Impact of Pipe Size and Contaminant Properties on Persistence of Organic Chemicals in Polyethylene Water Pipes

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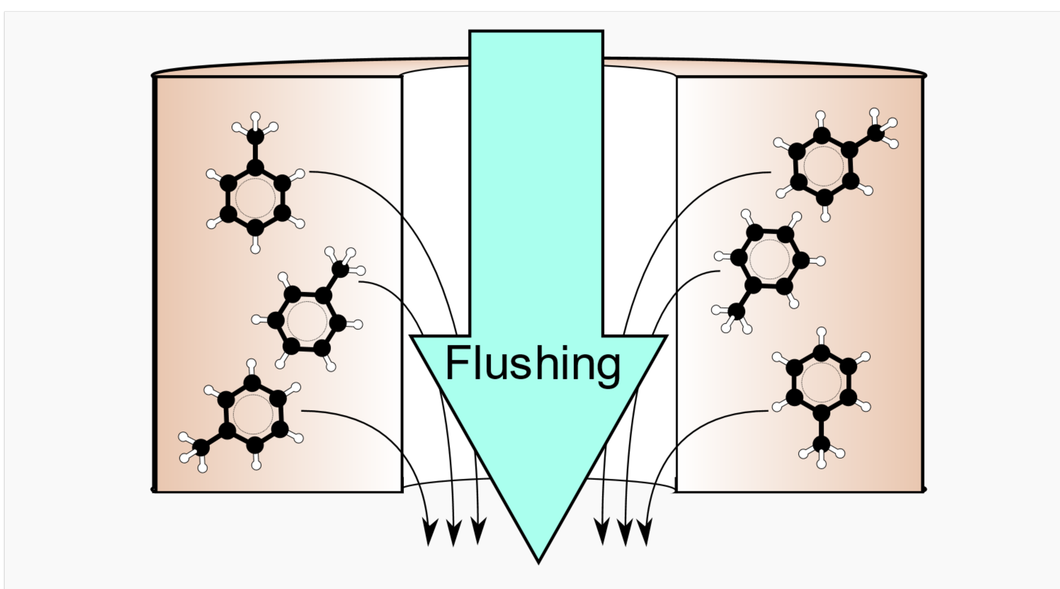
Introduction



Some polymers, such as polyethylene and polypropylene, are vulnerable to permeation by organic chemicals. Permeation can cause persistent, recurring contamination in water distribution systems. For example, benzene contamination following damage from wildfires in Paradise, California persisted in some high density polyethylene service lines for months after contaminated water was initially purged. However, the kinetics for sorption and desorption of organic contaminants resulting from such incidents is poorly understood.

In this work, we employ an experimentally calibrated, numerical method to estimate the effect of pipe dimensions and contaminant properties on the flushing time required to remediate contaminated polyethylene tubing. Results of our work suggest that, the effect of pipe diameter on decontamination kinetics is expected to be nonlinear and dependent on wall thickness and the partition coefficient between the contaminant and the pipe material.

Theory

Partial Differential Equations

1-D radial diffusion in pipe wall:

$$\frac{\partial C}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(rD\frac{\partial C}{\partial r}\right)$$

Boundary condition at inner surface of stagnant pipe:

$$\frac{\partial C_a}{\partial t} = 2D\frac{K_{p,w}}{r_a}\frac{\partial C_a}{\partial r}$$

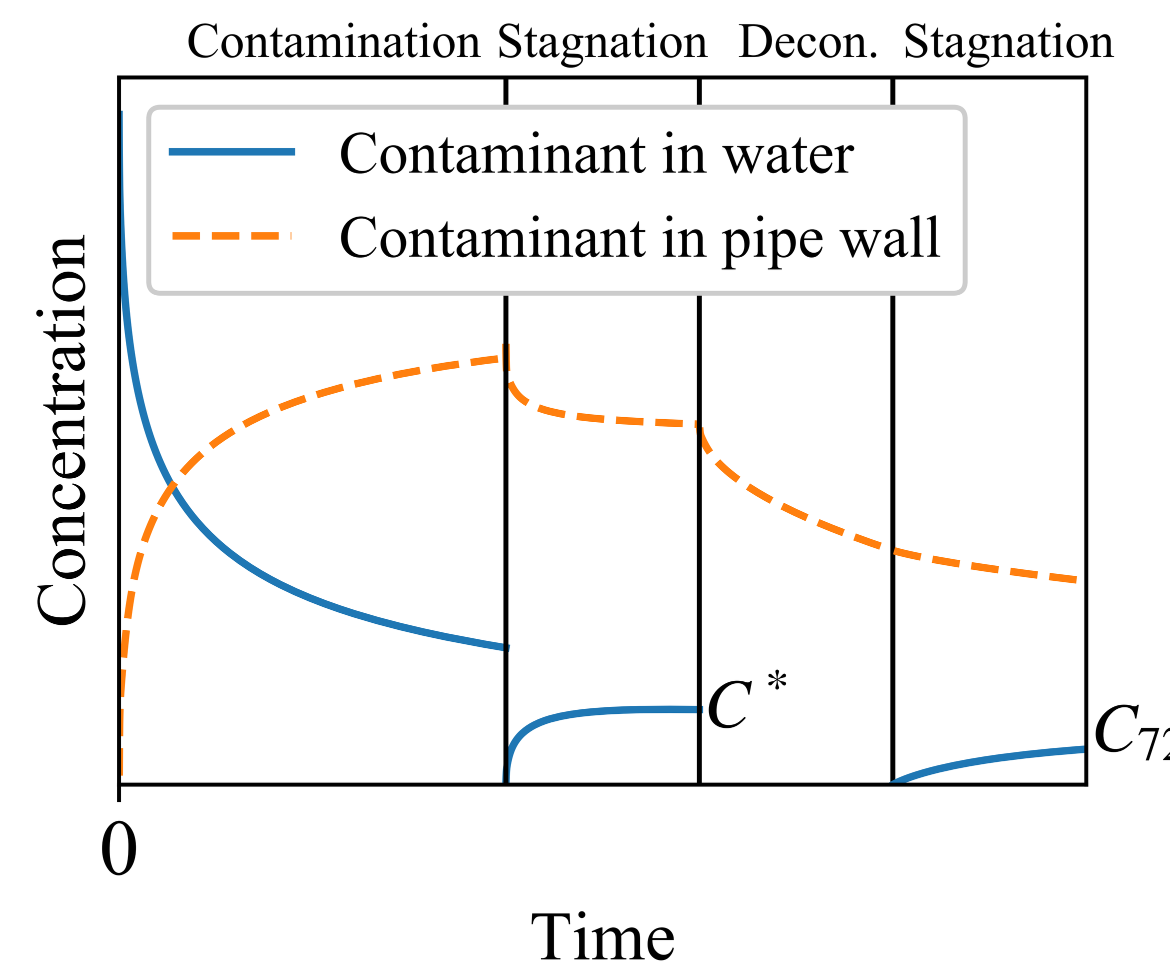
$K_{p,w}$ is the partition coefficient between pipe wall and water. These equations apply to rubbery polymers, such as polypropylene and high density polyethylene, but not to PVC in its glassy state.

Scenario Description

Water contaminated with a volatile compound enters a pipe and stagnates there for two weeks. During this time, contaminant migrates from the water into the pipe material. Contaminant molecules that reach the outer surface of the pipe escape immediately.

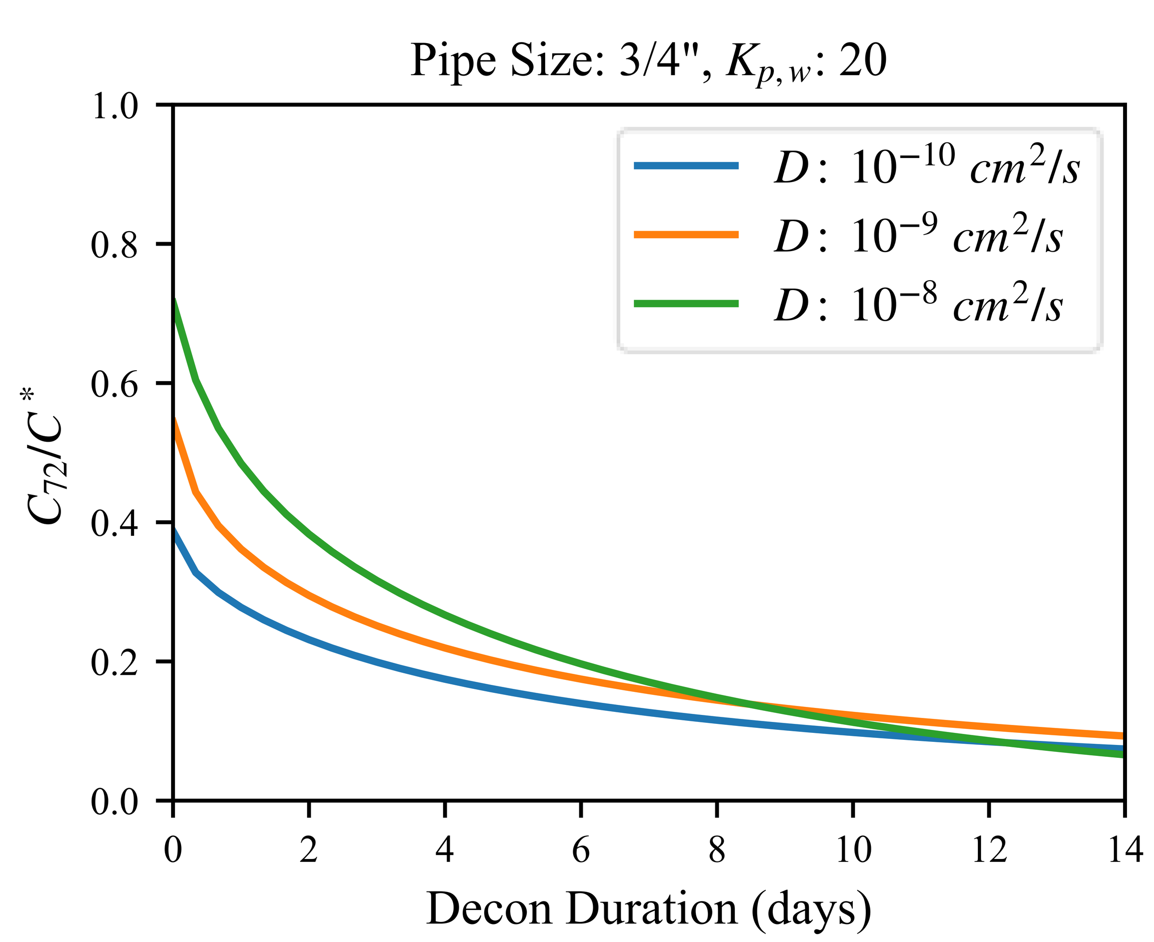
At the end of the two week period, contaminated water is flushed from the pipe. The fresh water is allowed to stagnate for three days. The water is then sampled and the contaminant is discovered at concentration C^*. Because contaminant migration through the polymer is the rate determining step for decontamination, continuous flushing is inefficient. Accordingly, the pipe is decontaminated by exchanging the water three time per day. The concentration in the water following a hypothetical three day stagnation, C_{72}, is used to assess decontamination success or failure. The value C_{72}/C^* is the relative reduction in three-day stagnant leaching concentration

Note: The decontamination scenario and assessment criteria here are presented for illustration purposes only.



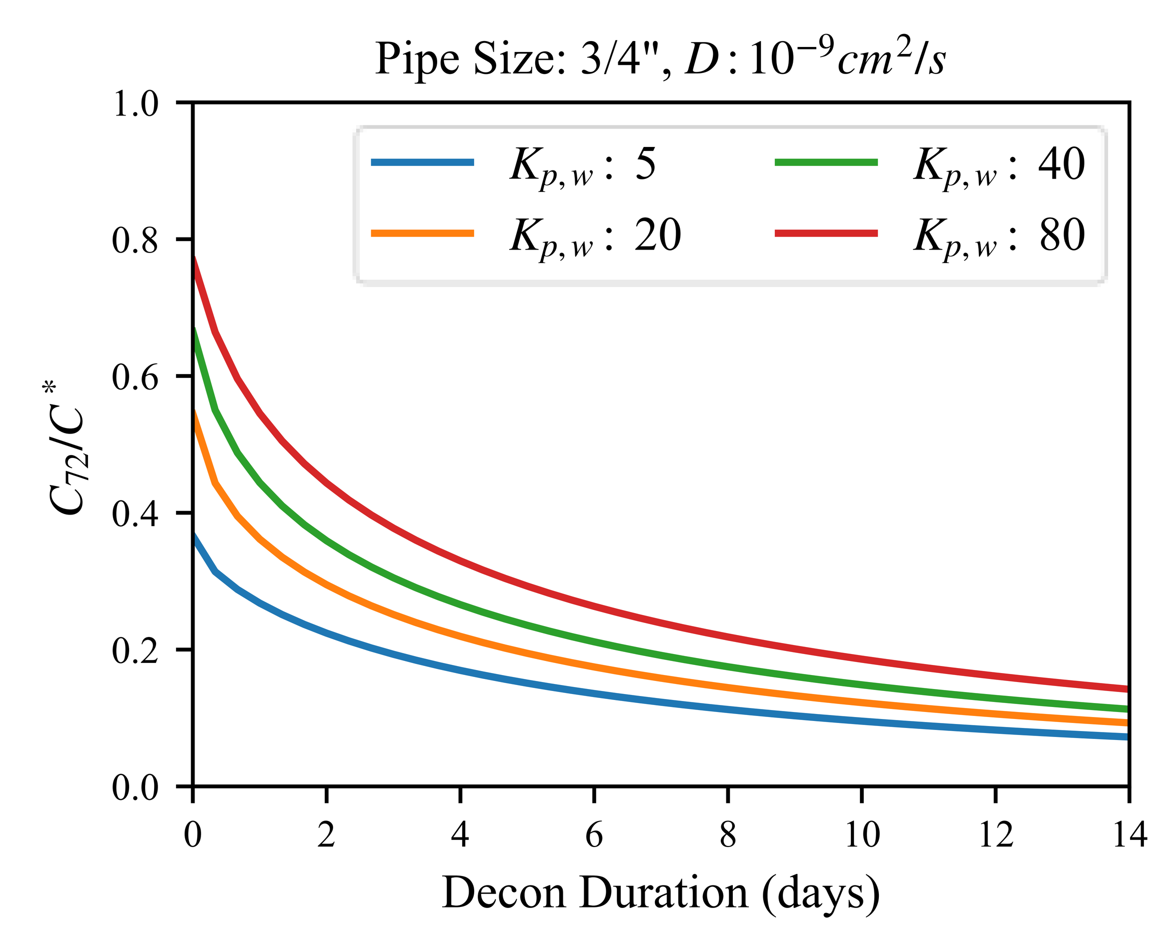
Diffusion

The diffusion coefficient, D, determines how quickly a contaminant can move through the pipe wall. Compounds with high D can cause significant contaminant sorption in a short period of time. However, these compounds also desorb from pipe walls more quickly. This combination of effects results in decontamination curves with different shapes.



Partitioning

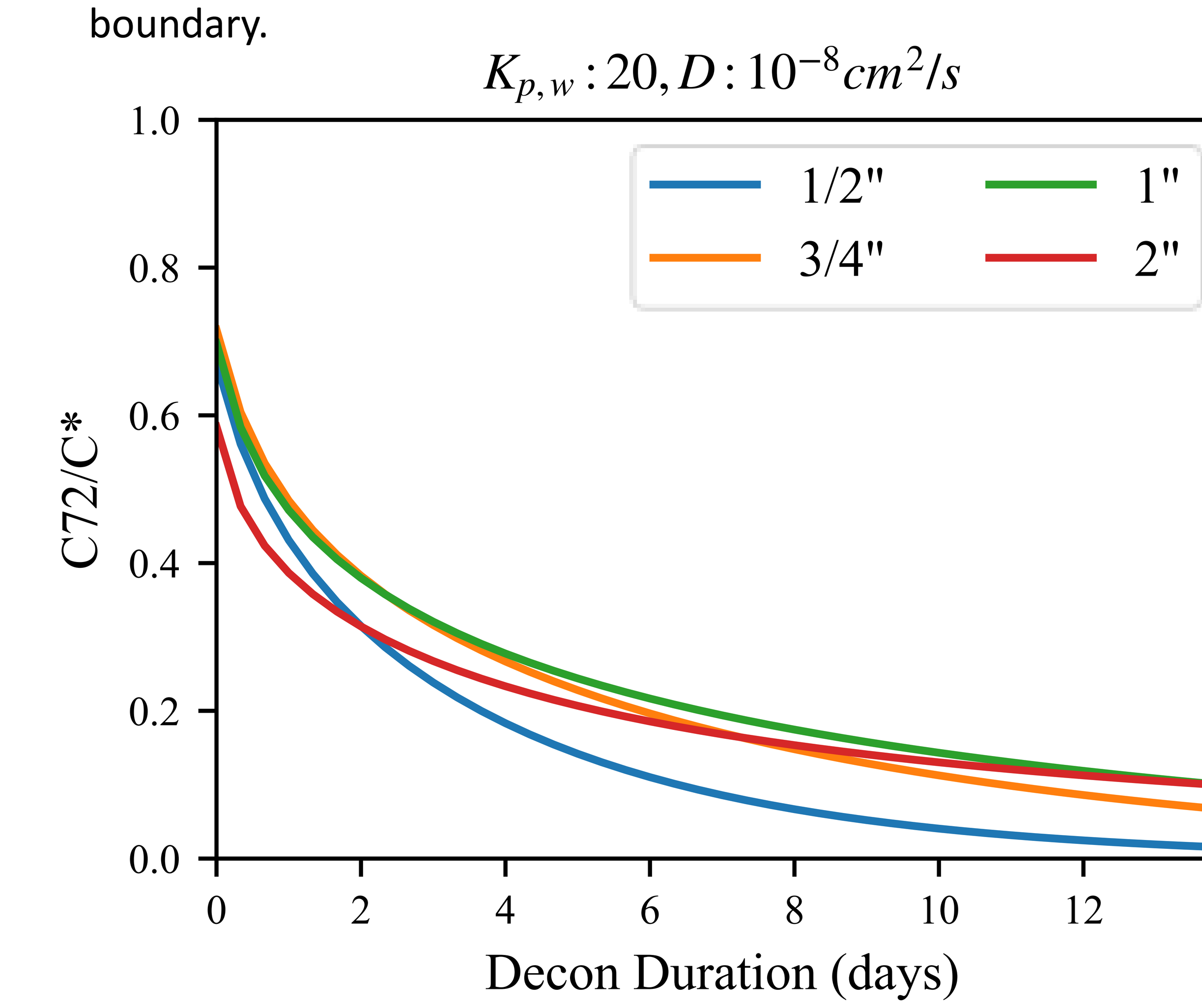
Compounds with high $K_{p,w}$ prefer pipe material to water. The higher $K_{p,w}$ is, the greater the proportion of contaminant that can sorb to the pipe during contamination. Conversely, high $K_{p,w}$ compounds desorb only a small fraction of their mass during stagnant desorption. Thus, high $K_{p,w}$ compounds can be resistant to decontamination by intermittent flushing.



Haupert, Levi M., and Matthew L. Magnuson. "Numerical Model for Decontamination of Organic Contaminants in Polyethylene Drinking Water Pipes in Premise Plumbing by Flushing." Journal of Environmental Engineering 145, no. 7 (2019): 04019034.

Pipe Size

Pipe dimensions change sorption and desorption behavior through specific surface area and pipe wall thickness. The thicker the pipe wall, the longer it takes for contaminants to travel from one side to the other. Thus, thicker-walled pipes tend to be more resistant to permeation from outside. However, thicker walled pipes also take longer to decontaminate because contaminants in the middle of the pipe wall take a long time to remove. Additionally, thin-walled pipes will likely experience a greater decontamination contribution from off gassing at the outer boundary.



Conclusions

General trends for sorption and desorption of organic chemicals from plastics under laboratory conditions are fairly straightforward to understand. However, the behavior of organic contaminants during field decontamination is complex and depends on the contaminant and pipe parameters in ways that can be surprising.

None of the cases examined predicted >99% reduction in three-day stagnant leaching concentration within a two-week decontamination period. Rapid response is desirable (although not always possible) for incidents involving organic contaminants and plastic pipes in order to reduce permeation severity.

The model predictions presented here are currently the subject on an ongoing experimental investigation.

Disclaimer