6.10: "PEX tubing indented for use in the transport of potable water shall have a minimum extrapolated time-to-failure of 50 years when tested in accordance with F2023.

Product listing includes a CLR/ Class rating 1, 3 or 5.

- **Class 1** - 25% of time at 140°F, 75% at 73.4°F
- **Class 3** - 50% of time at 140°F, 50% at 73.4°F
- **Class 5** - 100% of time at 140°F, 0% at 73.4°F

It should be noted that a CLR rating is an "extrapolated" time to failure, "not an actual" time to failure. These ratings define the percentage of time that the piping material may be exposed to hot water.

Currently there is no PP based pipe grade material – PP-RCT or other - on the market that exceeds a rating of CLR 3 - 50% of time at 140°F, 50% of time at 73.4°F.

Understanding that hot water systems operate more than 50% of the time, a rating less than CLR 5 means that the product should not be specified for use in potable hot water distribution systems treated with common US disinfection methods.

A material with CLR/ Class 3 rating does not lend itself to recirculating hot water systems.

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In Contrast, CPVC is not attacked by chlorine containing water disinfectants.

Disinfectant Trends

"Disinfectant use since 1978 indicates a general trend towards the use of alternative disinfectants (that is, chloramines, chlorine dioxide, ozone) to chlorine." (Carollo Engineers, 2008)

The AWWA has conducted a survey among Drinking Water Utilities. The primary objective of the survey is to compile information on key disinfection-related issues and practices at drinking water utilities, and to identify trends in disinfection among the survey group based on recent changes in legislation, costs, system effectiveness and other factors. The survey results below primarily compare results from four studies dating from 2007 back to 1978. The results of the last two surveys (1998 to 2007) show a departure from chlorine gas (70% down to 63%) and increases in all other disinfectants; most notable were sodium hypochlorite, Chloramines (11% up to 30%), Ozone (2% up to 9%), and Chlorine Dioxide (4.5% up to 8%). Included below is an extract from the 2007 survey report.

AWWA Disinfection Survey, Part 1 - October 2008

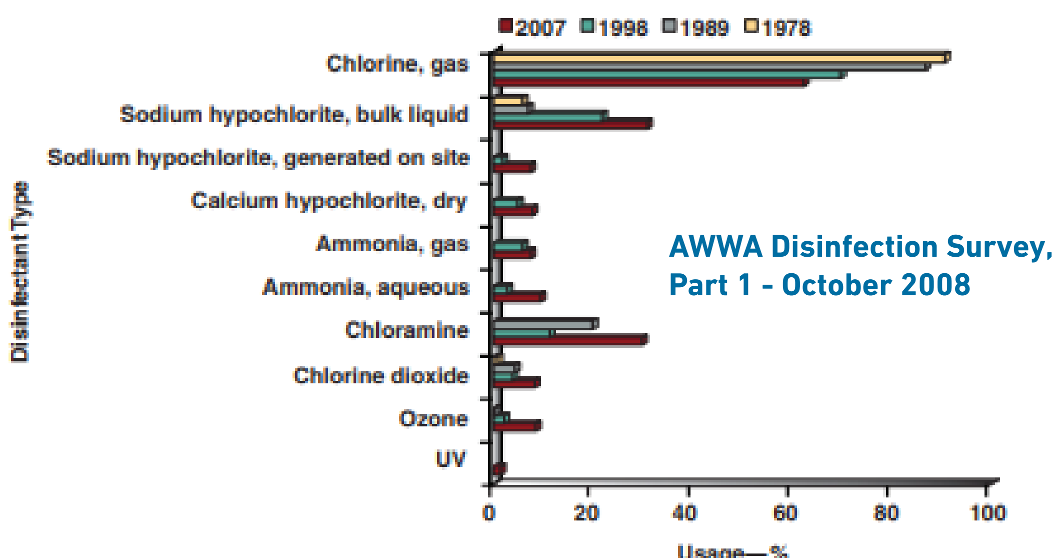
Now more than ever before, it's important for insurance companies, plumbing engineers, and contractors to make sure the specified piping products are compatible with existing disinfectants and disinfectants that may be utilized at some future point during the life of the piping system.

Conclusion

The impact of chlorine, chloramines, hypochlorous acid and other chlorine compounds on Polyolefin thermoplastics (PP, PP-R, PP-RCT) and CPVC were compared. The presence of chlorine in the water as a disinfectant, in the US, was highlighted and compared against European. In Europe, the residual disinfectant concentrations (ppm) in drinking water are much lower than in the USA. **Thus, the usage of polyolefin based piping systems does not pose the same risks in Europe as observed in the USA.**

The strong C-Cl polar bonds in CPVC, which increase the stability of this material against oxidation, encourages the use of this material for piping systems carrying chlorine treated water. Based on the survey and market research conducted thus far, it is evident that piping systems based on Polyolefin materials could finally reach a much shorter

FIGURE 4 Disinfectant use identified in the four committee surveys



UV—ultraviolet light

The 1978 and 1989 surveys included very few small systems (< 10,000 population) and did not poll types of sodium hypochlorite or ammonia. Sixty percent of those surveyed in 1998 were small systems; 32% of those surveyed in 2007 were small systems.

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service life than the CPVC piping systems in application with disinfected water.

In the USA, CPVC has proven to be an ideal and robust material for hot and cold potable water systems inside buildings.

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