Sewer pipe repair technologies and the most popular sewer repair technology, cured-in-place-pipe (CIPP): Raw materials, the manufacture process, and defects

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Visit www.CIPPSafety.org for more information

March 16, 2020

Interactive Government Agency Discussion Meeting:
Sewer Vapor Intrusion and Sewer Repair

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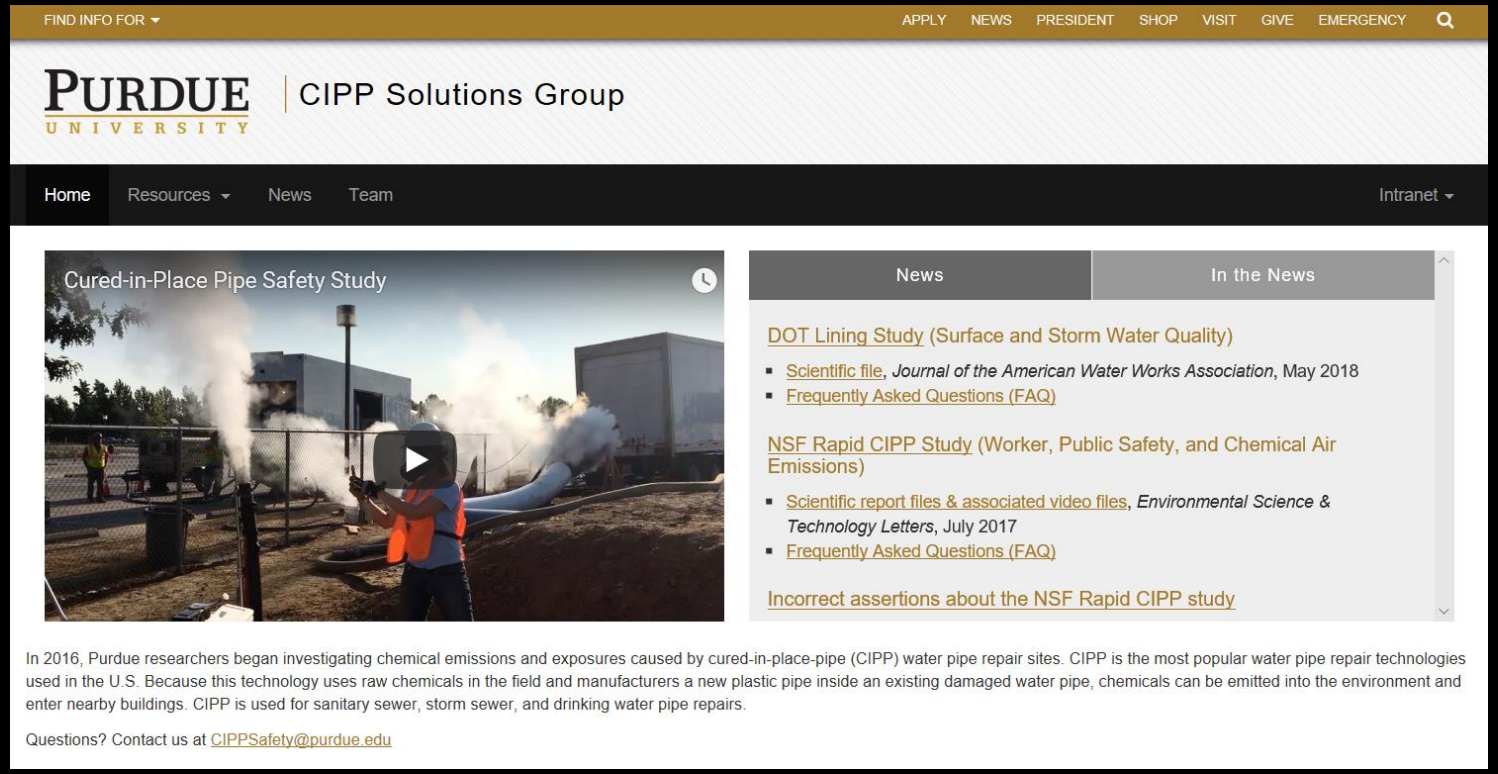
Learn More. Freely downloadable FAQs, videos, studies, & resources at *www.CIPPSafety.org*



Download free:

- 6 State Lining Report & Recommendations
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- FAQs
- Videos
- NIOSH 2019 report
- NEHA 2017 webinar
- ATSDR 2005 Report
- CDPH 2017 Safety Alerts
- And more...

Support provided by:

National Science Foundation RAPID grant CBET-1624183

Federal Highway Administration TP (3)339 Pooled Fund Study (VA, CA, KS, OH, NC, NY)

Public donations through crowd funding

Purdue University Lyles School of Civil Engineering

NIOSH-University of Illinois at Chicago Center

National Institute of Environmental Health Sciences (NIH NIEHS)

Miles and miles of repairs needed

Public drinking water pipes	0.97 million
Public sewer pipes	0.8 million
Private drinking water pipes	> 6 million
Private sewer lateral pipes	0.5 million

40%+ need to be repaired or replaced

Stormwater culverts and repairs in the U.S.

12 million+ linear feet of culvert in place (FHWA 2005)

1 million+ existing culverts require rehabilitation (FHWA 2010)

Mechanical failures can be catastrophic (traffic disruption, public safety)

The Way things Used to Be…

Damaged Pipe? Dig it up and Replace

Water outages

Traffic disruptions

Closed roads

Safety issues

Trenchless Technology

Disruptive Innovation

"Methods by which underground utilities may be installed without damage to overlying pavement, if proper precautions are observed"

Instead of replacing the damaged pipes, often trenchless rehabilitation approaches are applied

Trenchless Technology Options

Slip lining

Spiral wound pipe

Close fit pipe

Thermoformed pipe

Fold-and-form pipe

Spray-on coating (mortar vs. polymer)

Cured-in-place-pipe (CIPP)

50% of all water pipes

Potential Challenges for Some Options

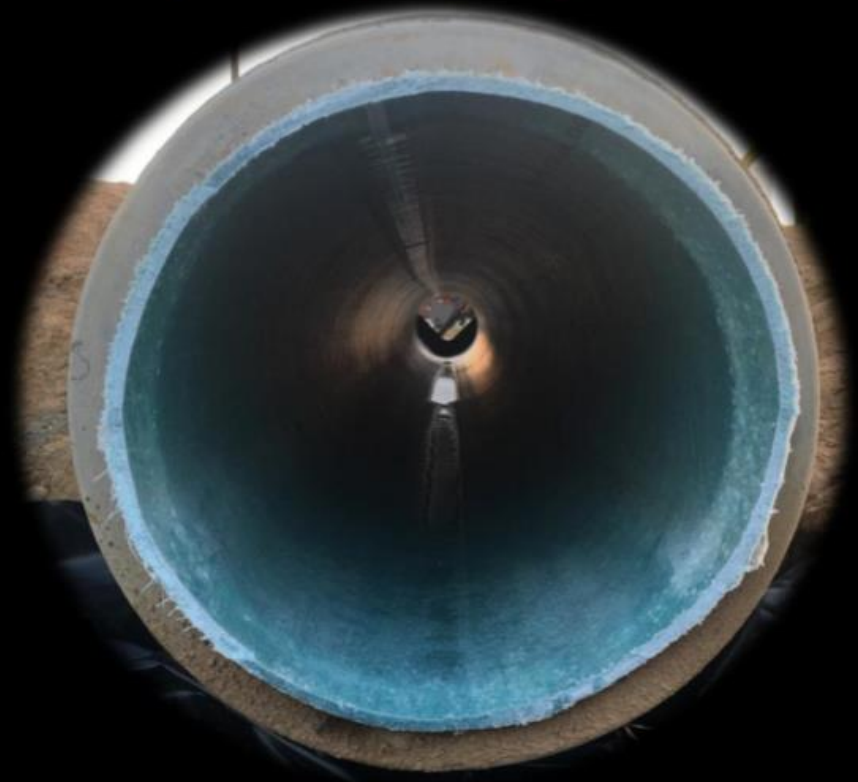
- Water flow diversion
- Grouting necessary
- Reduction in cross-sectional area
- Structural integrity not improved
- Host pipe must be dry
- Cost

Today, Transportation Agencies and Municipalities are Choosing to Install Cured-in-Place-Pipes (CIPP)

Resin impregnated tube hardened inside a broken pipe

Curing methods: Hot water, Steam, UV light

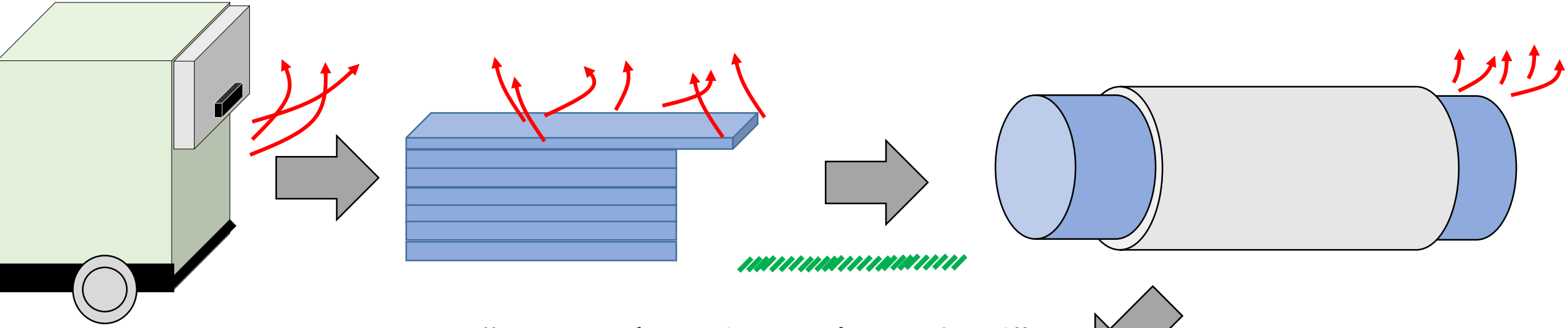
Deliberate curing time: Hours to many days



Uncured **RESIN** tube delivered on a truck

Uncured **RESIN** tube inserted into damaged pipe (raw chemicals)

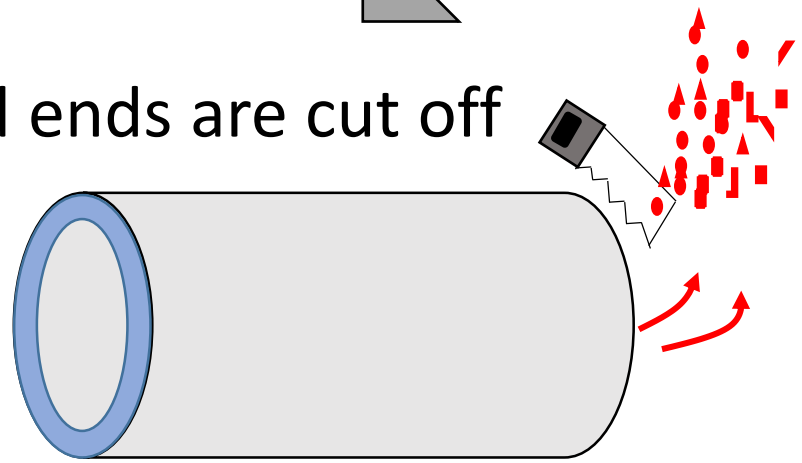
Uncured **RESIN** tube inflated with air inside host pipe



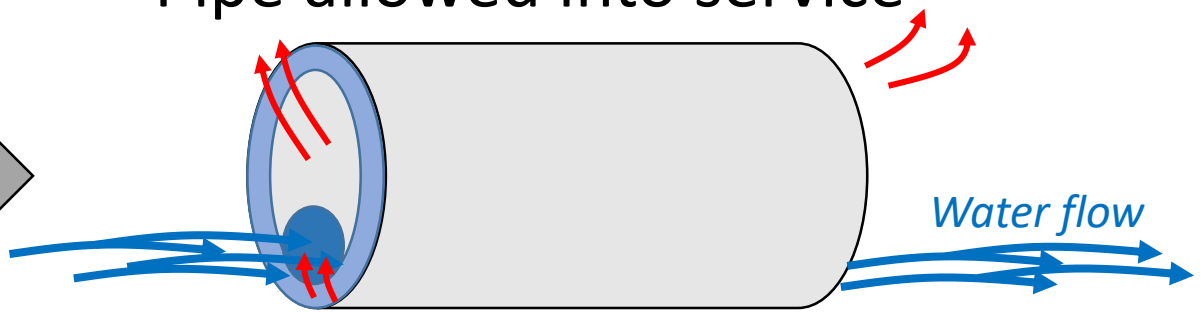
"Curing (Hardening) Method"

Hot Water or Steam or UV Light

Hard ends are cut off



Pipe allowed into service



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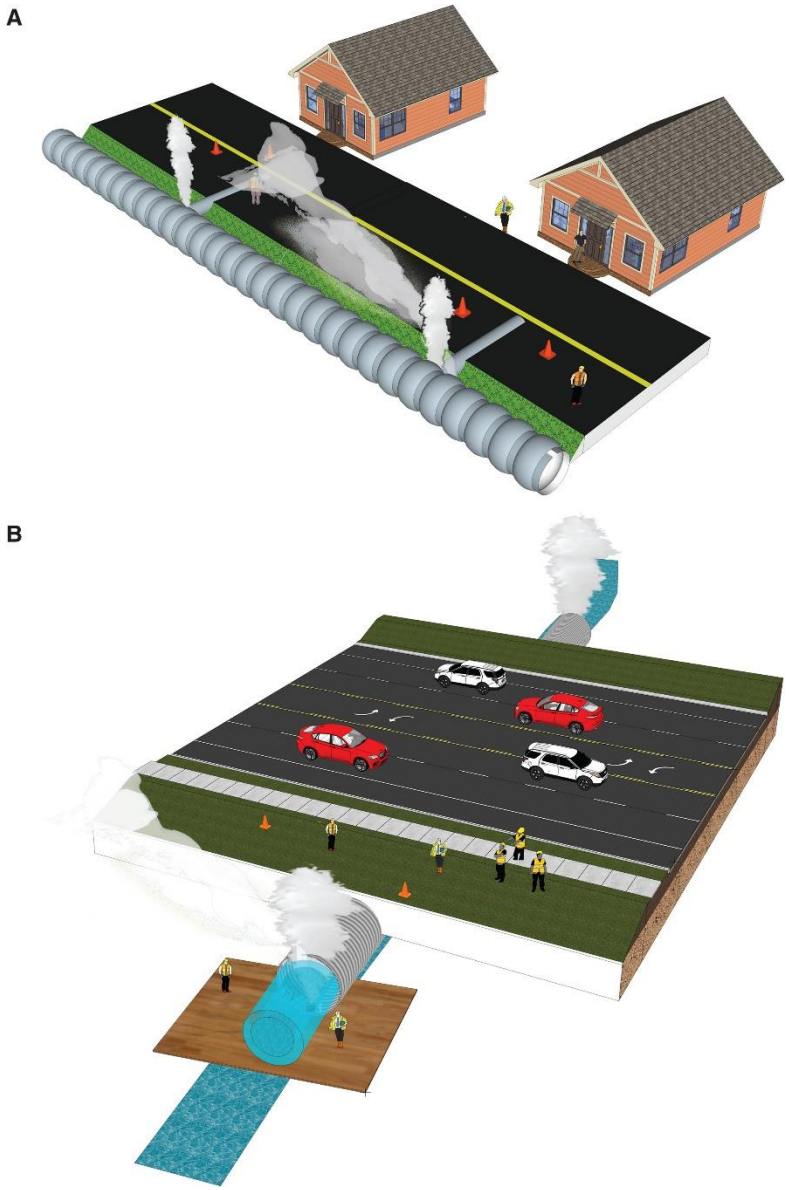


Sanitary Sewer

Storm Sewer

Ra et al. (2018) Critical Review: Surface Water & Stormwater Quality Impacts of Cured-In-Place-Pipe Repairs. *J. Am. Water Works Assoc.* OPEN ACCESS. https://doi.org/10.1002/awwa.1042

Resin Types

- **Polyester (est. most popular)**
- **Vinyl ester (est. > cost of polyester)**
- **Epoxy (est. >> cost of polyester)**

People also say “Styrene resin” vs. “Non-styrene based” resin

Resin + Solvents + Fillers + Catalysts + Initiators are added to create an uncured resin tube

Method to insert uncured resin tubes

- **Air inversion**
- **Water inversion**
- **Pull in place**

Sometimes resin may leave the tube and flow into cracks and sewer laterals. May not cure.

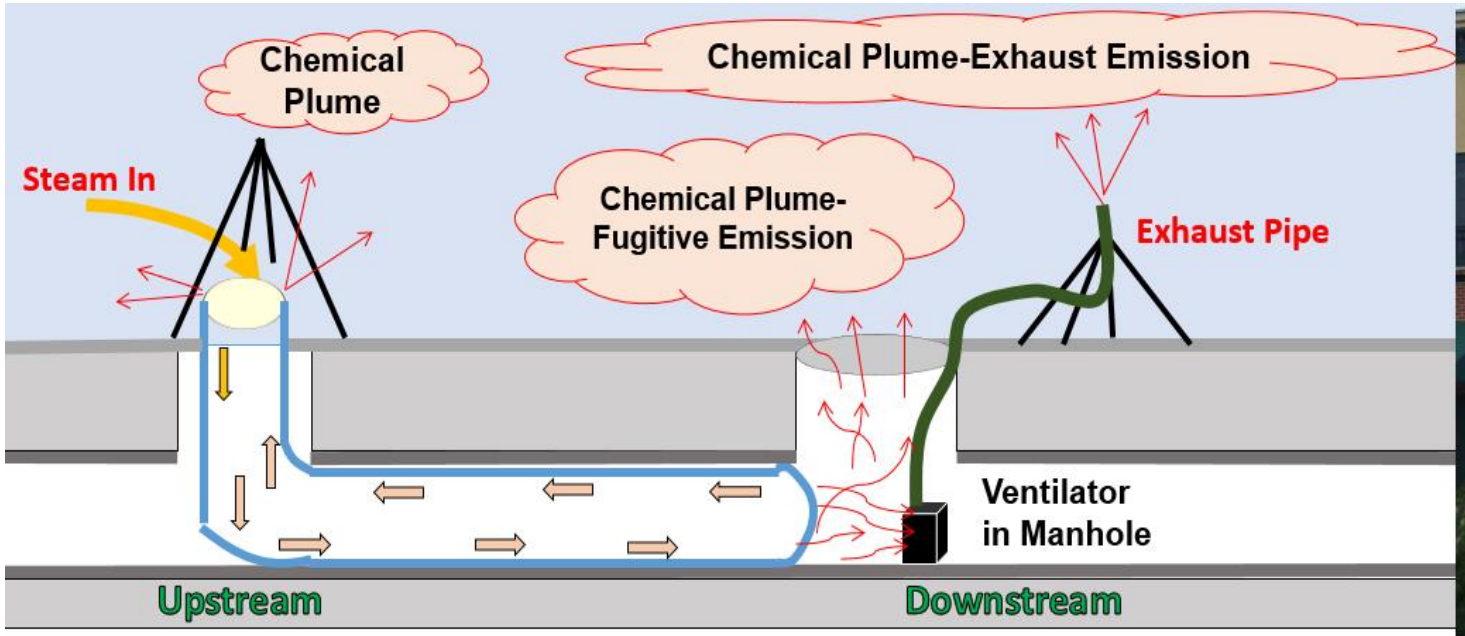
Tubes sometimes have a plastic coating. Plastic “preliners” sometimes used.

Method to polymerize resin

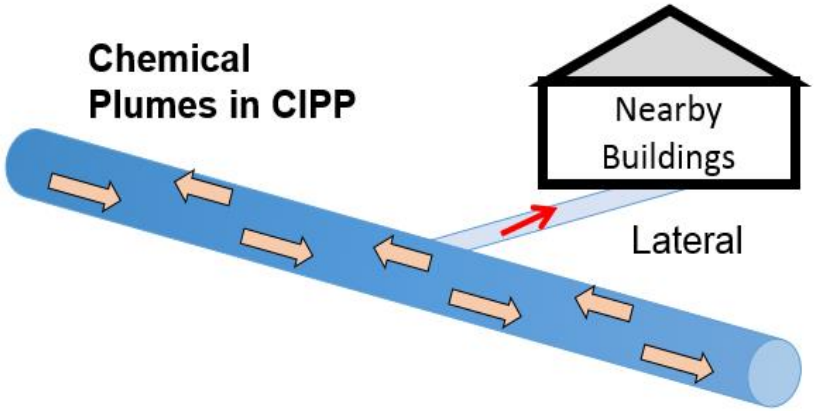
- **Thermal – Steam injection (most popular)**
- **Thermal – Hot water recirculation**
- **UV – Light exposure (est. most growth)**

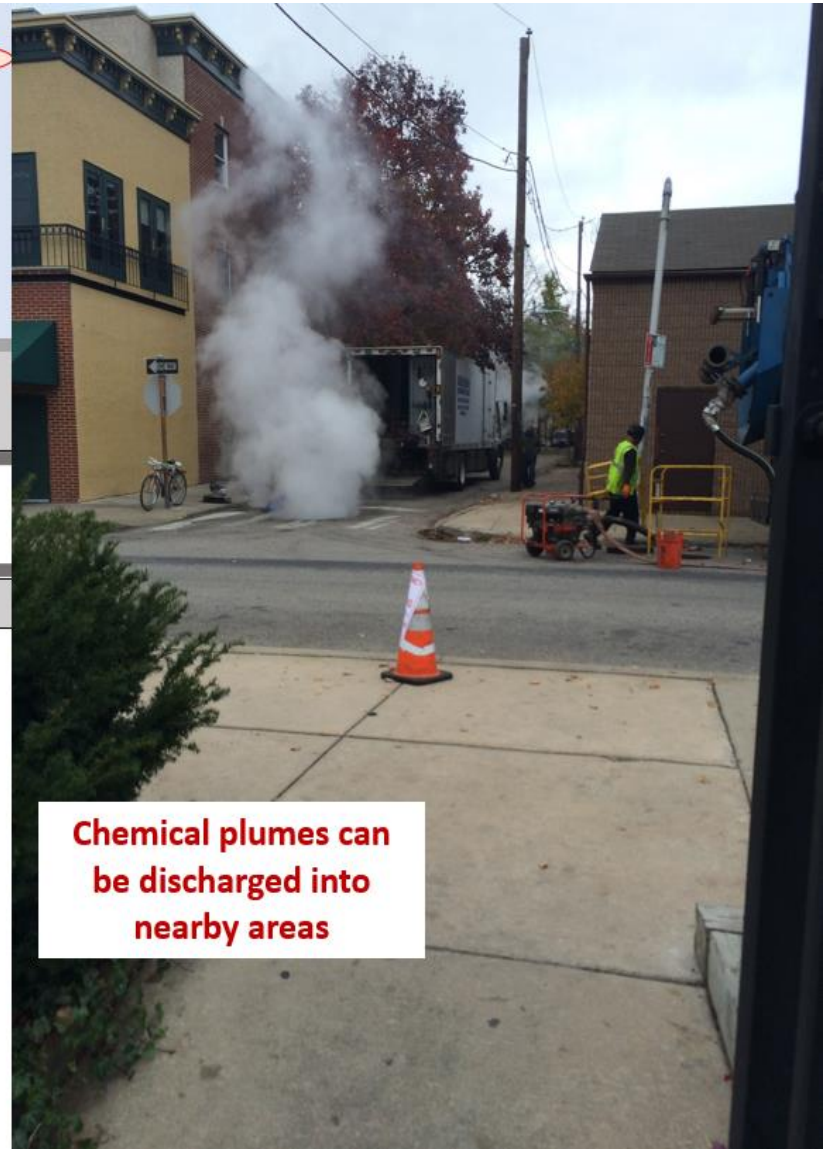
Cooldown method

- **Forced hot air**
- **Forced ambient air**
- **Recirculated water**



Chemical Plumes Generated by CIPP can Escape the Pipe Being Repaired





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RESOURCES ➔ ONLINE EDUCATION

https://engineering.purdue.edu/CIPPSafety/resources/cipp-plastics-ed

Online Plastics & CIPP Education

Basics of Plastics

- *Plastics*. Websters Dictionary definition: (noun) "Any of numerous organicsynthetic or processsed materials that are mostly thermoplastic or thermosetting polymers of high molecular weight and that can be made into objects, films, or filaments"
- What plastics are used for sewer repair? [PDF]
- What ingredients are used for plastic polymerization [PDF]
- Additives impact physical properties [Video.mp4]
- What is polymerization? [PDF]
- How do thermoplastic vs. thermoset plastics differ? [Video.mp4]
- Created plastics are not pure [PDF]
- Plastics can be damaged by chemical or physical forces during manufacture or use [PDF]

The CIPP Manufacturing Process

- The overall CIPP manufacturing process [PDF]
- Raw materials: some examples of resin, initiators, filler, reinforcements [PDF] – Video of resin [Video.mp4]
- The resin safety data sheets (SDS) do not list all the chemicals present in the resin, created during CIPP manufacture, or in the waste [PDF]
- Inserting the uncured resin tube into the buried pipe [Video.mp4]
- Inserting the uncured resin tube into the buried pipe in Arkansas. Notice the materials being sprayed around the workers [Image]
- When steam is inserted thermal curing takes place and emissions occur [Video.mp4]
- Some chemicals are created onsite, are released into air and the environment and remain inside new CIPPs [PDF]

Waste is Created During CIPP Manufacture and It's Forms and Composition are Varied

- *Waste*. Websters Dictionary definition: (noun) "an unwanted byproduct of a manufacturing process"
- Uncured resin tube on the sidewalk, not exposed to steam but chemical reactions and waste is being emitted [Video.mp4]
- Waste is discharged into the air sometimes in neighborhoods [PDF] – video of exhaust waste [Video.mp4]
- Waste is discharged into the air in Sacramento, CA during thermal CIPP manufacture and Purdue worker protects themselves with a full-face piece respirator [Video.mp4]
- Waste is discharged into the environment in New York City, NY after UV CIPP manufacture [Video.mp4]
- Liquid and vapor waste can be released through the exterior of the CIPP during after manufacture [Video.mp4]
- After active curing of the new CIPP, the ends are mechanically cut off. Particulates can be released into the environment [Video.mp4]
- During CIPP cutting, solids are discharged into the air and environment [Video.mp4] – These CIPP cutting solids have high amounts of leachable chemicals [PDF]

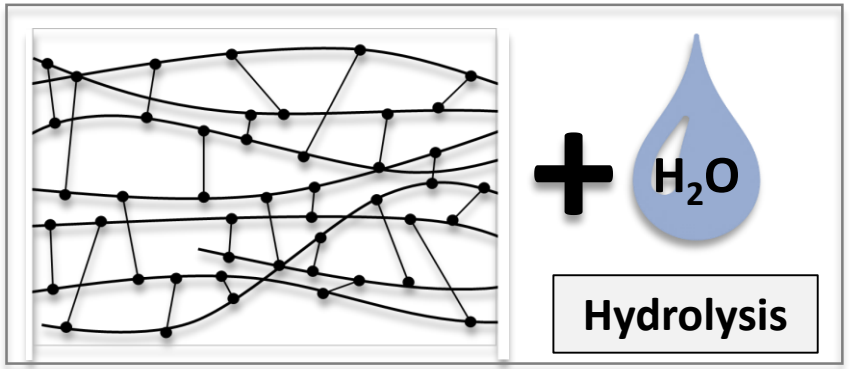
After lunch, you'll learn about what makes plastics plastics, and CIPP topics

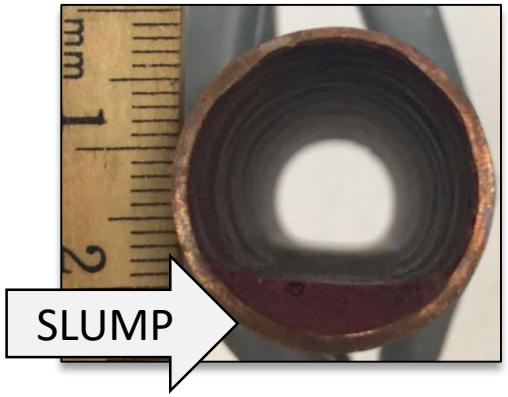
Chemicals Can Enter Nearby Buildings and Public Spaces

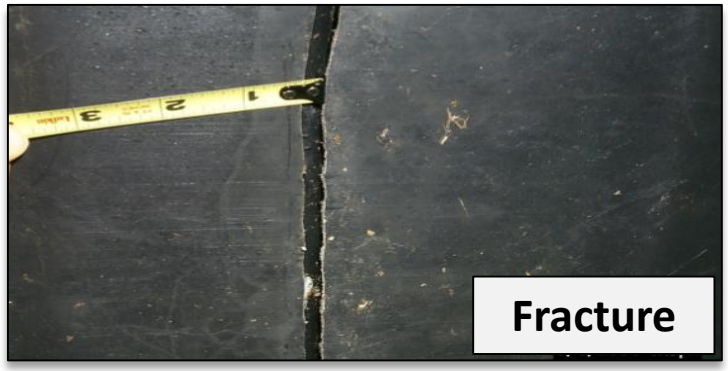
- It's common that CIPP contractors blow their waste into the environment, and do not capture it [City of West Plains, Missouri Video] [City of Wentzville, Missouri Video]
- There are multiple pathways where CIPP waste can enter buildings and public spaces [PDF]
- Waste, also sometimes called chemical emissions, can travel above ground, far away from the waste discharge location due to environmental conditions [Video.mp4]
- Pouring water into sink and toilet drains does not prevent the high pressure CIPP waste from entering buildings [PDF]
- This video shows how even low pressure can displace water in plumbing traps and cause that water to "blowback" [Video.mp4]

Human Health and Environmental Impacts can Occur

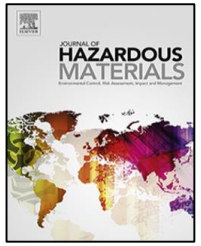
- 4-gas meters are not effective for monitoring CIPP waste discharge. Calibrated and handheld photoionization detectors (PIDs) [sometimes called organic vapor monitoring] can indicate something is changing, but at CIPP worksites the concentrations they report for styrene levels can be off by a factor of 10x to 1000x than the actual styrene air concentrations [Video.mp4]
- CIPP chemical waste exposure incidents: Worksites, schools, homes, office buildings, medical centers [PDF]
- List of the growing number of human health and environmental impact incidents associated with CIPP waste [Link to List]
- Typically reported symptoms assocaited with CIPP waste exposure incidents [PDF]
- 2019 NIOSH CIPP health hazard evaluation for one UV CIPP contractor [report download here]
- 2017 CIPP worker fatality and OSHA penalty citation, Streamwood, Illinois [report download here]







Defects & Damage



2020

Considerations for emission monitoring and liner analysis of thermally manufactured sewer cured-in-place-pipes (CIPP)

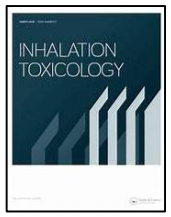
https://doi.org/10.1016/j.jhazmat.2019.02.097

Here Are Some CIPP Studies we Frequently Receive Requests For

2019

Outdoor manufacture of UV-Cured plastic linings for storm water culvert repair: Chemical emissions and residual☆

https://doi.org/10.1016/j.envpol.2018.10.080

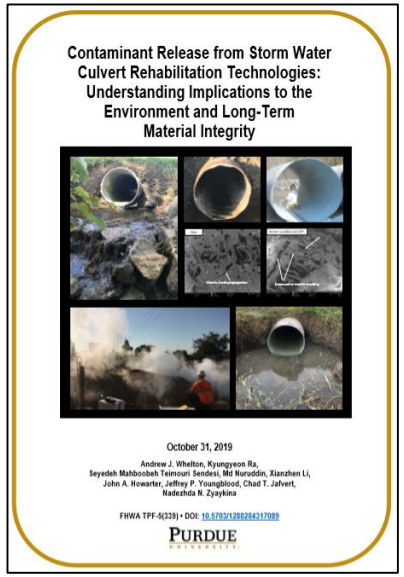


2019

***In vitro* toxicity assessment of emitted materials collected during the manufacture of water pipe plastic linings**

https://doi.org/10.1080/08958378.2019.1621966

FHWA Report, 2019



https://doi.org/10.5703/1288284317089

2019

NIOSH

Evaluation of Exposures to Styrene During Ultraviolet Cured-in-place Pipe Installation

[This is a NIOSH publication, not Purdue. Contact Dr. Ryan LeBouf, igu6@cdc.gov.]

2018

Journal

Critical Review: Surface Water and Stormwater Quality Impacts of Cured-In-Place Pipe Repairs

https://doi.org/10.1002/awwa.1042

2017

Environmental Science & Technology Letters

Worksite Chemical Air Emissions and Worker Exposure during Sanitary Sewer and Stormwater Pipe Rehabilitation Using Cured-in-Place-Pipe (CIPP)

https://doi.org/10.1021/acs.estlett.7b00237

FREE Available at www.CIPPSafety.org MORE STUDY REPORTS COMING…..

Sewer pipe repair technologies and the most popular sewer repair technology, cured-in-place-pipe (CIPP): Raw materials, the manufacture process, and defects

Let's Discuss:

What questions do You Have?

What are your thoughts?

Is there anything you think we and others would benefit from knowing?

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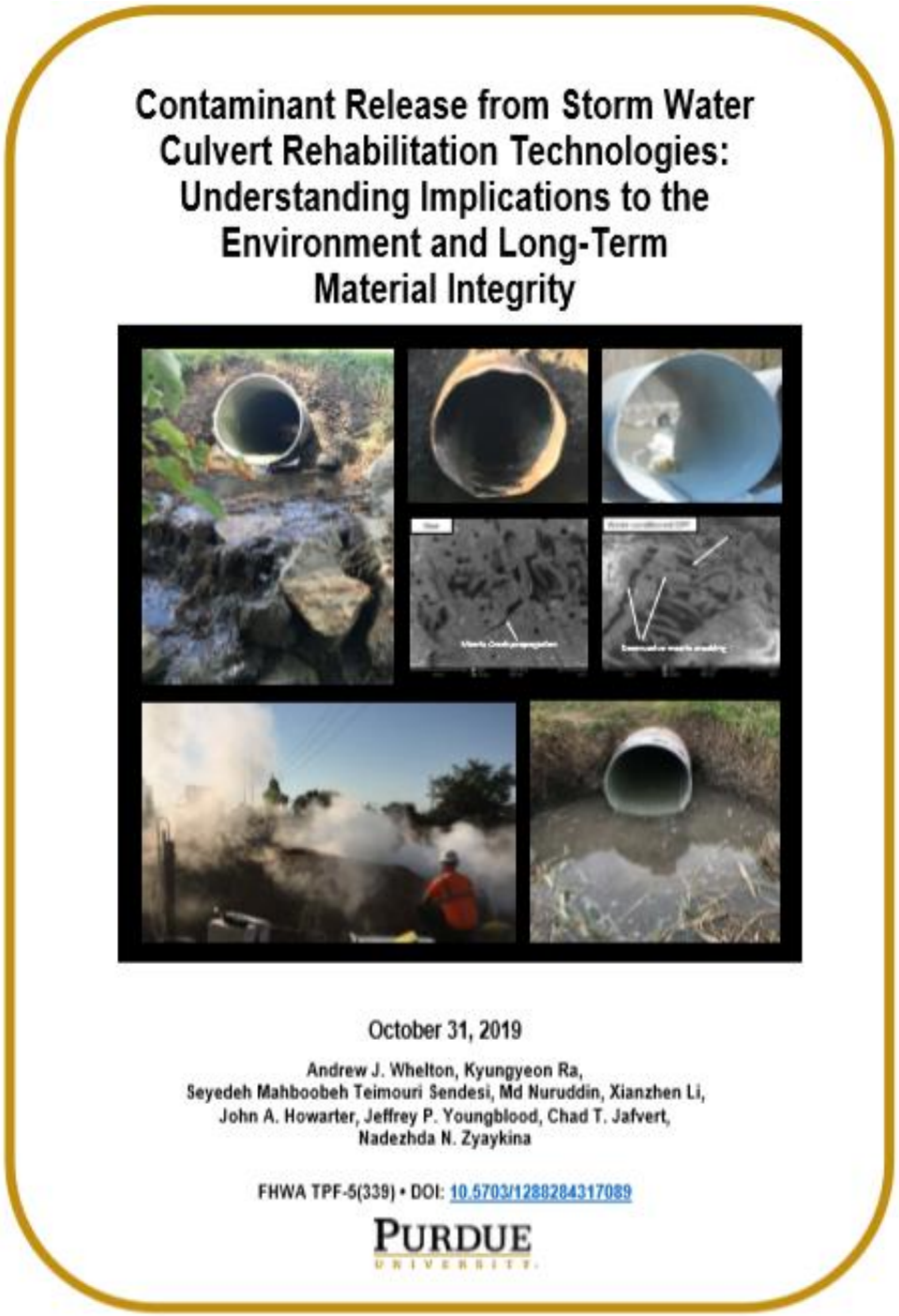


NEW: FREE "6 STATE LINING STUDY" REPORT

1. Go to the Purdue Libraries website and click on the "JTRP Program Affiliated Reports: https://docs.lib.purdue.edu/jtrpaffdocs/

2. Now click on the report title: Contaminant Release from Storm Water Culvert Rehabilitation Technologies: Understanding Implications to the Environment and Long-Term Material Integrity,

REPORT OUTLINE

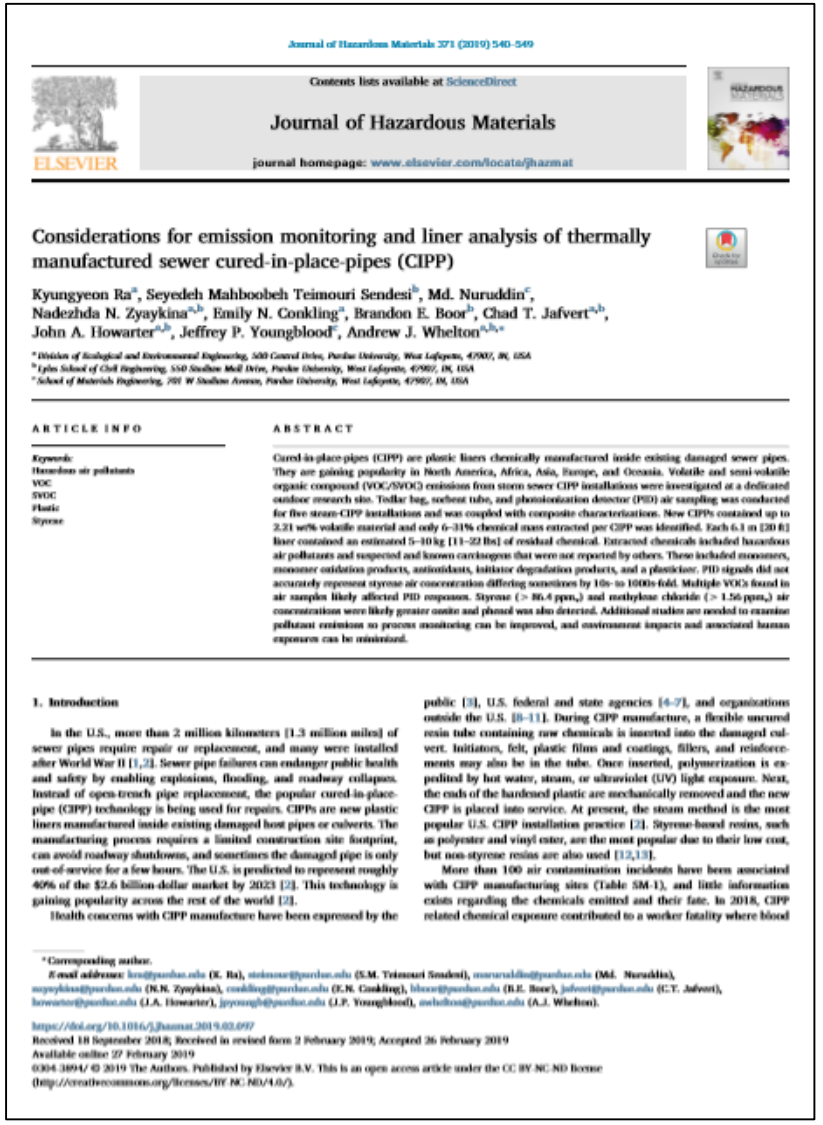
Executive Summary
Section 1. Project goal & objectives
Section 2. Spray-on lining: Incidents & agency construction spec survey
Section 3. CIPP lining: Incidents & agency construction spec survey
Section 4. CIPP lining: Water quality impacts in multiple states
Section 5. Laboratory aging tests for CIPP
Section 6. CIPP safety observations and recommendations
Section 7. Construction spec recommendations
7.1 Spray-on lining
7.2 CIPP lining

2020

Considerations for emission monitoring and liner analysis of thermally manufactured sewer cured-in-place-pipes (CIPP)

https://doi.org/10.1016/j.jhazmat.2019.02.097

Cured-in-place-pipes (CIPP) are plastic liners chemically manufactured inside existing damaged sewer pipes. They are gaining popularity in North America, Africa, Asia, Europe, and Oceania. Volatile and semi-volatile organic compound (VOC/SVOC) emissions from storm sewer CIPP installations were investigated at a dedicated outdoor research site. Tedlar bag, sorbent tube, and photoionization detector (PID) air sampling was conducted for five steam-CIPP installations and was coupled with composite characterizations. New CIPPs contained up to 2.21wt% volatile material and only 6–31% chemical mass extracted per CIPP was identified. Each 6.1m [20ft] liner contained an estimated 5–10kg [11–22lbs] of residual chemical. Extracted chemicals included hazardous air pollutants and suspected and known carcinogens that were not reported by others. These included monomers, monomer oxidation products, antioxidants, initiator degradation products, and a plasticizer. PID signals did not accurately represent styrene air concentration differred sometimes by10s-to1000s-fold. Multiple VOCs found in air samples likely affected PID responses. Styrene (>86.4ppmv) and methylene chloride (>1.56ppmv) air concentrations were likely greater onsite and phenol was also detected. Additional studies are needed to examine pollutant emissions so process monitoring can be improved, and environment impacts and associated human exposures can be minimized.



Journal of Hazardous Materials 371 (2019) 540–549

Contents lists available at ScienceDirect

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Considerations for emission monitoring and liner analysis of thermally manufactured sewer cured-in-place-pipes (CIPP)

Kyungyeon Ra[a], Seyedeh Mahboobeh Teimouri Sendesi[b], Md. Nuruddin[c], Nadezhda N. Zyaykina[a,b], Emily N. Conkling[a], Brandon E. Boor[b], Chad T. Jafvert[a,b], John A. Howarter[a,b], Jeffrey P. Youngblood[c], Andrew J. Whelton[a,b,*]

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ABSTRACT

Cured-in-place-pipes (CIPP) are plastic liners chemically manufactured inside existing damaged sewer pipes. They are gaining popularity in North America, Africa, Asia, Europe, and Oceania. Volatile and semi-volatile organic compound (VOC/SVOC) emissions from storm sewer CIPP installations were investigated at a dedicated outdoor research site. Tedlar bag, sorbent tube, and photoionization detector (PID) air sampling was conducted for five steam-CIPP installations and was coupled with composite characterizations. New CIPPs contained up to 2.21 wt% volatile material and only 6–31% chemical mass extracted per CIPP was identified. Each 6.1 m [20 ft] liner contained an estimated 5–10 kg [11–22 lbs] of residual chemical. Extracted chemicals included hazardous air pollutants and suspected and known carcinogens that were not reported by others. These included monomers, monomer oxidation products, antioxidants, initiator degradation products, and a plasticizer. PID signals did not accurately represent styrene air concentration differing sometimes by 10s- to 1000s-fold. Multiple VOCs found in air samples likely affected PID responses. Styrene (> 86.4 ppmv) and methylene chloride (> 1.56 ppmv) air concentrations were likely greater onsite and phenol was also detected. Additional studies are needed to examine pollutant emissions so process monitoring can be improved, and environment impacts and associated human exposures can be minimized.

1. Introduction

In the U.S., more than 2 million kilometers [1.3 million miles] of sewer pipes require repair or replacement, and many were installed after World War II [1,2]. Sewer pipe failures can endanger public health and safety by enabling explosions, flooding, and roadway collapses. Instead of open-trench pipe replacement, the popular cured-in-place-pipe (CIPP) technology is being used for repairs. CIPPs are new plastic liners manufactured inside existing damaged host pipes or culverts. The manufacturing process requires a limited construction site footprint, can avoid roadway shutdowns, and sometimes the damaged pipe is only out-of-service for a few hours. The U.S. is predicted to represent roughly 40% of the $2.6 billion-dollar market by 2023 [2]. This technology is gaining popularity across the rest of the world [2].

Health concerns with CIPP manufacture have been expressed by the public [3], U.S. federal and state agencies [4–7], and organizations outside the U.S. [8–11]. During CIPP manufacture, a flexible uncured resin tube containing raw chemicals is inserted into the damaged culvert. Initiators, felt, plastic films and coatings, fillers, and reinforcements may also be in the tube. Once inserted, polymerization is expedited by hot water, steam, or ultraviolet (UV) light exposure. Next, the ends of the hardened plastic are mechanically removed and the new CIPP is placed into service. At present, the steam method is the most popular U.S. CIPP installation practice [2]. Styrene-based resins, such as polyester and vinyl ester, are the most popular due to their low cost, but non-styrene resins are also used [12,13].

More than 100 air contamination incidents have been associated with CIPP manufacturing sites (Table SM-1), and little information exists regarding the chemicals emitted and their fate. In 2018, CIPP related chemical exposure contributed to a worker fatality where blood

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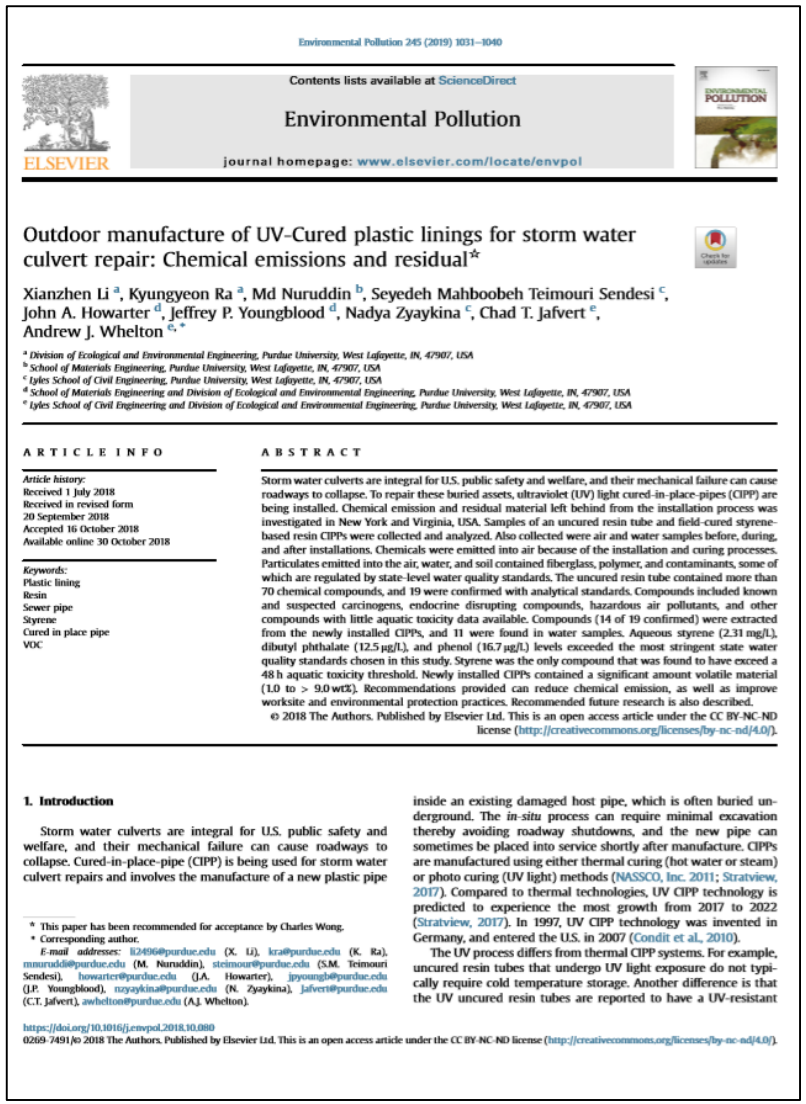
2019

Outdoor manufacture of UV-Cured plastic linings for storm water culvert repair: Chemical emissions and residual☆

https://doi.org/10.1016/j.envpol.2018.10.080



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Xianzhen Li [a], Kyungyeon Ra [a], Md Nuruddin [b], Seyedeh Mahboobeh Teimouri Sendesi [c], John A. Howarter [d], Jeffrey P. Youngblood [d], Nadya Zyaykina [c], Chad T. Jafvert [e], Andrew J. Whelton [e, *]

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ABSTRACT

Storm water culverts are integral for U.S. public safety and welfare, and their mechanical failure can cause roadways to collapse. To repair these buried assets, ultraviolet (UV) light cured-in-place-pipes (CIPP) are being installed. Chemical emission and residual material left behind from the installation process was investigated in New York and Virginia, USA. Samples of an uncured resin tube and field-cured styrene-based resin CIPPs were collected and analyzed. Also collected were air and water samples before, during, and after installations. Chemicals were emitted into air because of the installation and curing processes. Particulates emitted into the air, water, and soil contained fiberglass, polymer, and contaminants, some of which are regulated by state-level water quality standards. The uncured resin tube contained more than 70 chemical compounds, and 19 were confirmed with analytical standards. Compounds included known and suspected carcinogens, endocrine disrupting compounds, hazardous air pollutants, and other compounds with little aquatic toxicity data available. Compounds (14 of 19 confirmed) were extracted from the newly installed CIPPs, and 11 were found in water samples. Aqueous styrene (2.31 mg/L), dibutyl phthalate (12.5 μg/L), and phenol (16.7 μg/L) levels exceeded the most stringent state water quality standards chosen in this study. Styrene was the only compound that was found to have exceed a 48 h aquatic toxicity threshold. Newly installed CIPPs contained a significant amount volatile material (1.0 to > 9.0 wt%). Recommendations provided can reduce chemical emission, as well as improve worksite and environmental protection practices. Recommended future research is also described.

1. Introduction

Storm water culverts are integral for U.S. public safety and welfare, and their mechanical failure can cause roadways to collapse. Cured-in-place-pipe (CIPP) is being used for storm water culvert repairs and involves the manufacture of a new plastic pipe inside an existing damaged host pipe, which is often buried underground. The *in-situ* process can require minimal excavation thereby avoiding roadway shutdowns, and the new pipe can sometimes be placed into service shortly after manufacture. CIPPs are manufactured using either thermal curing (hot water or steam) or photo curing (UV light) methods (NASSCO, Inc. 2011; Stratview, 2017). Compared to thermal technologies, UV CIPP technology is predicted to experience the most growth from 2017 to 2022 (Stratview, 2017). In 1997, UV CIPP technology was invented in Germany, and entered the U.S. in 2007 (Condit et al., 2010).

The UV process differs from thermal CIPP systems. For example, uncured resin tubes that undergo UV light exposure do not typically require cold temperature storage. Another difference is that the UV uncured resin tubes are reported to have a UV-resistant

☆ This paper has been recommended for acceptance by Charles Wong.
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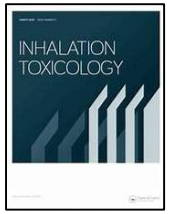
Storm water culverts are integral for U.S. public safety and welfare, and their mechanical failure can cause roadways to collapse. To repair these buried assets, ultraviolet (UV) light cured-in-place-pipes (CIPP) are being installed. Chemical emission and residual material left behind from the installation process was investigated in New York and Virginia, USA. Samples of an uncured resin tube and field-cured styrene-based resin CIPPs were collected and analyzed. Also collected were air and water samples before, during, and after installations. Chemicals were emitted into air because of the installation and curing processes. Particulates emitted into the air, water, and soil contained fiberglass, polymer, and contaminants, some of which are regulated by state-level water quality standards. The uncured resin tube contained more than 70 chemical compounds, and 19 were confirmed with analytical standards. Compounds included known and suspected carcinogens, endocrine disrupting compounds, hazardous air pollutants, and other compounds with little aquatic toxicity data available. Compounds (14 of 19 confirmed) were extracted from the newly installed CIPPs, and 11 were found in water samples. Aqueous styrene (2.31 mg/L), dibutyl phthalate (12.5 μg/L), and phenol (16.7 μg/L) levels exceeded the most stringent state water quality standards chosen in this study. Styrene was the only compound that was found to have exceed a 48 h aquatic toxicity threshold. Newly installed CIPPs contained a significant amount volatile material (1.0 to > 9.0 wt%). Recommendations provided can reduce chemical emission, as well as improve worksite and environmental protection practices. Recommended future research is also described.



2019

In vitro toxicity assessment of emitted materials collected during the manufacture of water pipe plastic linings

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Objectives: To understand hazards associated with CIPP-related emission exposures, an *in vitro* toxicity assessment was performed.
Materials and Methods: Mouse alveolar epithelial and alveolar macrophage cell lines and condensates collected at 3 worksites utilizing styrene-based resins were utilized for evaluations. All condensate samples were normalized based on the major emission component, styrene. Further, a styrene-only exposure group was used as a control to determine mixture related toxicity.
Results: Cytotoxicity differences were observed between worksite samples, with the CIPP worksite 4 sample inducing the most cell death. A proteomic evaluation was performed, which demonstrated styrene-, worksite-, and cell-specific alterations. This examination of protein expression changes determined potential biomarkers of exposure including transglutaminase 2, advillin, collagen type 1, perilipin-2, and others. Pathway analysis of exposure-induced proteomic alterations identified MYC and p53 to be regulators of cellular responses. Protein changes were also related to pathways involved in cell damage, immune response, and cancer.
Conclusions: Together these findings demonstrate potential risks associated with the CIPP procedure as well as variations between worksites regarding emissions and toxicity. Our evaluation identified biological pathways that require a future evaluation and also demonstrates that exposure assessment of CIPP worksites should examine multiple chemical components beyond styrene, as many cellular responses were styrene-independent.

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RESEARCH ARTICLE

In vitro toxicity assessment of emitted materials collected during the manufacture of water pipe plastic linings

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ABSTRACT

Objectives: US water infrastructure is in need of widespread repair due to age-related deterioration. Currently, the cured-in-place (CIPP) procedure is the most common method for water pipe repair. This method involves the on-site manufacture of a new polymer composite plastic liner within the damaged pipe. The CIPP process can release materials resulting in occupational and public health concerns. To understand hazards associated with CIPP-related emission exposures, an *in vitro* toxicity assessment was performed.
Materials and Methods: Mouse alveolar epithelial and alveolar macrophage cell lines and condensates collected at 3 worksites utilizing styrene-based resins were utilized for evaluations. All condensate samples were normalized based on the major emission component, styrene. Further, a styrene-only exposure group was used as a control to determine mixture related toxicity.
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KEYWORDS
Cured-in-place pipe; proteomics; macrophages; epithelial cells; styrene; cancer

Introduction

Millions of miles of US water pipes, which provide safe drinking water, drain excess water from roadways, and remove sewage require repair due to age related deterioration (Agency USEP 2002; Academies NRCotN 2006; Engineers ASoC 2013). To address this need, the cured-in-place pipe (CIPP) lining procedure is often applied because the old pipe does not have to be removed, therefore reducing time, disruptions, and expense. This method involves the on-site manufacture of a new polymer composite (plastic) lining within the damaged pipe. Use of the procedure is expected to expand globally, with the CIPP market exceeding $2.5 billion by 2022, and accounting for 40% of the US pipe rehabilitation market (Stratview Research 2017). However, a growing body of evidence from federal and state agencies as well as Universities indicates that the CIPP manufacturing process can release chemicals into the environment negatively impacting worker and public health (Tabor et al. 2014; Bourbour Ajdari 2016; Teimouri Sendesi et al. 2017; Health CDoP 2018; Ra et al. 2018).

The CIPP procedure involves the on-site use of raw chemicals as well as the generation and release of contaminants before, during, and after the plastic lining is manufactured resulting in worker and public health concerns. Briefly, the procedure comprises the insertion of a flexible raw chemical resin-impregnated tube into the damaged pipe, followed by the inflation of an uncured resin tube against the damaged pipe wall. Then resin is polymerized via curing to create a new plastic liner. Following establishment of the new liner, it can be air cooled and the ends are cut off. Resins are often referred to as either styrene or non-styrene based and popular curing methods include thermal (water or steam) or ultraviolet light processes. Currently, the

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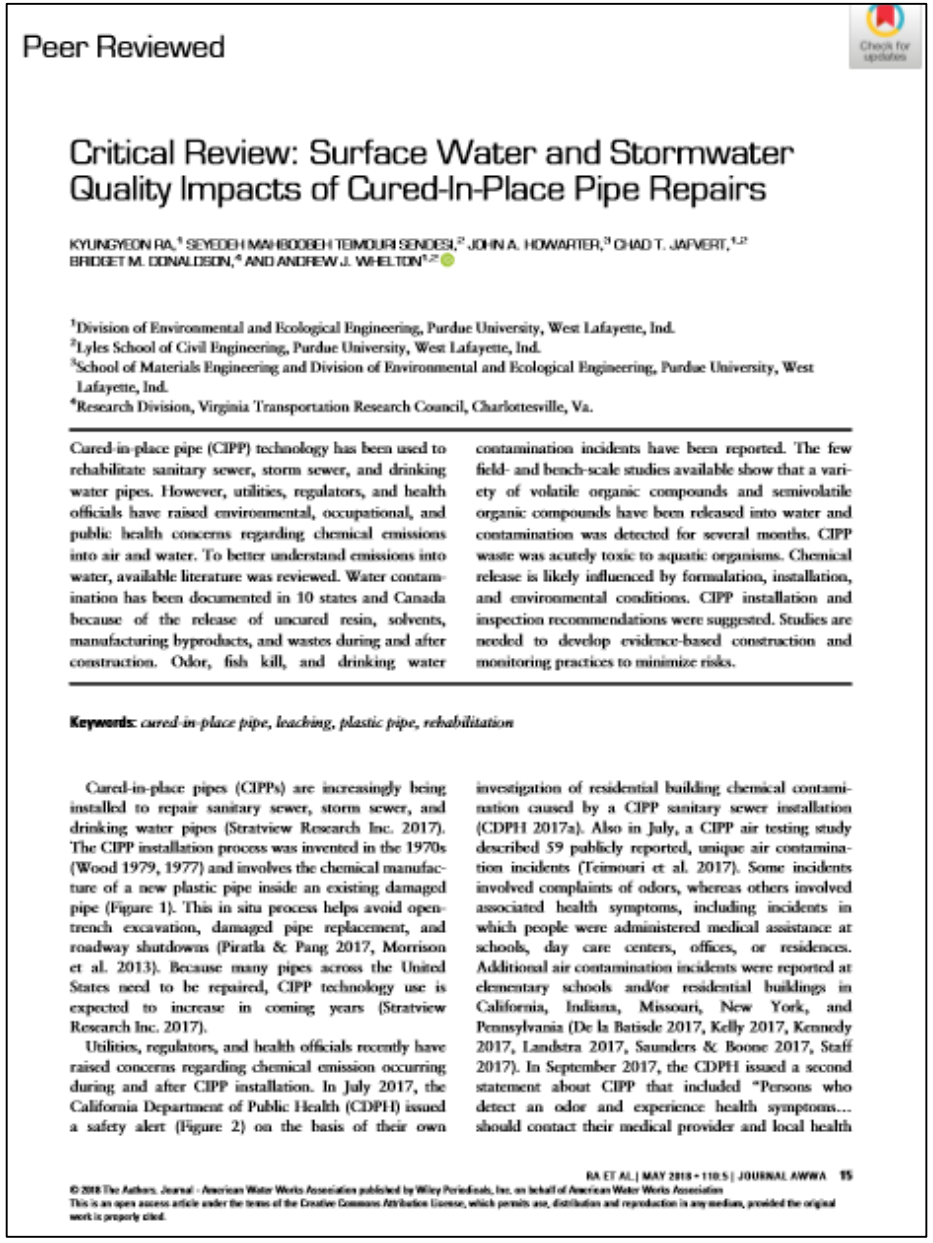
Supplemental data for this article can be accessed here.



Peer Reviewed

Critical Review: Surface Water and Stormwater Quality Impacts of Cured-In-Place Pipe Repairs

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Cured-in-place pipe (CIPP) technology has been used to rehabilitate sanitary sewer, storm sewer, and drinking water pipes. However, utilities, regulators, and health officials have raised environmental, occupational, and public health concerns regarding chemical emissions into air and water. To better understand emissions into water, available literature was reviewed. Water contamination has been documented in 10 states and Canada because of the release of uncured resin, solvents, manufacturing byproducts, and wastes during and after construction. Odor, fish kill, and drinking water contamination incidents have been reported. The few field- and bench-scale studies available show that a variety of volatile organic compounds and semivolatile organic compounds have been released into water and contamination was detected for several months. CIPP waste was acutely toxic to aquatic organisms. Chemical release is likely influenced by formulation, installation, and environmental conditions. CIPP installation and inspection recommendations were suggested. Studies are needed to develop evidence-based construction and monitoring practices to minimize risks.

Keywords: *cured-in-place pipe, leaching, plastic pipe, rehabilitation*

Cured-in-place pipes (CIPPs) are increasingly being installed to repair sanitary sewer, storm sewer, and drinking water pipes (Stratview Research Inc. 2017). The CIPP installation process was invented in the 1970s (Wood 1979, 1977) and involves the chemical manufacture of a new plastic pipe inside an existing damaged pipe (Figure 1). This in situ process helps avoid open-trench excavation, damaged pipe replacement, and roadway shutdowns (Piratla & Pang 2017, Morrison et al. 2013). Because many pipes across the United States need to be repaired, CIPP technology use is expected to increase in coming years (Stratview Research Inc. 2017).

Utilities, regulators, and health officials recently have raised concerns regarding chemical emission occurring during and after CIPP installation. In July 2017, the California Department of Public Health (CDPH) issued a safety alert (Figure 2) on the basis of their own investigation of residential building chemical contamination caused by a CIPP sanitary sewer installation (CDPH 2017a). Also in July, a CIPP air testing study described 59 publicly reported, unique air contamination incidents (Teimouri et al. 2017). Some incidents involved complaints of odors, whereas others involved associated health symptoms, including incidents in which people were administered medical assistance at schools, day care centers, offices, or residences. Additional air contamination incidents were reported at elementary schools and/or residential buildings in California, Indiana, Missouri, New York, and Pennsylvania (De la Batiside 2017, Kelly 2017, Kennedy 2017, Landstra 2017, Saunders & Boose 2017, Staff 2017). In September 2017, the CDPH issued a second statement about CIPP that included "Persons who detect an odor and experience health symptoms... should contact their medical provider and local health

Journal 2018

Critical Review: Surface Water and Stormwater Quality Impacts of Cured-In-Place Pipe Repairs

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Cured-in-place pipe (CIPP) technology has been used to rehabilitate sanitary sewer, storm sewer, and drinking water pipes. However, utilities, regulators, and health officials have raised environmental, occupational, and public health concerns regarding chemical emissions into air and water. To better understand emissions into water, available literature was reviewed. Water contamination has been documented in 10 states and Canada because of the release of uncured resin, solvents, manufacturing byproducts, and wastes during and after construction. Odor, fish kill, and drinking water contamination incidents have been reported. The few field- and bench-scale studies available show that a variety of volatile organic compounds and semivolatile organic compounds have been released into water and contamination was detected for several months. CIPP waste was acutely toxic to aquatic organisms. Chemical release is likely influenced by formulation, installation, and environmental conditions. CIPP installation and inspection recommendations were suggested. Studies are needed to develop evidence-based construction and monitoring practices to minimize risks.

2017

ENVIRONMENTAL Science & Technology LETTERS

Worksite Chemical Air Emissions and Worker Exposure during Sanitary Sewer and Stormwater Pipe Rehabilitation Using Cured-in-Place-Pipe (CIPP)

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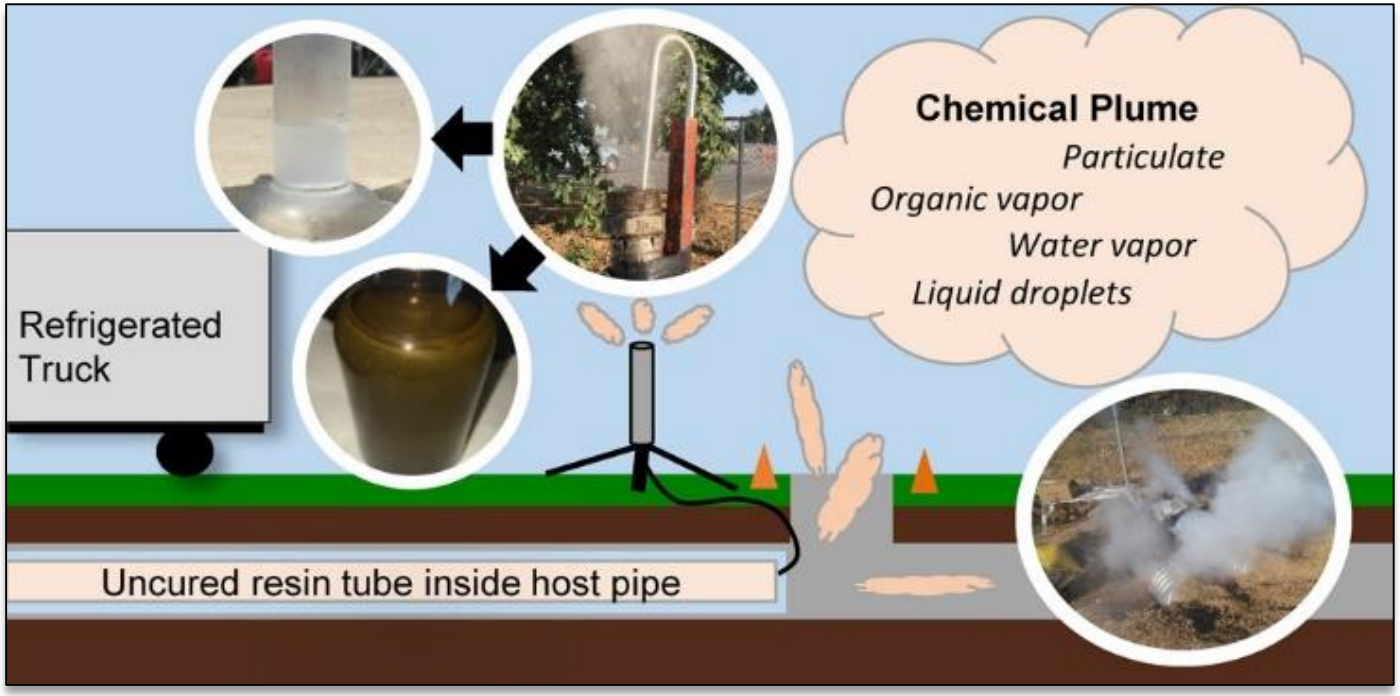

ENVIRONMENTAL Science & Technology LETTERS

Letter

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Worksite Chemical Air Emissions and Worker Exposure during Sanitary Sewer and Stormwater Pipe Rehabilitation Using Cured-in-Place-Pipe (CIPP)

Seyedeh Mahboobeh Teimouri Sendesi,[†] Kyungyeon Ra,[‡] Emily N. Conkling,[‡] Brandon E. Boor,[†] Md. Nuruddin,[§] John A. Howarter,[†,§] Jeffrey P. Youngblood,[§] Lisa M. Kobos,[∥] Jonathan H. Shannahan,[∥] Chad T. Jafvert,[†,‡] and Andrew J. Whelton*[,†,‡]

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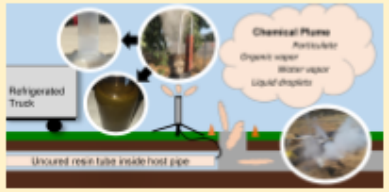
Supporting Information

ABSTRACT: Chemical emissions were characterized for steam-cured cured-in-place-pipe (CIPP) installations in Indiana (sanitary sewer) and California (stormwater). One pipe in California involved a low-volatile organic compound (VOC) non-styrene resin, while all other CIPP sites used styrene resins. In Indiana, the uncured resin contained styrene, benzaldehyde, butylated hydroxytoluene (BHT), and unidentified compounds. Materials emitted from the CIPP worksites were condensed and characterized. An emitted chemical plume in Indiana was a complex multiphase mixture of organic vapor, water vapor, particulate (condensable vapor and partially cured resin), and liquid droplets (water and organics). The condensed material contained styrene, acetone, and unidentified compounds. In California, both styrene and low-VOC resin condensates contained styrene, benzaldehyde, benzoic acid, BHT, dibutyl phthalate, and 1-tetradecanol. Phenol was detected only in the styrene resin condensate. Acetophenone, 4-*tert*-butylcyclohexanol, 4-*tert*-butylcyclohexanone, and tripropylene glycol diacrylate were detected only in the low-VOC condensate. Styrene in the low-VOC condensate was likely due to contamination of contractor equipment. Some, but not all, condensate compounds were detected in uncured resins. Two of four California styrene resin condensates were cytotoxic to mouse alveolar type II epithelial cells and macrophages. Real-time photoionization detector monitoring showed emissions varied significantly and were a function of location, wind direction, and worksite activity.



1. INTRODUCTION

Cured-in-place-pipe (CIPP) is a popular sanitary sewer, stormwater, and drinking water pipe repair technology that was invented in the 1970s.[1,2] A resin-impregnated felt tube is inserted into a damaged pipe and is cured in place with hot water, steam, and/or ultraviolet light.[3−9] In the United States, styrene-based polyester and vinyl ester resin systems are popular because they are less expensive than their alternatives.[10] Non-styrene resin systems such as epoxy are also used.[10] For non-styrene unsaturated polyester or vinyl ester resins, fatty acid-based reactive monomers are available.[11,12] Because concentrated chemicals are used and CIPP is manufactured in the field, forced air, pressurized steam, and other activities can release chemicals into the worksite, nearby pipes, and environment during site setup, installation, and cleanup (Figure 1).[13−25]

CIPP installation activities have caused ambient and indoor air contamination incidents, but the types and magnitudes of materials emitted have received little scrutiny. Air contamination has been documented inside (49) and outside (10) the United States (see Table S1 for details). Persons near CIPP installation sites have reported odors and illness symptoms (i.e., nausea, headache, vomiting, difficulty breathing, eye and nasal irritation, etc.). In some cases, buildings were evacuated and emergency services responded. During the past 16 years, only four CIPP chemical air emission studies have been conducted. A 2015 Los Angeles, CA study revealed styrene exited three sewer pipe manholes during steam curing (250−1070 ppm$_v$) and during cool down (3.6−76.7 ppm$_v$).[26] The styrene 700 ppm$_v$ immediately dangerous to life and health

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