Missouri Department of Natural Resources

Controlling Vinyl Chloride in Drinking Water Distribution Systems

Water Protection Program Technical Bulletin 6/2006

This technical bulletin is designed to inform public utilities about alternatives to controlling vinyl chloride originating from "early era" (pre-1977) PVC pipe in water distribution systems.

What's the problem?

Drinking water distribution systems containing "early-era" PVC pipe (manufactured prior to 1977) are at risk of vinyl chloride monomer leaching from the pipe into the drinking water in the water distribution system. The majority of the cases of excess vinyl chloride concentrations in drinking water distribution systems have been reported in Kansas, Missouri, Texas, and Arkansas (Mansur, 1999a), although the problem may be more widespread.

What is vinyl chloride?

Vinyl chloride is an odorless, colorless, volatile organic chemical (VOC). Vinyl chloride is used in the manufacture of numerous products and is used in many industries. Vinyl chloride is slightly soluble in water (Merck Index, 1996). Vinyl chloride can cause liver cancer in humans (Letterman, 1999).

What is the regulatory limit for vinyl chloride?

The maximum contaminant level (MCL) is set at 2.0 ìg/L (or 0.002 mg/L) (Letterman, 1999).

How does vinyl chloride get into a drinking water distribution system?

The primary route for vinyl chloride entering a water distribution system is by leaching from early-era PVC pipe.

Which systems or parts of systems are generally affected?

Due to relatively slow rates of leaching of vinyl chloride from PVC pipe, current data suggests that in system mains or dead-ends with "*adequate"* flow rates, vinyl chloride concentrations rarely exceed the regulatory limits. The problem of elevated vinyl chloride levels is generally limited to dead-end lines that have periods of non-use or very low flows.

What factors affect the vinyl chloride concentration in a dead-end segment of a drinking water distribution system?

Several factors can affect the concentration of vinyl chloride in the drinking water within a distribution system. First, only pipe manufactured prior to the mid-1970s have been reported to contain vinyl chloride at levels that can lead to problems within a distribution system. After this date, the manufacturing process was controlled to prevent excess levels of vinyl chloride within the pipe.

A second factor is the amount of vinyl chloride originally in a PVC pipe. The amount of vinyl chloride in early-era PVC pipe can vary widely and, therefore, the amount of vinyl chloride leach-

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ing into the distribution system will also vary from system to system. This initial level of vinyl chloride can be estimated by measuring the rate of increase of vinyl chloride concentration after flushing the segment of pipe in a rebound study.

A third-factor is the temperature of the water and pipe. Higher temperatures lead to higher diffusion rates of vinyl chloride within the PVC pipe, and hence from the pipe into the water. Thus, vinyl chloride may leach from a pipe at much higher rates during the summer months when water temperatures within the pipe are often much higher than in the winter months. This is a critical consideration in adjusting flush frequencies for seasonal temperature swings.

A fourth factor is pipe diameter. Specifically, excessive concentrations of vinyl chloride will tend to be more of a problem in smaller pipes than in larger pipes. This is because small pipes contain less water to dilute the vinyl chloride that leaches into them. More specifically, greater pipe surface area leads to a greater mass of vinyl chloride entering the water. Greater water volume within the pipe, however, leads to more dilution of the vinyl chloride and lower vinyl chloride concentrations overall. Therefore, the larger the surface area-to-volume ratio of a pipe, the greater the vinyl chloride concentration one would expect to find (with all other factors the same). Because smaller pipes have larger surface area-to-volume ratios, vinyl chloride leaching may be a greater problem.

A fifth factor is pipe age. Because there was a finite amount of vinyl chloride within the pipe, eventually most of the vinyl chloride will leach from it. However, calculations show that at the present time, only a small percentage of the vinyl chloride has leached from a typical pipe. Calculations show that for a typical pipe of age 25 versus 40 years, the time it would take to leach sufficient vinyl chloride to exceed the MCL might only vary by approximately 25 percent (with other factors the same).

Finally, the flowrate of water within the pipe is a critical factor controlling the concentration of vinyl chloride in the water. Vinyl chloride leaches from a PVC pipe at a fixed rate independent of the amount of water flowing through it. When there is a greater flow of water flowing through the pipe, the vinyl chloride is more diluted and the resulting vinyl chloride concentration reaching customers is lower. Thus, the amount of water used (or flushed) is directly related to the maximum vinyl chloride concentration that would be detected in the water.

What are the options for controlling vinyl chloride?

Several solutions to the problem of vinyl chloride contamination of drinking water via leaching from PVC pipes are available to water utilities. First, they may elect to simply replace the early-era pipe with new pipe that meets current ASTM standards. Sites such as Doniphan County RWD # 5, KS, have implemented this solution (McCool, 2000). The costs associated with pipe replacement may vary significantly between locations, depending on pipe depths, nearby roads and structures, proximity to other utility lines, geological conditions, and other factors.

A second potential solution involves utilizing point-of-use (POUs) treatment devices (at the consumer's tap). This approach, however, is problematic as it requires regular maintenance and relies on the consumer rather than the utility to maintain water safety (The rules require a public water system to do the maintenance of POUs if installed to comply with an MCL.)

A third, more practical approach is the development and implementation of an appropriate flush protocol. Such a protocol would specify criteria to determine when flushing of the lines is needed and what flush volume should be employed. Depending on a utility manager's specific constraints, either manual or automatic flushing through end-of-pipe flush valves could be implemented at relatively low cost.

How does a utility determine the water quantity and the frequency for flushing?

The following example demonstrates the procedures for determining answers to these questions.

Consider a 0.25-mile dead-end line in a rural water district containing early-era, 2.0-inch, Schedule 40 PVC pipe installed in the 1960s. In our example, monitoring has shown that the vinyl chloride concentrations periodically exceed the MCL. It has been decided to implement a flushing protocol to control the problem.

The utility recognizes that if the occupants leave for some extended period, flushing of the line will be necessary to purge accumulated vinyl chloride. The utility wants to determine, however, whether the line needs to be flushed on a regular basis and what flush volume to use.

Step 1 – Determination of initial vinyl chloride concentrations (C_0) - The utility manager has several choices as to how to determine (or assume) the initial vinyl chloride concentration within the pipe (C_0):

a) A conservative approach is to assume the pipe has a high concentration of excess vinyl chloride (e.g., 500 ppm)
b) Another approach is to assume a lower C_0 but monitor the resulting vinyl chloride concentrations closely to ensure a conservative enough value was selected.
c) A final approach is to have a rebound study conducted to estimate the actual C_{0-} for the specific section of pipe.

In our example, the utility manager had a rebound study conducted which resulted in an estimated C_0 of 250 ppm of vinyl chloride in the pipe.

Step 2 – Determination of maximum allowable leaching time (MALT) - Several pieces of information are required to determine the maximum allowable leaching time (MALT), that is, the estimated time required for the vinyl chloride concentration in the water to exceed a maximum allowable concentration (MAC). The following information is needed:

a) MAC (1 ppb is suggested)
b) water temperature, and
c) pipe diameter.

For our example, a MAC of 1 ppb, a water temperature of 50ºF, and a pipe diameter of 2.0 inches were determined or assumed. With this information, using Figure 1 the manager can determine the MALT. Specifically, in this example, if C_0 is 250 mg/L, the MALT is 1.8 days. (Note: We see from the figure that if the water temperature were greater or lesser, the MALT would be correspondingly shorter or longer, respectively. For example, if the temperature of the water and pipe increased to 70ºF in the summer, the maximum allowable leaching time (MALT) would decrease to just 1.0 days (Figure 1).

Step 3 – Determination of flush volume - Next the system manager determines the volume of the entire dead-end section that would be flushed using either:

a) $$\text{Pipe vol (gal)} = (\text{pipe length, ft}) \cdot \left(\frac{(\text{Pipe diameter, ft})^2 \cdot 3.14}{4}\right) \cdot 7.48 \frac{\text{gal}}{\text{ft}^3}$$

$$= (5280 / 4) \cdot (2 / 12)^2 \cdot 3.1415 \cdot 7.48 = 215 \text{ gallons}$$

or

b) the chart in Figure 2.

Step 4 – Determination of whether flushing is required

a) Stated simply, if less than the entire dead-end volume has been used during the maximum allowable leaching time (MALT), then the entire dead-end pipe should be flushed. (This is because the last slug of water in the pipe had time to exceed the maximum allowable vinyl chloride concentration.)

b) In many cases, it may be more convenient to think in terms of average flowrates rather than absolute volumes and times. To do this, we define the critical average flowrate (CAF) as:

$$\text{Critical average flowrate (CAF)} = \frac{\text{Deadend volume}}{\text{Maximum Allawable Leaching Time (MALT)}}$$

The criterion for flushing is if the average use rate in the dead-end line (over any period of time equal to the predetermined MALT) is less than the critical average flowrate (CAF), then the line should be flushed.

The Missouri Department of Natural Resources often assumes an average use rate of 200 gallons-per-day per dwelling (gpd) (or 6,000 gallons-per-month-per-dwelling). More accurate data is available, however, by looking at actual use rates by customers on a dead-end segment. Customers where an elderly person lives alone - the use rate can be 40-50 gallons per day or less. This makes for a good worst case situation.

In some cases, the daily water usage by a consumer will be more than adequate to control the vinyl chloride concentration within a pipe. A utility manager should, however, educate the consumer to the flushing issue so that if the customer leaves for a sufficient period of time (e.g., on vacation) to cause an unacceptable buildup of vinyl chloride, that the line may need to be flushed when the customer returns.

Implementation of flushing plan and monitoring of results

The purpose of the protocol just described is to serve as a guide for estimating the frequency and volume of flushes required to prevent vinyl chloride concentrations from exceeding allowable levels. Due to the uncertainty associated with the leaching model and the critical need to maintain vinyl chloride concentrations within regulatory limits, it is imperative that utility managers monitor the resulting vinyl chloride concentrations in an appropriate manner.

Where do I go for additional information including help with my system?

You can get additional information on managing vinyl chloride with water distribution systems by contacting:

Missouri Department of Natural Resources
Water Protection Program
P. O. Box 176
Jefferson City, MO 65102
1-800-361-4827 or (573)751-1300
(573) 751-1146 fax
www.dnr.mo.gov/env/wpp Program Home Page

OR

Prof. Craig D. Adams, P.E.
Univ. of Missouri-Rolla
202 Civil Engineering Bldg.
Rolla, MO 65401
(573) 341-4041
adams@umr.edu

References

The protocols described in this document were developed under a cooperative agreement between the University of Missouri-Rolla, and the Missouri Department of Natural Resources (Adams and Beardsley, 2000).

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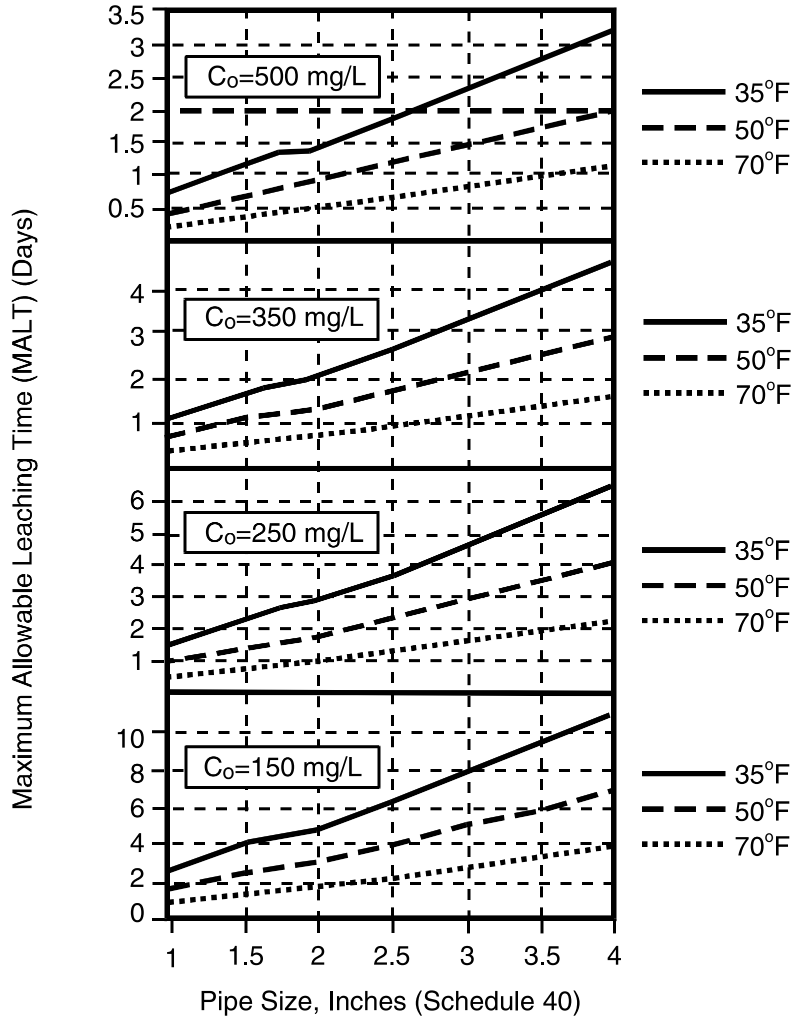

Figure 1. Chart for calculating the Maximum Allawable Leaching Time (MALT) to reach a Maximum Allowable Concentration (MAC) of 1 ?g.L for 25-year old Schedule 40 PVC pipe.

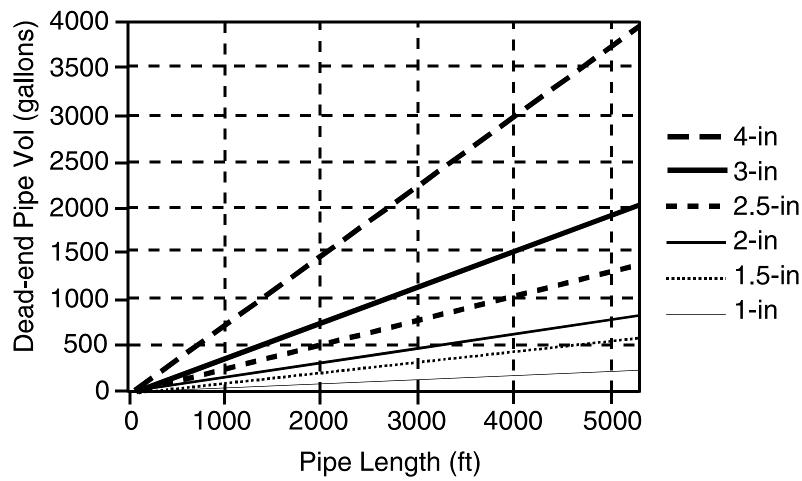

Figure 2. Chart for calculating the dead-end pipe volume for various pipe diameters and lengths.