Evaluation of Potential Release of Organic Chemicals in the Steam Exhaust and Other Release Points during Pipe Rehabilitation Using the Trenchless Cured-In-Place Pipe (CIPP) Method

Final Report

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ABOUT NASSCO

The National Association of Sewer Service Companies (NASSCO) is a nonprofit organization established in 1976 with the goal of increasing the success of everyone involved in pipeline rehabilitation by the delivery of high quality products through education, technical resources and industry advocacy. NASSCO's mission is to set industry standards for the assessment, maintenance and rehabilitation of underground infrastructure, and to assure the continued acceptance and growth of trenchless technologies. For the most current updates and to learn more about the benefits of becoming a NASSCO member, visit www.nassco.org

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ACGIH	American Conference of Governmental Industrial Hygienist
ACH	Air Change per Hour
AEGL	Acute Exposure Guideline Level
AGW	Occupational Exposure Limits
ANOVA	Analysis of Variance
AQMV	Air Quality Monitoring Value
ASCE	American Society of Civil Engineers
ASTM	American Society of Testing and Materials
BHT	Butylated Hydroxytoluene
CALTRANS	California Department of Transportation
CIPP	Cured-In-Place Pipe
COD	Chemical Oxygen Demand
CUIRE	Center for Underground Infrastructure Research and Education
DO	Dissolved Oxygen
DOT	Department of Transportation
EC	Effective Concentration
EPA	Environmental Protection Agency
ESL	Effect Screening Level
GAC	Granular Activated Carbon
GC	Gas Chromatography
HSE	Health and Safety Executive
IKT	Institute for Underground Infrastructure
LC	Lethal Concentration
MAC	Maximum Workplace Concentration
MCL	Maximum Contaminant Level
MEK	Methyl Ethyl Ketone
MH	Manhole
MS	Mass Spectrometer
NASSCO	National Association of Sewer Service Companies
NASTT	North American Society for Trenchless Technology

NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational Exposure Limits
OSHA	Occupational Safety and Health Administration
PECM	Precision Electro-Chemical Machining
PEL	Permissible Exposure Limit
PEUU	Poly Etherurethane Urea
PID	Photoionization Detector
PPE	Personal Protective Equipment
PPM	Parts Per Million
PWCSA	Prince William County Service Authority
QA	Quality Assurance
QC	Quality Control
REL	Recommended Exposure Limit
RFP	Request for Proposal
STEL	Short-Term Exposure Limit
TAMIS	Texas Air Monitoring Information System
TCEQ	Texas Commission on Environmental Quality
TCLP	Toxicity Characterization Leaching Procedure
TLV	Threshold Limit Value
TO-15	Toxic Organics - 15
TOC	Total Organic Carbon
TWA	Time Weighted Average
UV	Ultraviolet
VCP	Vitrified Clay Pipe
VDOT	Virginia Department of Transportation
VER	Vinyl Ester Resin
VERTCM	Vinyl Ester Resin Thermoset Composite Material
VOC	Volatile Organic Compound
VROM	Ministry of Housing, Spatial Planning and the Environment
VTRC	Virginia Transportation Research Council

GLOSSARY

Acute Exposure Guideline Levels	Exposure guidelines designed to help responders deal with emergencies involving chemical spills or other catastrophic events where members of the public exposed to a hazardous airborne chemical.
Air Change Per Hour	A measure of the air volume added to or removed from a space (normally a room or house) divided by the volume of the space.
Air Quality Monitoring	The systematic, long-term assessment of pollutant levels by measuring the quantity and types of certain pollutants in the surrounding, outdoor air.
Analysis of Variance	A statistical method in which the variation in a set of observations divided into distinct components.
Chemical Oxygen Demand	Measure of the capacity of water to consume oxygen during the decomposition of organic matter and the oxidation of inorganic chemicals such as ammonia and nitrite.
Dissolved Oxygen	Dissolved oxygen refers to microscopic bubbles of gaseous oxygen mixed in water and available to aquatic organisms for respiration.
Effect Screening Level	Screening levels used in the environment quality air permitting process to evaluate air dispersion modeling predicted impacts used to evaluate the potential for effects to occur because of exposure to concentrations of constituents in the air.
Effective Concentration	Concentration of a substance that causes a defined magnitude of response in a given system.
Gas Chromatography	The separation of a mixture by passing it as a vapor through a medium in which the components move at different rates.
Granular Activated Carbon	A highly porous adsorbent material, produced by heating organic matter, such as coal, wood and coconut shell, in the absence of air, which is then crushed into granules.
Leaching	Leaching is the loss or extraction of certain materials from a carrier into a liquid.

Lethal Concentration	The lethal concentration is the concentration of a chemical that will kill certain percent of the sample population under scrutiny.
Mass Spectrometer	An apparatus for separating isotopes, molecules, and molecular fragments according to mass.
Maximum Contaminant Level	Standards set by the United States Environmental Protection Agency (EPA) for drinking water quality.
Maximum Workplace Concentration	Maximum concentration of a chemical substance (as gas, vapor or particulate matter) in the workplace air which generally does not have known adverse effects on the health of the employee nor cause unreasonable annoyance even when the person is repeatedly exposed during long periods, usually for 8 hours daily but assuming on average a 40-hour working week.
Occupational Exposure Limits	An occupational exposure limit is an upper limit on the acceptable concentration of a hazardous substance in workplace air for a particular material or class of materials.
Permissible Exposure Limit	The limit for exposure of an employee to a chemical substance or physical agent.
Photoionization Detector	A type of gas detector to measure volatile organic compounds and other gases in concentrations from sub parts per billion to parts per million.
Precision Electro-Chemical Machining	Precision electrochemical machining is a nonconventional machining process that can help deliver complex and precise components quickly and accurately.
Quality Assurance	The maintenance of a desired level of quality in a service or product, especially by means of attention to every stage of the process of delivery or production.
Quality Control	A system of maintaining standards in manufactured products by testing a sample of the output against the specification.
Recommended Exposure Limit	An occupational exposure limit recommended by the United States National Institute for OSHA for adoption as a permissible exposure limit.

Short-Term Exposure Limit	The acceptable average exposure over a short period, usually 15 minutes as long as the time-weighted average not exceeded.
Threshold Limit Value	A level to which a worker exposed day after day for a working lifetime without adverse effects.
Time Weighted Average	The average exposure over a specified period, usually a nominal eight hours.
Total Organic Carbon	The amount of carbon found in an organic compound and used as a non-specific indicator of water quality.
Vinyl Ester Resin	A resin produced by the esterification of an epoxy resin with an unsaturated monocarboxylic acid.
Volatile Organic Compound	The organic chemicals that have a high vapor pressure at ordinary room temperature referred as the Volatile Organic Compounds.

EXECUTIVE SUMMARY

Introduction

The Cured-in-Place Pipe (CIPP) process involves a liquid thermoset resin-saturated material that is inserted into the existing pipeline by hydrostatic or air inversion, or by mechanically pulling-in and inflating. The liner material is cured-in-place using hot water, steam or light cured using UV light resulting in the CIPP product.

Need Statement

In response to the growing usage of CIPP installations and recent industry reports, NASSCO issued a request for proposals to facilitate a formal review of potential health impacts associated with CIPP. Of particular interest was the use of polyester resins in CIPP that result in volatilization of styrene during the curing process. Previous studies have focused on the concentration of styrene present in the air of residential homes tied to sanitary sewers during pipeline renewal. There have been very few studies, however, on the impact that styrene has on the safety and health of construction workers and the general public when used for renewing sanitary and storm sewer pipes. Therefore, there is a critical need to study organic chemical emissions (in both gas and liquid-phase) associated with the CIPP installation process, and recommend methods to mitigate any potential adverse impacts on human health. After careful consideration of all responses received, NASSCO awarded the review to the Center for Underground Infrastructure Research and Education (CUIRE) at the University of Texas at Arlington. Project began on December 1, 2017, and completed on April 6, 2018.

Objectives

The overall goal of this project was to (1) review literature and (2) to develop a comprehensive work plan for data collection and analysis to evaluate potential release of organic compounds during pipe renewal/rehabilitation using the steam-cured CIPP method.

Methodology

The methodology for this project included the following two tasks:

- Task A: To review 21 recent publications (16 published in the U.S. and five in Europe) that proposed the presence of organic chemicals related to emissions associated with the CIPP installation process. Additionally, a database (MS Access, Appendix C) of 155 papers related to all aspects of CIPP installations was prepared, which was broken down into 6 books, 37 conference papers, 9 dissertations and theses, 58 refereed journals, 29 magazines, and 16 research reports.

- Task B: To develop a scope of services for additional sampling and analysis of emissions during the field installation of CIPP using the steam-cured process and for measurement of potential release of emissions into the air from six CIPP sites.

Results

Most of the steam-cure studies captured temporal variation in emissions, by measuring concentrations before, during, and after curing. The studies were less complete in capturing spatial variation in concentrations. Most studies measured styrene around the termination manhole, or inside the manhole or sewer pipe itself. Maximum values at the outlet point and inside the terminal manhole ranged from 20 to 1,070 ppm, which are levels that exceed some exposure limits. However, since workers and certainly the public should not typically enter or stand directly at the termination manhole in the exhaust plume, this information is not very helpful.

At the steam-cured sites, additional field measurements of styrene concentrations surrounding the terminal manhole are needed. Only four of the steam-cure studies measured concentrations at locations surrounding the terminal manhole (at least 3 ft (1 m) away, not in the manhole itself or in the exhaust plume).

Atmospheric concentrations of compounds are functions of the source emission rate, meteorological conditions, and the receptor location. Since concentrations are expected to vary as a function of distance from the manhole, measuring at few locations gives an incomplete picture. In addition, concentrations are expected to vary with wind speed and wind direction, so measuring on one day does not capture what levels may be under differing meteorological conditions. Finally, measuring concentrations at one site does not capture variability in emission rate, such as, for projects with larger diameter pipes, longer pipe segments, higher curing temperatures, etc.

At the steam-cured sites, additional field measurements of worker exposure to styrene are also needed. Only two of the steam-cure studies measured worker exposure using a personal sampling device. On one project, (Paper No. 12), employees walked the construction area periodically but spent a good deal of time in their work trucks due to the cold weather. Hence, these measurements were likely not typical of worker exposures. Additional worker exposure data should be collected to capture variability in source emission rate, meteorological conditions, and the worker's location with respect to the terminal manhole.

Recommendations for Future Studies

In summary, existing studies do not adequately capture worker exposures, or levels in the surrounding areas to which workers or citizens may be exposed. Spatial variation of concentrations, and variations in concentrations with different meteorological conditions, are not well determined. Studies also do not adequately capture variations in concentrations from different kinds of pipes (different diameters, lengths, curing temperatures, etc.). The overall results of this project indicate that the 21 papers reviewed have defective methodologies, and therefore, the results presented are not conclusive. More sampling and data evaluation and analysis are needed, as proposed in Chapter 5 of this report.

CHAPTER 1

INTRODUCTION

1.1. Background

Cured-in-place-pipe (CIPP) installation was introduced in 1971 as an alternative to digging up and replacing sewers, and since then hundreds of millions of feet of renewed pipe have been installed around the world. Currently, CIPP is one of the most widely used methods of trenchless pipeline renewal and for both structural and nonstructural purposes. The CIPP process involves a liquid thermoset resin-saturated material that is inserted into the existing pipeline by hydrostatic or air inversion, or by mechanically pulling-in and inflating. The liner material is cured-in-place using hot water, steam- or light-cured using UV light resulting in the CIPP product.

CIPP can be used effectively for a wide range of applications that include storm and sanitary sewers, gas pipelines, potable water pipelines, chemical and industrial pipelines, and similar applications. The flexibility of uncured material makes CIPP especially suitable for different types of pipe geometries including straight pipes, pipes with bends, pipes with different cross-sectional geometries, pipes with varying cross sections, pipes with lateral connections, and deformed and misaligned pipelines. However, several factors must be evaluated before choosing CIPP as the method of renewal for an individual project. Space availability, chemical composition of the fluid carried by the pipeline, number of service laterals, number of manholes, installation distance, renewal objectives, structural capabilities of the old pipe and the like must be assessed before making a choice on the renewal system. CIPP is also used for localized repairs in a wide range of applications.

The primary components of CIPP are a flexible fabric tube and a thermosetting resin system. For typical CIPP applications, the resin is the primary structural component of the system. These resins generally fall into one of the following generic groups, each of which has distinct chemical resistance and structural properties. The most common resin types used for CIPP applications are unsaturated polyester, vinyl ester, and epoxy.

Unsaturated polyester resins were originally selected for the first CIPP installations because of their chemical resistance to municipal sewage, good physical properties in CIPP composite, excellent working characteristics for CIPP installation procedures, and economic feasibility. Unsaturated polyester resins have remained the most widely used for the CIPP process for over four decades.

Vinyl ester and epoxy resin systems are typically used in industrial and pressure pipeline applications, where their tensile properties, special corrosion resistance, solvent resistance, and higher temperature performance are needed. These systems can also be used for sanitary sewers and house service laterals. However, costs will increase.

The primary function of the fabric tube is to carry and support the resins until it is installed and cured. This requires that the fabric tube withstand installation stresses with a controlled amount of stretch but with enough flexibility to dimple at side connections and expand to fit the existing pipeline irregularities. The fabric tube material can be woven or nonwoven, with the most common material being a nonwoven, needled felt. Polyethylene, polypropylene and polyurethane coatings are commonly used on the exterior, or interior, or both surfaces of the fabric tube to protect the resin during installation. The layers of the fabric tube can be seamless, as with some woven material, or longitudinally joined with stitching or heat bonding.

In response to the growing usage of CIPP installations and recent industry reports, NASSCO issued a request for proposals to facilitate a formal review of potential health impacts associated with CIPP. Of particular interest was the use of polyester resins in CIPP that result in volatilization of styrene during the curing process. Previous studies have focused on the concentration of styrene present in the air of residential homes tied to sanitary sewers during pipeline renewal. There have been very few studies, however, on the impact that styrene has on the safety and health of construction workers and the general public when used for renewing sanitary and storm sewer pipes. Therefore, there is a critical need to study organic chemical emissions (in both gas and liquid-phase) associated with the CIPP installation process, and recommend methods to mitigate any potential adverse impacts on human health. After careful consideration of all responses received, NASSCO awarded the review to the Center for Underground Infrastructure Research and Education (CUIRE) at the University of Texas at Arlington.

1.2. Objectives

The overall goal of this project was to evaluate the potential release of organic compounds during pipe renewal/rehabilitation using the steam-cured CIPP method. Potential impacts on health were assessed and policies recommended protecting construction workers, the public, and the environment. This project began on December 1, 2017, and was completed on April 6, 2018, consisting the following two tasks:

- Task A: To review recent publications that propose the presence of organic chemicals and other available literature relating to emissions associated with the CIPP installation process.

- Task B: To develop a scope of services for additional sampling and analysis of emissions during the field installation of CIPP using the steam-cured process to evaluate the potential release of emissions into the air.

1.3. Scope and Deliverables

In addition to the literature review report conducted for Task A, the CUIRE researchers developed a work plan and a schedule to verify findings from the literature review, as well as gain additional data where insufficient data was found in Task A. This work plan covers emissions from steam-cured CIPP installation sites, and was peer-reviewed by environmental consultants qualified to perform the work prescribed.

The work scope included a work plan for comprehensive evaluation of air emissions from steam-cured CIPP and potential impacts on workers and the surrounding community. This work plan (Task B) plan included the following elements:

- Measurement of styrene and other VOC concentrations at six CIPP installation sites, representing different pipe diameters (8”, 12”, and larger) and lengths, to capture variation in emissions.

- Measurements before, during, and after curing at the termination manhole, as well as various locations in the surrounding outside area and inside nearby buildings.

- Measurement of worker exposure using personal exposure monitors for parts per million (ppm) levels for VOCs over an 8-hour shift.

- Dispersion modeling to estimate compound concentrations at a large number of locations for a wide variety of meteorological conditions.

- Collection of appropriate control/background samples.

- Condensate analysis.

Measured and modeled concentrations will be compared to appropriate health-based action levels from OSHA, ACGIH, NIOSH, and other agencies to determine if any potential health risks exist for workers or citizens in the surrounding community. Based on data collected, the plan will estimate styrene emission per pound of resin cured.

CHAPTER 2

METHODOLOGY

As shown in Figure 2.1, UTA Library, and several databases such as ProQuest, Engineering Village, ASCE and NASTT, Google Scholar, Open Access Information of Web Pages of National Agencies in Germany, Special Local Databases of European Universities, Research Organizations and Electronic Science Magazines were used to gather information. The available information was collected and categorized. Follow-up phone calls were made with some experts.

Based on all the review results, with consultation with NASSCO and the Technical Review Committee, CUIRE along with IKT shortlisted twenty-one relevant literature and made a literature review template as per the Request for Proposal (RFP). Appendices A (U.S.) and B (Europe) present review results of individual papers. Chapter 3 provides a summary of these reviews.

All collected literature reviews were included in a MS Access software database (Appendix C) and categorized based on type of publication (journal paper, conference paper, book, magazine article, etc.).

Chapter 5 presents a work plan for Phase 2 of this study (Task B), which includes methods and equipment for sampling and testing requirements. An approximate cost estimate and schedule is provided for Phase 2.

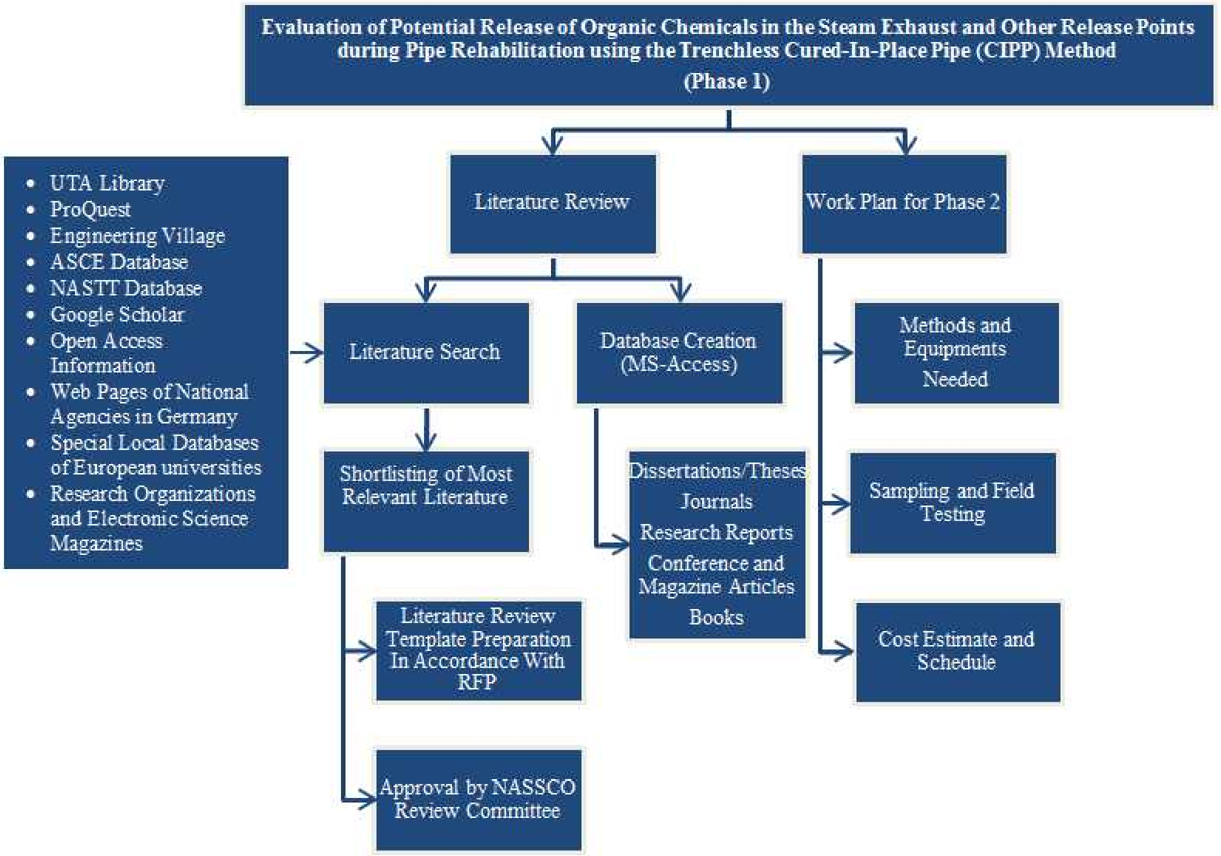


Figure 2.1. Phase 1 Methodology

CHAPTER 3

LITERATURE REVIEW SUMMARIES

3.1. CIPP Air Emission Studies

In the U.S., the National Institute of Occupational Safety and Health (NIOSH) and U.S. Environmental Protection Agency (EPA) recommend styrene short-term exposure limits and exposure limit guidelines are enforced by the Occupational Health and Safety Administration (OSHA). As shown in Table 3.1, national short-term exposure limit values for styrene vary from 20-1900 ppm, depending on averaging time and severity of effects. For countries in the European Union, 8-hour styrene exposure limits vary from 10 to 100 ppm (most common are 20 ppm and 50 ppm), and 10-30 min. exposure limits range from 37.5-250 ppm.

Table 3.2 summarizes field measurements of styrene concentrations at CIPP installation sites. The first section of the Table 3.2 (Rows 1 through 4) shows cases of styrene being measured in response to citizen’s complaints. Indoor levels ranging from 0.32 to 200 ppm are reported. Two of the three indoor styrene measurements are above the 10-min. 20-ppm discomfort guideline recommended by U.S. EPA; two of the four studies report concentrations above the 100-ppm short-term (15-min.) exposure limit recommended by U.S. NIOSH. This indicates that additional study is warranted to investigate potential exposures.

Studies conducted with the goal of measuring styrene emissions from CIPP installation are reported in References 5-14 in Table 3.2. Studies 5 and 6 were for hot water cured and UV-cured, respectively, and found a maximum styrene level of 3.2 ppm. Studies 7-14 included steam-cure, and found noticeably higher concentrations than the hot water and UV cure studies. The steam-cure studies will thus be discussed in more detail.

Most of the steam-cure studies captured temporal variation in emissions, by measuring concentrations before, during, and after curing. The studies were less complete, however, in capturing spatial variation in concentrations. Most studies measured styrene at the termination manhole, or inside the sewer pipe itself. Maximum values at the terminal manhole ranged from 20 to 300 ppm, which are levels that exceed short-term exposure limits, as well as some long-term limits. However, since even workers would typically not stand directly at the termination manhole in the exhaust plume, this information is not very helpful.

At steam-cure sites, additional field measurements of styrene concentrations surrounding the terminal manhole are needed. Only four of the steam-cure studies in Table 3.2 (Rows 9, 10, 11 and 14) measured concentrations at locations surrounding the terminal manhole (at least 1 m away, not in the manhole itself or in the exhaust plume). Ajdari (2016) measured styrene at only one location besides the terminal manhole. Sendesi et al. (2017) measured concentrations at only one location away from the terminal manhole per site. IKT (2011) measured in 5-m increments from 5-20 m downwind from the manhole at one site. Wessex Water (2016) measured 1 m away from the manhole, and in surrounding gullies at one site.

Atmospheric concentrations of compounds are functions of the ***source emission rate***, ***meteorological conditions***, and the ***receptor location***. Since concentrations are expected to vary as a function of distance from the manhole, measuring at few locations gives an incomplete picture. In addition, concentrations are expected to vary with wind speed and wind direction, so measuring on one day does not capture what levels may be under differing meteorological conditions. Finally, measuring concentrations at one site does not capture variability in emission rate, for projects with larger diameter pipes, longer pipe segments, higher curing temperatures, etc.

At steam-cure sites, additional field measurements of worker exposure to styrene are also needed. Only two of the steam-cure studies in Table 3.2 (Rows 12 and 13) measured worker exposure using a personal sampling device. For study 12, employees walked the construction area periodically but spent a good deal of time in their work trucks due to the cold weather. Hence, these measurements were likely not typical of worker exposure. For study 12 in Table 3.2, the worker exposures are much lower than the 8-hour exposure guidelines; however, the study is not publically available. Additional worker exposure data should be collected to capture variability in source emission rate, meteorological conditions, and the worker’s location with respect to the terminal manhole.

In summary, existing studies did not adequately capture worker exposure, or levels in the surrounding area to which workers or citizens may be exposed. Spatial variation of concentrations, and variations in concentrations with different meteorological conditions, were not well determined. **Studies also did not adequately capture variations in concentrations from different kinds of pipe (different diameters, lengths, curing temperatures, etc.).**

Table 3.1. Gas-Phase Regulatory Standards/Guidelines for Styrene

Agency	Guidelines or Standards		Short-Term Guideline/Standard				Long-Term Guideline/Standard			
			Value (mg/m^3)***	Value (ppm)	Averaging Time	Basis	Value (mg/m^3)	Value (ppm)	Averaging Time	Basis
Occupational Safety and Health Administration (OSHA) (from ACGIH)	Construction Permissible Exposure Limit (PEL) Standard		420	100	8-hr	Health	N/A	N/A	N/A	N/A
			840	200	8-hr ceiling (must not be exceeded for any 15-min. period)	Health	N/A	N/A	N/A	N/A
			2,520	600	5-min.	Health	N/A	N/A	N/A	N/A
National Institute for Occupational Safety and Health (NIOSH)	Recommended Exposure Limit (REL)		215	50	10-hr	Health	N/A	N/A	N/A	N/A
			425	100	15-min	Health	N/A	N/A	N/A	N/A
US Environmental Protection Agency (EPA)	Acute Exposure Guideline Level (AEGL)	Level 1 (discomfort/ transient effects)	85	20	10-min	Health	N/A	N/A	N/A	N/A
			85	20	30-min	Health	N/A	N/A	N/A	N/A
			85	20	1-hr	Health	N/A	N/A	N/A	N/A
			85	20	4-hr	Health	N/A	N/A	N/A	N/A
			85	20	8-hr	Health	N/A	N/A	N/A	N/A
		Level 2 (serious, irreversible impacts)	980	230	10-min	Health	N/A	N/A	N/A	N/A
			680	160	30-min	Health	N/A	N/A	N/A	N/A
			550	130	1-hr	Health	N/A	N/A	N/A	N/A
			550	130	4-hr	Health	N/A	N/A	N/A	N/A
			550	130	8-hr	Health	N/A	N/A	N/A	N/A
		Level 3 (life-threatening)	8080	1,900	10-min	Health	N/A	N/A	N/A	N/A
			8080	1,900	30-min	Health	N/A	N/A	N/A	N/A
			4680	1,100	1-hr	Health	N/A	N/A	N/A	N/A
			1450	340	4-hr	Health	N/A	N/A	N/A	N/A
			1450	340	8-hr	Health	N/A	N/A	N/A	N/A

Agency	**Guidelines or Standards**	**Short-Term Guideline/Standard**				**Long-Term Guideline/Standard**			
		Value (mg/m^3)***	**Value (ppm)**	**Averaging Time**	**Basis**	**Value (mg/m^3)**	**Value (ppm)**	**Averaging Time**	**Basis**
Texas Commission on Environmental Quality (TCEQ)	Effect Screening Level (ESL) Guideline*	0.110	0.026	1-hr	Odor	0.140	0.033	Annual	Health
	Air Quality Monitoring Value (AQMV)**	0.110	0.026	1-hr	Odor	N/A	N/A	N/A	N/A
	Air Quality Monitoring Value (AQMV)	22	5.2	1-hr	Health	0.470	0.110	Annual	N/A

*ESLs are screening levels used in TCEQ's air permitting process to evaluate air dispersion modeling's predicted impacts. ESLs are set to protect human health and welfare

**AQMVs are screening levels for ambient air data that are set to protect human health and welfare.

*** The conversion between mg/m^3 and ppm is calculated as follows:

$$C_{mg/m^3} = \frac{MW*P}{R*T} C_{ppm}$$

Where:

C_{mg/m^3} = concentration in mg/m^3
C_{ppm} = concentration in ppm
MW = molecular weight (104.15 for styrene)
R = ideal gas law constant = 0.08206 l-atm/(mol-K)
T = temperature in K = 298 (equivalent to 25 ^{0}C)
P = 1 atmospheric pressure

Table 3.2. Previous Field Measurements of Styrene Concentrations at CIPP Installation Sites

No.	Reference	Type of Reference	Location	Cure Type	No. of Sites	Process Phases Measured	Liner Length, Dia., Thickness	Curing Time & Temp.	Measurement/ Analysis Method	Styrene Concentrations				
										Termination MH (ppm)	Surrounding Property		Worker Exposure (ppm)	Other (ppm)
											Outdoors (ppm)	Indoors (ppm)		
MEASUREMENTS IN RESPONSE TO CITIZEN COMPLAINTS														
1	*Washington Post* (Gowen, 2004)	News article	Alexandria, VA	Not known	1	Unknown	N/A	N/A	N/A	N/A	N/A	N/A	N/A	500: hose at site
2	U.S. Agency for Toxic Substances & Disease Registry (ATSDR, 2005)	Govt. document	Milwaukee, WI	Not known	1	Unknown	N/A	N/A	N/A	N/A	N/A	0.32	N/A	N/A
3	Public Health, England (CRCE, 2011)	Govt. log	Birming-ham, UK	Not known	1	After cooling	N/A	N/A	N/A	N/A	N/A	15-200	N/A	N/A
4	*Worcester Telegram and Gazette* (Dayal, 2011)	New article	Worcester, MA	Not known	1	Unknown	N/A	N/A	N/A	N/A	N/A	60-70	N/A	N/A
STUDIES WITH WATER OR UV CURE														
5	AirZOne (2001)	Consultant report	Toronto, Canada	Hot water	N/A	Before, during, after CIPP installation	N/A	4-6 h at 80°C	Sorbent tubes with sampling pumps, GC/MS	0.16-3.2	Outside homes, upwind of manholes	0.1-0.2 (8 houses)	0.08-0.5	N/A
6	IKT (2007, 2008, 2013)	Report	A special test stand, Germany	UV	6	Before, during, after curing	8.7’ x 23.6” x 0.28”; 8.7’ x 11.8” x 0.15”	N/A	Air layer of test rig, closed & sealed against ambient air, measurements via adsorption (activated charcoal tubes) with auto sampler	N/A	N/A	N/A	N/A	0.001 – 0.013 ppm, air layer of test stand, closed & sealed against ambient air

No.	Reference	Type of Reference	Location	Cure Type	No. of Sites	Process Phases Measured	Liner Length, Dia., Thickness	Curing Time & Temp.	Measurement/ Analysis Method	Styrene Concentrations				
										Termination MH (ppm)	Surrounding Property		Worker Exposure (ppm)	Other (ppm)
											Outdoors (ppm)	Indoors (ppm)		
STUDIES WITH STEAM CURE														
7	Bauer & McCartney (2004)	Conference proceeding	Ottawa, Canada	Steam	4	Before, during, after curing (cont.)	253’ x 30” x 1.16”; 53’ x 30” x 1.34”	N/A	PID: PE Photovac Model 2020	20, 115		2.5	N/A	N/A
8	Ajdari (2016) (University of New Orleans)	Ph.D. dissertation	New Orleans, LA, US	Steam	3	Before, during, after curing	235’, 304’, 309’; x 8”	45-60 min., 60°C	Tedlar bag with pump, GC	250-1,070	N.D. (One location only)	N/A	N/A	Steam hose
9	Wessex Water (2016)	Consultant Report	Bath, UK	Steam (1) & water (3)	4	Before, during, after curing (cont.)	568’ x 11.8” x 0.24”	4 h, 40°C - 100°C	Field PID – 4 sites; Sorbent tubes (thermal desorption/ GC) – 2 sites	PID: Steam cure max.: 165	Steam cure: PID: max 6 (1 m from term MH), 24(in gully); Sorbent tubes: all 8 < UK 8-h TWA & 15-min STEL	N/A	N/A	N/A
10	Sendesi et al. (2017)	Journal article	CA (5 sites), US; IN (2 sites), US	Steam	7	Before, during, after curing (cont.)	19.7’ x 18” x 0.3”	N/A	PID	Styrene not indepen-dently measured		Styrene not indepen-dently measured	Styrene not indepen-dently measured	
11	Prince William County Service Authority (2017)	Report	VA, US	Steam	4	Before, during, after curing (cont.)	353’; 248, 272, and 124’	N/A	Personal PID & passive monitoring badge on 2 employees	N/A	N/A	N/A	104 ppm peak; 0.077 avg	N/A
12	Unpublished data (2017)	N/A	N/A	Steam	N/A	N/A	N/A	N/A	Personal data logger, GC/MS	N/A	N/A	N/A	1.4 ppm 8-h TWA	N/A

No.	Reference	Type of Reference	Location	Cure Type	No. of Sites	Process Phases Measured	Liner Length, Dia., Thickness	Curing Time & Temp.	Measurement/ Analysis Method	Styrene Concentrations				
										Termination MH (ppm)	Surrounding Property		Worker Exposure (ppm)	Other (ppm)
											Outdoors (ppm)	Indoors (ppm)		
13	IKT (2011)	Report	Ruhr, Germany	Steam	1	During curing	15.7” dia.	N/A	DRÄGER Accuro tubes/pump	N/A	20 at 5 m away from term. MH, 1.5 m height	N/A	N/A	N/A
14	RIVM (2006)	Report	Cuijk-Vianen, Barendrecht, Sevenum, The Netherlands	Not known (likely steam)	3	During & after curing & cooling, during cutting of holes for laterals	249’ x 11.8”, 167’ x 13.8”, 469’ x 17.7”	N/A	Not known	300 in MH; 85 (vent)	N/A	9	N/A	N/A

Note: Cont. = Continuous

3.2. CIPP Water Quality Studies

Water quality concerns have been documented for styrene-based resins used in the CIPP process, particularly for steam cure. Under the Safe Drinking Water Act, the Maximum Contaminant Level (MCL) permitted for styrene is 0.1 mg/L, and the following studies measured concentrations above these levels:

- Lee et al. (2008) measured styrene concentrations in CIPP-repaired pipe of 51 mg/L after hot water cure, and 5.5 mg/L for steam-cure after two flushings.

- Tabor et al. (2014) measured styrene levels ranging from 0.01 to 7.4 ppm (equivalent to mg/L in water) at the outlet of a culvert that had been repaired via steam-cure CIPP, as well as a 50-m downstream, for a period of 35 days.

- In a study conducted for the Virginia Transportation Research Council, Donaldson and Baker (2008) studied seven steam-cure CIPP installations in surface water and stormwater conveyances in Virginia. Styrene levels at five of the seven sites were higher than the styrene MCL. Styrene was detected at five sites for a minimum of 5 days to at least 71 days after installation and was detected at these sites up to 40 m downstream.

However, subsequent Virginia DOT studies showed that the release of styrene was caused by poor CIPP installation practices, and implementing new specifications could eliminate these problems.

Other studies have also documented approaches for successfully mitigating water quality concerns from steam cure:

- Leondorf (2009) reported that styrene levels in water from CIPP installation (water and steam cure) were successfully reduced to less than 2 mg/L using a granular activated carbon system.

- Currier (2017) found that adherence to the Caltrans specification for CIPP installation (based on the Virginia DOT specifications) is sufficient to avoid fish kills.

- Another study (Donaldson, 2012) assessed the impacts of UV cure as an alternative to steam cure, and vinyl ester-based resin as alternatives to styrene-based resins. Following UV CIPP installations, no water quality impacts were documented from culvert outlets with water flow; however, styrene concentrations following one of the installations exceeded toxicity thresholds for aquatic species in standing water. For the vinyl ester CIPP, concentrations of the primary resin constituent exceeded toxicity thresholds for aquatic species in six subsequent water-sampling events; however, adherence to Virginia Department of Transportation CIPP specifications for styrene-based liners is expected to minimize contaminant leaching from the installation and use of this product.

3.3. Summaries of Critiques

Paper No. A1: Worksite Chemical Air Emissions and Worker Exposure during Sanitary Sewer and Stormwater Pipe Rehabilitation Using Cured-in-Place-Pipe (CIPP)

Citation: Sendesi, S., Ra, K., Conkling, E., Boor, B., Nuruddin, M., Howarter, J., Youngblood, J., Kobos, L., Shannahan, J., Jafvert, C. and Whelton, A. (2017). "Worksite Chemical Air Emissions and Worker Exposure during Sanitary Sewer and Stormwater Pipe Rehabilitation Using Cured-in-Place-Pipe (CIPP)." Environmental Science & Technology Letters, 4(8), 325-333.

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. Data samples represented seven CIPP installation sites. Photoionization detector (PID) sampling was done every 2 minutes at the Indiana sites and every 2 seconds at the California sites. The PID did not measure styrene directly, but detected a response to what may have been a mixture of compounds. Location of sampling was not uniform for all the sites. The samples were not representative since the sampling locations and time intervals varied at the two places.

Styrene, benzaldehyde, benzoic acid, BHT, dibutyl phthalate, 1-tetradecanol, phenol, acetophenone, 4-tert-butylcyclohexanol, 4-tert-butylcyclohexanone, and tripropylene glycol were the compounds of interest. However, no investigation was done to detect and quantify the chemical exposure risks to employees as per the OSHA, ACGIH, NIOSH or any other standards. The article states the employees were not wearing PPE. During this investigation, CIPP workers did not use respirators and resided inside and walked through the chemical plumes and exposures occurred even when plumes were not visible. Contractors also sometimes handled the uncured resin tube and CIPP with their bare hands.

Strengths: A strength of this study is that emissions were measured at seven sites. Measured concentrations real-time using a PID, at exhaust pipe and fugitive emission locations at each site. Photographs and graphics provided visual pictures of the CIPP installation and sampling points.

Weaknesses: Styrene was not measured directly. Measurements were not taken at different locations relative to the steam exhaust discharge source. More sampling locations are required to study downstream wind concentrations of styrene to analyze the impact to public and neighborhood. Worker exposure was not measured. Meteorological data was not collected. As there are many resins and CIPP installation variables, and because very few studies have been conducted to characterize air emissions, additional investigations are needed.

Paper No. A2: Volatile Organic Compound (VOC) Emission during Cured-in-Place-Pipe (CIPP) Sewer Pipe Rehabilitation

Citation: Ajdari, E. (2016). "Volatile Organic Compound (VOC) Emission during Cured-in-Place-Pipe (CIPP) Sewer Pipe Rehabilitation." thesis, presented to University of New Orleans, LA, in in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

This study involved measurement of volatile organic compound emissions at three CIPP sanitary sewer installation sites in one U.S. city. Of 22 CIPP sites in New Orleans, three were chosen for measurement of air emissions, using Tedlar bags with pumps and subsequent analysis via gas chromatograph. The study does not explain how these three pipes were chosen, so it is difficult to determine whether they were representative of the population of pipes. Samples were collected before curing, during curing, and during cooling.

Various regulatory styrene exposure limits range from 20 to 700 ppm. Styrene concentrations measured in the manhole exhaust ranged from 250 to 1,070 ppm, indicating that further investigation of this high reading is required, as it appears that this measurement was taken inside the manhole. The styrene concentration measured on the nearest private property to the downstream manhole at one site was not detectable.

Strengths: The study directly measured styrene and other VOCs from exhaust from steam curing of CIPP lining at three sites. Sufficient attention was paid to QA/QC.

Weaknesses: Exhaust coming directly from the termination manhole was all that was measured (except for one measurement on private property). No measurements of direct worker exposure were conducted. Concentrations in the surrounding community were only measured in one location at one site.

Paper No. A3: Understanding Environmental Implications of CIPP Rehab Technology

Citation: Kampbell, E. (2009). "Understanding Environmental Implications of CIPP Rehab Technology." Rehabilitation Technology, Underground Technology Cutting Edge Technical Information for Utility Construction and Rehabilitation, 2009.

This article reported on research conducted by the Virginia Department of Transportation (VTRC 08 R16) to evaluate the potential for impacts on water quality from use of the steam-cured CIPP (cured-in-place pipe). In the Virginia DOT study, seven sites of steam CIPP installation were studied for styrene concentration in water. Timing of the samples taken to measure the styrene content in the downstream waterway was varied; in some cases, the sampling was delayed until 15 days. In several sites, upstream sampling was missed prior to CIPP installation and in several sites, downstream sampling was missed post CIPP installation. The maximum limit detected was 44 ppm, which is greater than the limit set by the Safe Drinking Water Act of 0.1 ppm. The test method in the field could not be verified due to lack of information.

Strengths: Seven sites of steam CIPP installation were studied for styrene concentration in water, with three installers involved in the installations.

Weaknesses: QA/QC was poor, there was no statistical evidence, and only steam cured treatment was studied. The study does not talk about other water quality analyses and does not focus on soil or air contamination due to CIPP installation.

Paper No. A4: Risk Associated with CIPP Lining of Stormwater Pipes and the Release of Styrene

Citation: Lee, R. K. (2008). "Risk Associated with CIPP Lining of Stormwater Pipes and the Release of Styrene." *Proceedings* of the North American Society for Trenchless Technology (NASTT) NO-DIG Conference, NASTT, Dallas, TX, 2008; Paper E-1-05.

Fairfax County and Malcolm Pirnie decided to undertake a study to determine the concentrations of styrene during and after using CIPP to rehabilitate storm sewers. Different types of CIPP installation including water inversion, air inversion and pull-in place, hot water cure, and steam cure were studied with respect to styrene leaching downstream. CIPP was flushed twice after the cool down process. Grab samples were taken by Malcolm Pirnie at various points of CIPP installation. USEPA SW-846 8260B method was used for testing the volatile organic compounds. The data samples collected do not represent the whole population, the reason being that the samples were grab sampled and were not done for all the installations.

Under the Safe Drinking Water Act, the Maximum Contaminant Level permitted for styrene is 0.1 mg/L. However, the average styrene concentration found in this study for hot water cure after completion of hot water recirculation was 51 mg/L. Hot water cure CIPP after two flushings demonstrated an average styrene concentration of 19 mg/L in storm water. A steam-cured CIPP installation after two flushings showed an average styrene concentration of 5.5 mg/L in storm water. A concentration of 9.1 mg/L of styrene is sufficient to kill fish, according to 72-hour and 96-hour tests by the Styrene Producers Association. For hot water cure CIPP after completion of hot water recirculation and hot water cure CIPP after two flushings, both exceeded this value. Only a grab sampling was done per site, and data at different locations is not available.

Strengths: Different types of CIPP installation including water inversion, air inversion and pull-in place, hot water cure, and steam cure were studied with respect to styrene leaching downstream. Standard sampling and analysis methods were followed.

Weaknesses: Grab sampling was not performed at a specific interval or specific time post-CIPP installation. Styrene concentrations downstream at different locations were not studied. The grab samples were collected from the CIPP installation site alone and were analyzed. No report of control samples or duplicate samples to ensure accuracy and QA/QC.

Paper No. A5: Stormwater Chemical Contamination Caused by Cured-in-Place Pipe (CIPP) Infrastructure Rehabilitation Activities

Citation: Tabor, M., Newman, D., Whelton, A. (2014). “Stormwater Chemical Contamination Caused by Cured-in-Place Pipe (CIPP) Infrastructure Rehabilitation Activities.” Environmental Science & Technology, 2014.

CIPP’s stormwater contamination potential and that of its condensate waste was characterized. Onsite water temperature, pH, dissolved oxygen (DO), and turbidity levels were measured. Three large pieces of excess CIPP at Site 2 (3 ft × 4 ft × 0.75 in. thick) were removed from the field and underwent the toxicity characterization leaching procedure (TCLP) at room temperature. Aquatic toxicity was tested using Daphnia magna as a bioindicator. Statistical analysis was performed with 2 factor analysis of variance (ANOVA) and post hoc Turkey- Kramer multiple comparison test. The Safe Drinking Water Act recommends styrene levels not more than 0.1 ppm. However, styrene levels in this study exceeded the threshold (up to 7.4 ppm).

It is difficult to determine whether the data sample represents entire population. Only two sites were sampled, and the criteria for selecting these sites was not discussed. In addition, data was only collected at the inlet, outlet, and 50 feet downstream. In some cases, concentrations were greater at 50 feet downstream. This begs the question of whether concentrations at other distances downstream may have been higher than at 50 feet. Furthermore, only three grab samples were collected at each location. These samples may not have been representative in terms of time. This study did not account for toxicity observed in warmer or colder temperatures indicative of waterways or the presence of natural organic matter. Previous studies showed that warmer water can increase chemical toxicity to D. magna, and dissolved organic material had no effect or increases organic contaminant toxicity to this organism.

Strengths: Excellent QA/QC was followed, detailed chemical analysis with detailed information reported, and statistical analysis was conducted.

Weaknesses: Only two sites were sampled, and the criteria for selecting these sites was not discussed. As stated by authors, the three pipe samples were not representative. The study did not illustrate how the measurements were made and samples were collected. Data were only collected at the inlet, outlet, and 50 feet downstream. In some cases, concentrations were greater at 50 feet downstream. This raises the question of whether concentrations at other distances downstream may have been higher than at 50 feet. Only three grab samples were collected at each location. These samples may not have been representative in terms of time. Since the presence of styrene was found on the 35th day, the study could have been continued for more days. Chemical toxicology study was limited to condensate and water quality. No further information is available about calibration and validation.

Paper No. A6: Water Quality of Flow through Cured-In-Place Pipe (CIPP)

Citation: Currier, B. (2017). "Water Quality of Flow through Cured-In-Place Pipe (CIPP)." Final Report; Office of Water Programs, California State University Sacramento: Sacramento, CA, 2017 (prepared for California Department of Transportation, Sacramento, CA).

To conservatively-measure the water quality impacts of CIPP methods, a small volume of water was introduced immediately after CIPP installations of 11 pipes. Minimizing the volume of water used to flush the pipes theoretically results in higher concentrations of chemical residuals from the CIPP installation materials. Water quality analysis for volatile organic compounds in samples taken from the induced flows demonstrated that adherence to the Caltrans specification for CIPP installation is sufficient to avoid fish kills.

Grab samples were collected in triplicate for this study. Sampling was done in time intervals of geometric progression. The data samples collected may not represent the whole population. No data are available with respect to reporting and detection limits. The maximum reported styrene level post curing is 120 ppb and is less than the limit set by the Safe Drinking Water Act of 0.1 mg/L**.**

Strengths: Well-scheduled sampling was performed: to start the schedule, the first sample was taken six hours after cool down. Subsequent sampling for each pipe occurred at 12 hours, 24 hours, 48 hours, and 96 hours after cool down for both field and simulated field studies. Simulated and field studies were done, and the simulated study was validated. Different types of post cure treatments were tested, providing more information on how the styrene concentration changes with post cure treatments. Temperature, precipitation and relative humidity data were also recorded.

Weaknesses: Samples were not collected at different locations downstream and hence lacks representativeness. No air quality data is available. Humidity will negatively affect volatilization, but this study does not quantify the relationship between humidity, styrene concentration in water, or volatilization into the air within the pipe

Paper No. A7: The Environmental Implications of Cured-in-Place Pipe Rehabilitation

Citation: Donaldson, B.M., and Baker, A. (2008). "The Environmental Implications of Cured-in-Place Pipe Rehabilitation." VTRC 08-CR12, Virginia Transportation Research Council, Charlottesville, 2008.

To evaluate the potential for impacts on water quality from the steam-cured CIPP process, seven CIPP installations in surface water and stormwater conveyances were identified and observed over the course of a 1-year study in Virginia. Water samples were collected from each project site and analyzed for styrene. The results were then evaluated for compliance with established regulatory standards and published aquatic toxicity criteria.

Styrene concentrations in water samples ranged from <0.005 mg/L to 77 mg/L, whereas the permissible level of styrene in water as per the Safe Drinking Water Act is 0.1 mg/L. At certain times after CIPP installation, styrene concentrations exceeded the MCL for drinking water at five of the seven study sites and exceeded the EC50 or LC50 values of the water flea6 and the rainbow trout (common indicator species) at four of the monitored project sites. Concentrations exceeded the MCL for drinking water for at least 5 days after installation at 5 sites and for at least 44 to 71 days at three of these sites. Concentrations above the MCL were detected up to 40 m downstream.

In this study, control sampling was performed in sites, 1, 3 and 4, prior to CIPP installation. Although several samples were sent to a second laboratory to verify results, control samples were not done for all the sites. A definite time interval was not followed for sampling. The data sample collected does not represent the whole population: there is no evidence of the basis for selecting the 7 sites or their representativeness. In addition, samples were not collected at the same time post- and pre- CIPP installation. The type of CIPP material used in this study is not stated.

Strengths: Real-world samples were collected following CIPP installation at 7 sites. USEPA method was followed for laboratory analysis. Several samples were sent to a second laboratory to verify results. Recommendations were made for reducing water quality impacts of CIPP installation.

Weaknesses: Since the CIPP installations observed continued up to 30 consecutive hours and because of the distance between the project sites, the authors could not be present to collect samples at consistent intervals during and after all installations. The type of CIPP material used for CIPP is not stated in this study. Control samples were not done for all the sites. The study could have been more organized to collect samples at uniform distances from steam exhaust and at consistent time intervals.

Paper No. A8: The Influence of Rehabilitated Stormwater Infrastructure on Water Quality and Daphnia magna Toxicity: A Field and Laboratory Investigation

Citation: Tabor, M. L. (2014). “The Influence of Rehabilitated Stormwater Infrastructure on Water Quality and Daphnia magna Toxicity: A Field and Laboratory Investigation.” Master’s Thesis, University of South Alabama.

The objectives of this research were to determine the water quality impacts of CIPP installed at two Alabama stormwater culverts, characterize wastewater generated by CIPP operations, and develop a laboratory leaching method that predicts water quality and aquatic toxicity impacts of newly installed CIPP material. CIPP wastewater was found to be acutely toxic to Daphnia magna within 24 hours. The wastewater’s pH was 6.2, but 36,000 ppm chemical oxygen demand (COD), elevated styrene levels, and numerous solvents (endocrine-disrupting chemicals and carcinogens) were also detected. Results from field stormwater sampling demonstrated that two newly installed CIPP imparted organic and inorganic contaminants for five weeks.

In this study, all water quality analyses followed standard test procedures. Sample preservation was done after sampling. Control sampling was done only for one site out of two. There were only two sites that were studied for water quality post CIPP installation. Although the water samples were collected at various locations, the data sample collected does not represent the whole population.

Strengths: This study was the first characterization of CIPP condensate. Toxicity Characteristic Leaching Procedure was performed to learn the leaching of chemicals post CIPP installation. Toxicity to D. Magna was studied. A laboratory leaching method, which predicts water quality and aquatic toxicity impacts of newly installed CIPP material, was tested. Standard test methods were followed.

Weaknesses: There were two sites included in this study, one site spanning 158 ft and the other 235 ft. This should have made considerable difference in the styrene concentration, as the same water flows through a longer distance in one pipe than in other. However, it did not seem to make a difference. Full modeling and statistical analysis would have helped in predicting the contaminants in the future.

Paper No. A9: A Comprehensive Review on the Challenges of Cured-in-Place pipe (CIPP) Installations

Citation: Das, S., Bayat, A., Gay, L., Salimi, M., & Matthews, J. (2016). “A Comprehensive Review on the Challenges of Cured-in-Place pipe (CIPP) Installations.” Journal of Water Supply: Research and Technology-Aqua, 65(8), 583-596.

This paper outlines the issues and challenges associated with cured-in-place pipe (CIPP) rehabilitation projects of sewer mains, water mains, and service laterals. Common problems and challenges are first reviewed from the available literature and CIPP installation site visits. These obstacles and risks are classified into five different categories: pipe condition and configuration, pre-installation, challenges during installation, post-installation, and environmental challenges. In addition, this paper discusses relevant measures adopted in the current practices to mitigate these challenges.

Information used in this paper was collected from academic publications, industrial guidelines, and specifications from various practitioners specializing in CIPP installation. Site visits to CIPP installation projects, performed in different municipalities by specialized CIPP providers, also produced a proportion of the information.

Although there were six articles that were reviewed with respect to the environmental impacts, not all available resources were reviewed.

Strengths: The review article talks about technical challenges faced during the CIPP installation, as well as the environmental challenges.

Weaknesses: Although there were six articles that were reviewed with respect to the environmental impacts, not all available resources were reviewed. In addition, the review cites a study by Whelton et al. (2012), in which a 500-ppm measurement was incorrectly reported as an indoor measurement. In actuality, the 500-ppm value was reported in a newspaper article (Gowen, 2004) as measured from a hose left on the job site. No information, however, is provided about how the concentration was measured.

Paper No. A10: Impact of Infrastructure Coating Materials on Storm-Water Quality: Review and Experimental Study

Citation: Whelton, A. J., Salehi, M., Tabor, M., Donaldson, B., and Estaba, J. (2012). “Impact of Infrastructure Coating Materials on Storm-Water Quality: Review and Experimental Study.” Journal of Environmental Engineering, 139(5), 746-756.

A literature review and 30-day leaching regime were conducted to determine the extent that storm-water infrastructure coatings affect water quality. Newly installed polymer-enhanced cement mortar (PECM) and poly (etherurethane urea) (PEUU) storm-water pipe coatings were removed from the field and underwent 10 three-day water immersion periods. For both materials, the greatest water quality alterations occurred during the first water contact period, followed by significant reductions in water quality alterations.

The data sample collected does not represent the whole population since the specimen of PECM and PEUU was collected from just one site, although there was a broad leaching study done with those specimens. There was only minimum sample available for testing and hence QA/QC on specimen collection was not extensive. For immersion testing, triplicate samples were taken and analyzed for each water-sampling period. Standard methods were used for all laboratory analyses.

<u>Strengths</u>: This experimental study appears to be the first documented water quality impacts of storm-water pipe coating materials using a static leaching experiment. This work demonstrates that inorganic and organic contaminants can be released from storm-water infrastructure coatings into waters they contact.

<u>Weaknesses</u>: Specimens collected do not represent the whole population; it seems to be an individual case study. A regression model could have been done on the data collected, since there was so much correlation between water quality parameters.

Paper No. A11: Influence of Temperature on Styrene Emission from a Vinyl Ester Resin Thermoset Composite Material

Citation: Crawford, S., & Lungu, C. T. (2011). “Influence of Temperature on Styrene Emission from a Vinyl Ester Resin Thermoset Composite Material.” Science of the Total Environment, 409(18), 3403-3408.

In this study, a typical VER composite made with resin containing 38% by weight styrene, reinforced with E-glass fiber and formed using a vacuum assisted resin transfer method, was characterized for styrene emissions by environmental test chamber (ETC) methodology. Styrene concentrations in the ETC were measured over a temperature range of 10 to 50 °C.

QA/QC was followed while constructing the environmental testing chamber such as testing well-mixed flow of air, testing air-tight condition, etc. Internal standards were run prior to analysis in gas chromatography. Actual styrene emissions during curing may get diluted with available air. However, this study helps us to expect the maximum styrene that can be emitted due to increase in temperature. There seemed to be good correlation of emission factor and maximum styrene emission to increase in temperature. Hence, it could be modeled.

The maximum concentration of styrene reported in the chamber was 0.345 ppm (1.47 mg/m^3), which is lower than the safe inhalation limit suggested by OSHA (8-hour STEL ceiling) of 50 ppm. The average of the styrene emitted for the temperature was 0.047 ppm (0.2 mg/m^3), which is also lower than the OSHA limit. The 8-hour time weighted average exposure for styrene as per OSHA is 100 ppm. The maximum and average concentrations observed in the chamber are both lower than that.

Strengths: This was the first ever study to examine the effect of temperature on styrene emissions from finished vinyl ester resin thermoset composite material or other dry building material. This is an insightful study, which can help in forecasting the emissions that can occur in extreme hot summer when resins are cured on-site, same as CIPP process.

Weaknesses: Field validation was not performed to check the styrene emissions due to vinyl ester at different temperatures. Statistical modeling was not performed in spite of excellent correlation between styrene emission factors and increases in temperature.

Paper No. A12: Styrene Removal Adds to the Challenges of Rehabilitating Sewer Pipeline in Reno, Nevada

Citation: Loendorf, T., & Waters, D. (2009). “Styrene Removal Adds to the Challenges of Rehabilitating Sewer Pipeline in Reno, Nevada.” *Proceedings* of the North American Society for Trenchless Technology (NASTT) No-Dig Conference. Liverpool, NY: NASTT.

In 2007, the City of Reno (City) asked Brown and Caldwell to design rehabilitation of approximately 26,000 linear feet of sewer pipeline using CIPP. Because of concerns raised by the local wastewater treatment facility, styrene levels in all water used during the lining process would be restricted to levels less than 2 milligrams per liter upon discharge into the sewer system. In this study, GAC was used to filter the condensate and initially discharged water from the CIPP. In addition to the normal requirements associated with all CIPP lining work, styrene removal adds multiple elements to each installation: longer bypass requirements in both time and length, greater traffic control needs, increased duration of each lining shot due to the treatment process, larger footprint required for additional equipment and laboratory testing requirements. This paper discusses the issues that were encountered due to the location of the sewer pipeline, public involvement and the affect styrene removal had on the project.

There is no information available on test methods, equipment or instruments used to collect or analyze the water samples. There is no information to verify that QA/QC was followed.

The study focuses on achieving the styrene concentration in process water below 2 mg/L. Although that was achieved, there is no evidence that the styrene concentrations were below the limit set by safe drinking water act of 0.1 mg/L. The field test method of using GAC for filtration of process water post-CIPP installation has been verified. There is no information on lab test method and hence cannot be verified.

Strengths: This study is innovative in the fact that the styrene levels in process water post-CIPP installation could be brought below 2 mg/L through GAC filtration. This could be extended to bring the styrene levels to those required by the Safe Drinking Water Act.

Weaknesses: There is no information on the following: Sampling method for process water, lab analysis for styrene, study on condensate post CIPP installation. In addition, there is no evidence of QA/QC being followed.

Paper No. A13: Water Quality Implications of Culvert Repair Options: Vinyl Ester Based and Ultraviolet Cured-in-Place Pipe Liners

Citation: Donaldson B. (2012). "Water Quality Implications of Culvert Repair Options: Vinyl Ester Based and Ultraviolet Cured-in-Place Pipe Liners." Virginia Center for Transportation Innovation & Research, Virginia, 2012.

The study included an environmental evaluation of two unconventional CIPP technologies available for use by Virginia Department of Transportation (VDOT): vinyl ester based (styrene-free) CIPP and styrene-based ultraviolet (UV) CIPP. To evaluate the potential for vinyl ester based and UV CIPP technologies to impact water quality, water samples were collected from field installations and simulations for up to 120 days. Samples were analyzed for product constituents listed in material safety data sheets (SDS). Results were then compared with established regulatory standards and published toxicity criteria for aquatic species.

The maximum concentration of styrene for UV cured CIPP installation was 12.9 mg/L. Toxicity thresholds of this contaminant were exceeded for six subsequent sampling events. Acrylate monomer concentrations did not exceed toxicity thresholds.

For this study, control samples were collected at each sampling event for water quality analysis. However, no QA/QC in sampling was done. Sampling duration and frequencies were different for each of the three pipes.

Strengths: Tests were performed with respect to the concentrations of actual monomers in the water post-CIPP installation, which no other study has done. Immersion test and flowing water test were performed on-site, which gives more insight towards variation of the styrene concentration with change in resin and curing type.

Weaknesses: The actual methodology of analysis for the styrene and the resin monomers is not reported. In addition, there was no QA/QC followed for sampling.

Paper No. A14: Odor Control - More Than Sewage When Installing Cured-In-Place Sewer Pipe Liners

Citation: Bauer, G., and McCartney, D. (2004). "Odor Control - More Than Sewage When Installing Cured-In-Place Sewer Pipe Liners." *Proceedings* of the North American Society for Trenchless Technology (NASTT) No-Dig Conference, New Orleans, LA.

This paper presents knowledge gained during a cured-in-place installation in the City of Ottawa. Styrene levels were monitored throughout the pipe lining process, and the results are presented and a successful odor control strategy explained.

The data sample collected was for two of the liner stretches where odor complaints occurred, related to poor plumbing connections in the sewers. The highest concentration of styrene was 110 ppm in the case study 1. The time-weighted average as per ACGIH is 20 ppm and the short-term exposure limit is 40 ppm. In both the case studies, the styrene level exceeded this limit several times. The highest level of styrene recorded in homes in this study was 2.5 ppm, which could be sensed by human beings. The employee chemical exposure is not reported in this report.

In this study, for each section being rehabilitated, calibration was carried out for the air monitor using a two-point calibration procedure. The working of air monitoring device was verified intermittently by taking it to streets and measuring air quality. Airflow direction was considered for air monitoring. Even the two cases studied here show high variations in styrene levels throughout the process. Hence, the data sample collected cannot be said to represent the whole population.

<u>Strengths</u>: Air monitoring was conducted, and odor complaints were addressed. Calibration and verification of air monitor was done intermittently.

<u>Weaknesses</u>: Air monitoring did not start prior to the CIPP installation and was delayed.

Paper No. A15: Environmental Effects of Cured-in-Place Pipe Repairs

Citation: Caltrans Division of Research and Innovation-Preliminary Investigation (2012). "Environmental Effects of Cured-in-Place Pipe Repairs." Produced by CTC & Associates LLC, August 2012.

This study conducted a literature search about the effects of CIPP on the environment and responsible methods and practices for using CIPP, with a focus on finding related studies by or on behalf of other state transportation agencies. They contacted Insituform Technologies, a CIPP manufacturer, regarding the environmental impacts of using CIPP. This study performed a brief survey of members of the AASHTO Standing Committee on the Environment regarding DOT use of CIPP, asking whether they have faced water quality problems and how they have addressed them.

They conducted follow-up phone interviews with four of the participating DOTs: New York, Oregon, Virginia and Washington. All the available research reports were reviewed. A follow up was conducted with states, which did not respond to the survey.

The data sample collected is from literature and surveys from 15 states and from the analysis they have done. This does not represent the whole population. The references do not support conclusions. There are references of Arkansas DOT and other DOT studies; however, weightage was given to VDOT studies. VDOT has done an extensive research on effect of CIPP on water quality. Other DOTs have done so also. The literature review is from journal articles and is peer reviewed.

<u>Strengths</u>: A detailed study with respect to effect of CIPP on water quality was probed, which is a positive factor for this study.

<u>Weaknesses</u>: The survey was focused on water quality only. Questions pertaining to air quality and soil contamination due to CIPP were not asked or reviewed in the literature. Not all states were surveyed.

Paper No. A16: Industrial Hygiene Evaluation: CIPP-Styrene Exposure

Citation: Willett, M. (2017). “Industrial Hygiene Evaluation: CIPP-Styrene Exposure.” Prince William County Service Authority, Woodbridge, VA.

Industrial hygiene sampling of Prince William County Service Authority (PWCSA) employees during contractor installation of cured-in-place piping (CIPP) was conducted in an effort to obtain initial styrene exposure data on two employees working with two different contractors working in neighborhoods serviced by PWCSA. A sampling strategy was devised by the PWCSA Safety and Security Program Manager and Circle Safety & Health Consultants to measure both time weighted average (TWA) exposures as well as ceiling and STELs. Air samples were taken in the breathing zone of the employee in order to estimate the amount of contaminant that would enter the body via the lungs without respiratory protection. Organic vapor badges were used for measuring styrene TWA exposure. A Honeywell ToxiRAE Pro PID (photoionization detector) single gas monitor with the correction factor set for styrene was used to measure averages, STELs and peaks/ceiling levels of for organic vapors.

Briefly, results of the air sampling found exposure levels below the detection limit for both passive badges. The real-time gas monitors picked up spikes in exposure when employees walked near the open truck, which hauled the lining, and when walking near the installation, especially near the exhaust end of the line. Even with these periodic exposures, average exposures (both time weighted averages and short-term exposure limits) were below recommended standards.

The samples collected do not represent the whole population. Only two employees wore the styrene badges. However, one of monitors was turned off due to low battery, not recording complete data. There was high odor issue reported in this study. Lab analysis were conducted as per NIOSH regulations and hence is verified.

Strengths: QA/QC is reported for the lab analysis. Weather data was collected. Employee exposure of styrene due to CIPP was studied.

Weaknesses: The study was restricted to two locations. The PC monitor turned off due to low battery, without recording entire data. Hence, the study may not be conclusive.

CHAPTER 4

REVIEW OF EUROPEAN (GERMAN, DUTCH, AND BRITISH) RESEARCH AND LITERATURE

4.1. Introduction

Within scope of this project, Institute for Underground Infrastructure (IKT) carried out a literature review **on scientific publications related to emissions associated with the CIPP installation process,** focused on the German-speaking area in Europe, the United Kingdom and The Netherlands. Open access information and web pages of national agencies in Germany as well as special local databases of European universities, research organizations and electronic science magazines were examined. The available information was collected and categorized. A follow-up was undertaken by phone with selected experts. IKT prepared interview transcripts for these and has analyzed the information provided. Based on these results, IKT has prepared this report of the main conclusions with reference to the German sources.

4.2. Styrene Limit Values in Germany, Netherlands and UK

According to the German Ordinance on Hazardous Substances (Gefahrenstoffverordnung – GefStoffV), the occupational exposure limit is the limit for the time-weighted average concentration of a substance in the air at the workplace in relation to a given reference period. It indicates at which concentration of a substance acute or chronic harmful health effects are generally not expected (§ three, Abs. 6, GefStoffV).

According to this ordinance, occupational exposure limits are set as mean shift values, usually with a daily 8-hour exposure for 5 days a week during working life. The occupational exposure limit of styrene is 20 ppm (86 mg/m³).

In the United Kingdom, this occupational exposure limit is called Time Weighted Average (TWA), also based on an 8-hour working day and a 40-hour working week (British Health and Safety Executive (HSE) guidance EH40/2005). The Time Weighted Average value for styrene is 100 ppm.

In Dutch literature, a maximum workplace concentration (MAC) is used (see www.ser.nl/en/grenswaarden/styreen.apsx). The MAC-value for styrene is 25 ppm (107 mg/m³). According to the German Ordinance on Hazardous Substances, exposure peaks during a work shift are assessed with short-term values as follows: styrene has an exceedance factor of two. Operational monitoring should be performed by metrological averaging over 15 minutes, e.g. through a 15 minute sampling. Specifically, this means that the occupational exposure limit for styrene of 20 ppm (86 mg/m^3) may be exceeded by a maximum of two-fold (40 mL/m³) for a period of 15 minutes (maximum 4 times per work shift).

This is similar to the British Health and Safety Executives (HSEs) guidance EH40/2005 Workplace exposure limits. This sets out a Short Term Exposure Limits (STEL), which is the concentration to which workers may be exposed continuously for a short period of time (usually

15 minutes). This is without suffering irritation, chronic or irreversible tissue damage or narcosis, of a sufficient degree to increase the likelihood of accidental injury, impair self-rescue or materially reduce work efficiency if the daily TWA is not exceeded. The STEL for styrene in the UK is 250 ppm (1075 mg/m^3). Table 4.1 gives an overview of the Occupational Exposure Limits for styrene in Germany, the Netherlands and the UK.

Table 4.1. Occupational Exposure Limits for Styrene in Germany, Netherlands and UK

Location	**Germany**	**United Kingdom**	**The Netherlands**
Exposure Limits	Occupational Exposure Limits (Arbeitsplatzgrenzwert – AGW)	Occupational Exposure Limits	Maximum Workplace Concentration (Maximaal Aanvaarde Concentratie – MAC)
Standards	German Ordinance on Hazardous Substances (Gefahrenstoffverordnung–GefStoffV)	British Health and Safety Executive (HSE) guidance EH40/2005 Workplace exposure limits	Gezondheidsraad RA 8/89
Time Weighted Average	20 ppm (86 mg/m^3)	100 ppm (430 mg/m^3)	25 ppm (107 mg/m^3)
Short Term Exposure Limit	40 ppm (172 mg/m^3)	250 ppm (1,080 mg/m^3)	N/A

4.3. Results of the Literature Search/Literature List

Table 4.2 presents results of the literature review of styrene measurements during CIPP-lining.

Table 4.2. Results of the Literature Review of Styrene Measurements during CIPP-Lining

No.	Location	Title	Authors	Notes
1	Germany	Untersuchungen der bei Kanalsanierungen mittels Schlauchliningverfahren auftretenden Styrolemissionen, sowie die Vereinheitlichung der Probennahme und Analysemethoden, die Festsetzung von Grenzwerten, die Optimierung der Sanierungsverfahren, sowie die Erarbeitung von allgemeingültigen Ausschreibungsempfehlungen (Abschlussbericht, 26.09.2004) Investigation of styrene emissions occurring during pipe rehabilitation with CIPP-Lining and the standardization of sampling and analytical methods, the setting of limit values, the optimization of rehabilitation procedures, and the development of general tender recommendations (Final Report, 09-26-2004)	N/A	See App. B, paper B1
2	Germany	Styrolemissionen beim Einbau von Linern (Prüfberichte von 2007, 2008 und 2013) Styrene emissions during installation of a CIPP-liner (Test Reports from 2007, 2008 and 2013)	Homann, Dieter; Homey, Claudia; Smarsly, Claudia; Leying, Nicole;	See App. B, paper B2
3	Germany	Styrolmessung (in einer Ruhrgebietsstadt, anonymisiert) (Prüfbericht von 2011) Styrene measurement (in a City of the Ruhr Area, anonymized) (Test Report from 2011)	Homann, Dieter; Kötters, Stefan	See App. B, paper B3
4	Netherlands	RIVM (Rijksinstituut voor Volksgezondheid en Milieu, Nederland) rapport 609021038/2006 Rioolrenovatie met kousmethoden - Achtergronden bij het informatieblad RIVM (National Institute for Health and Environment, Netherlands) report 609021038/2006 Sewer renovation with lining techniques – backgrounds in the information sheet	Dusseldorp, A.; Schols, E.	See App. B, paper B4
5	UK	TRENCHLESS OPPORTUNITIES REPORT for WESSEX WATER SERVICES Styrene Considerations (Strictly Confidental, 2016) Including: - Health risks associated with airborne styrene release from CIPP lining sites - Styrene Site Report “Ensbury Park Road, Bournemouth, BH9 2SQ” (OnSite) - Styrene Site Report 2 “Cavendish Road, Bath” (OnSite) - Styrene Site Report 3&4 “Newbridge Road, Bath” (OnSite) - Styrene Site Report 5 “Ludgersall Road, Collingbourne Ducis” (OnSite) - Report on hazardous substances “Newbridge Road, Bath”(AirTech) - Report on hazardous substances “Ludgershall Road, Tidworth” (AirTech) - Executive Summary 25th March 2016	Downey, D. B.	See App. B, paper B5

4.4. Literature Reviews Summary

The literature review on German studies found that there is only one case to date where emission measurements are made on steam-cured CIPP-liners (see Appendix B, Paper B3). The background to this is that the steam hardening process is predominantly used in CIPP by needle felt. In Germany, at least for the public sewers, this CIPP-method is declining sharply and styrene-containing resins are not used in the lateral connections to private property drainage pipes.

A good database on with steam-cured CIPP was found in the UK, comprising specific examples of rehabilitation work where styrene concentration was measured. In some of these cases, a significant styrene emission in the air was detected (23 ppm to 165 ppm). Consequently, specific measures had to be taken to protect employees and to maintain a minimum distance to members of the public (see Appendix B, Paper B5). A direct comparison between steam curing and water curing shows a lower styrene concentration in the air for water curing.

The study from The Netherlands contains a small amount of information about CIPP procedures and measurement technologies used, and the boundary conditions (see Appendix B, Paper B4). More detailed information could not be obtained. On the sides in the Netherlands, values of styrene concentrations in the air were measured up to 300 ppm (short peak in the air of a manhole during draining the water).

Particularly in Germany, there is comprehensive information available about the migration of styrene into soil, water and air during installation of CIPP (mainly UV-cured). In a research project titled “Bielefeld” (funded by the Ministry of the environment of North Rhine-Westphalia, see Appendix B, Paper B1), a test rig for CIPP was developed and evaluated, which can be used for emission measurements of styrene into soil, groundwater and air.

That study did not detect contamination by styrene in soil and groundwater. Regarding measured styrene emissions to air, it recommends preventing unauthorized persons approaching within 5 m of the lining work. By applying the corresponding quality assurance, the risk for the local residents is restricted to perception of odors.

The study covered CIPP with steam, water and UV cure. There are no information available about the allocation of styrene concentration to the curing procedure. Furthermore, there are no Information about measurement methods applied, instruments and individual measured values.

Findings from the specific application of this testing procedure at IKT’s testing center in 2007, 2008 and 2013, (see Appendix B, Paper B2) were that styrene concentrations observed in the air from UV curing were safe in all cases, because they complied with the air limit value or occupational limit. Table 4.3 presents results of the measurements from literature reviews.

Table 4.3. Results of the Measurements

No.	Paper	Country	Type of Cure	Information of Styrene Emissions		
				Maximum Measured Values	**Location of Maximum Measured Value (Stage of Work)**	**Measurement Method/Instrument**
1	Investigation of styrene emissions occurring during pipe rehabilitation with CIPP-Lining and the standardization of sampling and analytical methods, the setting of limit values, the optimization of rehabilitation procedures, and the development of general tender recommendations	Germany	Steam, Water, UV	N/A	N/A	See App. B, paper B1
2	Styrene emissions during installation of a CIPP-liner	Germany	UV	0.01386 – 0.01363 ppm (0.006 - 0.059 mg/m^3)	Air layer of the test rig, closed and sealed against the ambient air (unknown)	See App. B, Paper B2
3	Styrene measurement (in a City of the Ruhr Area, anonymized)	Germany	Steam	20 ppm (86 mg/m^3)	5 m from termination manhole in 1.5 m height above the road surface (During curing)	See App. B, Paper B3
4	RIVM report Sewer renovation with lining techniques	Netherlands	N/A	300 ppm (1290 mg/ m^3)	manhole downstream (During draining the water)	N/A
5	Trenchless opportunities report for WESSEX WATER SERVICES Styrene Considerations	UK	N/A	N/A	N/A	N/A
	Newbridge Road Site 1	N/A	Steam	165 ppm (709.5 mg/m^3)	Termination Manhole (During heating)	See App. B, Paper B5
	Newbridge Road Site 2	N/A	Steam	152 ppm (653.6 mg/m^3)	Termination Manhole (During curing)	See App. B, Paper B5
	Ludgershall Road	N/A	Water	23 ppm (98.9 mg/m^3)	Intermediate manhole (During end cutting)	See App. B, Paper B5
	Ensbury Park Road	N/A	Water	63 ppm (270.9 mg/m^3)	Inversion manhole (During inversion)	See App. B, Paper B5

No.	**Paper**	**Country**	**Type of Cure**	**Information of Styrene Emissions**		
				Maximum Measured Values	**Location of Maximum Measured Value (Stage of Work)**	**Measurement Method/Instrument**
	Cavendish Road	N/A	Water	57 ppm (245.1 mg/m^3)	Inversion manhole (During heating)	See App. B, Paper B5

CHAPTER 5

WORK PLAN FOR PHASE 2: DATA COLLECTION AND ANALYSIS

5.1. Overview

The work scope described below is designed to provide a comprehensive evaluation of air emissions from steam-cured cured-in-place pipe (CIPP) installations and potential impacts on workers and the surrounding community. It calls for measurement of styrene and other organic compounds at six CIPP installation sites, representing different pipe diameters (8”, 12”, and larger) and lengths, to capture variation in emissions. Measurements will be conducted before, during, and after curing at the termination manhole, as well as various locations in the surrounding outside area and inside nearby buildings. Worker exposure will also be measured via personal exposure monitors. Finally, dispersion modeling will be conducted to estimate compound concentrations at a large number of locations for a wide variety of meteorological conditions. Measured and modeled concentrations will be compared to appropriate health-based action levels to determine if any potential health risks exist for workers or citizens in the surrounding community.

5.2. Motivation

Concerns have arisen regarding the potential release of organic chemicals in the steam exhaust and other release points during pipe rehabilitation using the trenchless, steam-cured, Cured-In-Place Pipe (CIPP) method. Safety and health is of utmost importance, and that standards are in place to protect contractors, construction workers, the public and the environment.

A number of previous studies have examined the potential release of organic chemicals into stormwater runoff and surrounding water bodies during steam-cured CIPP installations. Only a few studies, however, have adequately sampled and measured the potential release of organic chemicals into air. These previous air studies have largely focused on emissions exiting the terminal manhole directly and have not comprehensively examined potential impacts on workers or the surrounding community. Spatial variation of concentrations, and variations in concentrations with different meteorological conditions, are not well determined. Studies also do not adequately capture variations in concentrations from different kinds of pipe installation (different diameters and lengths, etc.).

The work scope described below is designed to fill the gaps in the existing literature by providing a more comprehensive evaluation of air emissions from the steam cured CIPP, and potential impacts on workers and the surrounding community. The work scope allows evaluation regarding the presence of the chemicals below at a steam-cured CIPP job site and whether they, along with styrene, pose health concerns due to potential levels of exposure.

5.3. Compounds of Interest

Past literature reviews claim that steam-cured of CIPP potentially emits the following compounds:

- Acetone*
- Benzaldehyde
- Benzene*
- Benzoic acid
- 1,3-butadiene*
- Carbon disulfide*
- Carbon tetrachloride*
- Chloroform*
- Cyclohexane*
- 1,4-dioxane*
- Ethanol
- Ethyl acetate*
- Ethylene glycol
- Ethylbenzene*
- Hexane*
- Isopropanol*
- Isopropylbenzene
- p-isopropyltoluene
- 2-methylbutane
- 2-methyl-2-butanol
- Methylene chloride
- Methyl ethyl ketone (MEK)*
- 2-methylnaphthalene
- Naphthalene
- Propionitrile
- n-propyl benzene
- Styrene*
- Toluene*
- 1,1,2-trichloro-1,2,2-trifluoroethane
- Trans-1,3-dichloropropene
- 1,2,4-trimethylbenzene*
- 1,3,5-trimethylbenzene*
- m,p-xylene*
- o-xylene*

Compounds marked with a "*" are on the US Environmental Protection Agency's (EPA) TO-15 list "*Determination of Volatile Organic Compounds (VOCs) In Air Collected In Specially-Prepared Canisters and Analyzed By Gas Chromatography/Mass Spectrometry (GC/MS).*" The selected research team will measure and model TO-15 compounds, as described below.

5.4. Field Site Measurements of Compounds within and Around the CIPP Work Area

5.4.1. Site Selection

At least six test locations (jobsites) will be selected in conjunction with NASSCO. CIPP installation procedures at each site selected should be in accordance with NASSCO best practices. Sites will be selected to represent a range of emission scenarios, including:

A. Three sites with different pipe diameters (8", 12", and larger, e.g., 24"), with approximately the same length;

B. Two sites with the same pipe diameter, but different pipe lengths;

The sites will represent the following controls at minimum:

- Only unsaturated polyester resin will be used (styrenated).

- Only AOC and Interplastic resins will be used.

- Steam-cured only.

- Sites away from large traffic sources and other emission sources will be selected if possible to minimize interference.

At least two sites with publicly accessible or vacant buildings in close proximity to the termination manhole will be selected, so that concentrations inside these buildings can be measured. In addition, the impact of buildings in terms of downwash and limits on dispersion can be assessed.

5.4.2. Measurement of Air Emissions Directly from Termination Manhole

For each site selected in 5.4.1, measurements of concentrations of TO-15 pollutants will be conducted of steam exhaust and emissions coming directly from the termination manhole. Concentrations will be measured using either:

1. A device that continuously records instantaneous readings (e.g., portable/mobile mass spectrometer (MS)) or,

2. A device that collects time-averaged samples (e.g., canisters or sorbent tubes with subsequent lab GC/MS analysis according to EPA TO-15, or similar appropriate method).

Instantaneous readings are preferred because they better capture variation in the data.

Multiple concentration measurements will be conducted during each phase:

- Before curing (15 min. of continuous measurement or a 15-min. time-averaged sample),

- During curing (15 min. of continuous measurement or a 15-min. time-averaged sample),

- At the time that curing is completed and the CIPP is opened to the atmosphere (15 min. of continuous measurement, or 3 5-min. time-averaged samples),

- Additional post-opening measurements (1-hour of continuous measurement or four 15-min. time-averaged samples).

In addition to concentrations, the following measurements and observations will be conducted at each terminal manhole:

- Multiple measurements of flow velocity and temperature of the steam plume and the gas from the curing liner,

- Diameters and heights of the release points for the steam plume and curing liner.

5.4.3. Measurement of Compounds in Air in the Area Surrounding the Termination Manhole

For each site selected in 5.4.1, measurements of concentrations of TO-15 pollutants will be conducted within and around the CIPP work area, to assess potential exposure of workers and the surrounding community. Concentrations will be measured using one of the methods listed in Section 5.4.2. Multiple measurements will be made to assess variability in concentrations as functions of time and space as follows:

Measurements before liner installation (and before refrigerated truck holding the liner is opened):

- Upwind background readings (15 min. of continuous measurement or a 15-min. time-averaged sample) to evaluate concentrations of pollutants entering the site,

- Baseline readings at the initiation (inlet) manhole (15 min. of continuous measurement or a 15-min. time-averaged sample).

Measurements during curing:

- At the steam/air manifold, before the air/steam mixture enters the pipe (15 min. of continuous measurement or a 15-min. time-averaged sample).

- Downwind of termination (outlet) manhole (15 min. of continuous measurement, walking around to capture different locations, or 5-min. time-averaged samples at three or more locations).

Measurements after curing:

- Downwind of termination manhole (1-hour of continuous measurement, walking downwind at least 100 ft to capture different locations; or at least 10 5-min. time-averaged samples at different locations).

- Crosswind from termination manhole (1-hour of continuous measurement, walking crosswind at least 50 feet on each side of the termination manhole to capture different locations; or at least 10 5-min. time-averaged samples at different locations, 5 on each side of the manhole).

5.4.4. Meteorological Measurements

Compound concentrations downwind of a source are a function of:

1. The emission rate of the source, and

2. Atmospheric conditions, which transport and dilute pollutants.

The area measurements made in Section 5.4.3 are specific to the meteorological conditions on the day of sampling. So that we know the meteorological conditions on the day of sampling, meteorological measurements will be conducted.

At each of the six sites, a portable meteorological station will be used during monitoring to continuously measure wind speed, wind direction, temperature, relative humidity, atmospheric pressure and solar radiation, which are parameters likely to impact downwind concentrations. Meteorological measurements will be made during the entire period that concentration measurements are being conducted.

5.4.5. Personnel Sampling: Workers

To assess potential risk to workers over the course of a workday, personnel sampling will be conducted for two persons at each of the six sites over an 8-hour shift. The persons chosen for sampling will include the person who opens the truck to take out the uncured liner, and the person(s) who feeds the liner into the inlet manhole.

Sampling will be conducted using sorbent tubes, with subsequent analysis according to EPA TO-15. The tubes will be attached to each person’s collar or shirt near the breathing zone, in order to represent the actual inhalation exposure without respiratory protection. Battery-operated personal sampling pumps will be used to maintain a constant flow rate to collect compounds on sorbent tubes.

5.4.6. Measurement of Indoor Concentrations in Buildings Near the Work Site

For at least for two sites, concentrations will be measured indoors in a building near the work site. This will allow measurement of any compounds that migrate through lateral piping into the building. Measurements will be conducted before the beginning of liner installation (15 min. of continuous measurement or a 15-min. time-averaged sample), and after the CIPP is opened to the atmosphere (1 hour of continuous measurement, or four 15-min. time-averaged samples).

In addition, follow-up measurements will be conducted at the buildings to determine any residue of chemical compounds on surfaces, outside and inside.

5.4.7. Condensate Analysis

At each of the six sites, three samples of condensate will be collected after the steaming, and thus curing, is finished, and it is safe to collect the sample. Collection of the samples will required confined-space entry training, as well as appropriate personal protective equipment. It is recommended therefore that workers conducting the CIPP installation collect the samples.

The condensate samples will be analyzed for the compounds listed in 4.3 using GC/MS. Liquid-liquid extraction with ethyl acetate or a similar solvent will enable direct injection of the extract into the GC/MS for speciation and quantitation.

5.4.8. Other Measurements

At each site, heights of the buildings surrounding the termination manhole will be determined (to the nearest foot if possible); this information is needed for the dispersion modeling to be conducted in Section 5.5.

In addition, observations will be made of degree to which installation procedures follow standard guidelines, along with safety protocols and personal safety gear of workers (PPEs).

5.4.9. QA/QC

Source emission rate and ambient air monitoring: Blanks and standards will be measured, and instruments will be calibrated as appropriate.

Personnel sampling: After sample collection, the sorbent tubes will be immediately sealed, and transported to the laboratory for analysis in black bags to prevent any photo-driven reactions from occurring. Tube blanks (carried to the site but not worn by personnel) will also be analyzed. Two tubes will be attached to two of the persons, to provide sample duplicates. GC analysis duplicates will be measured.

5.5. Dispersion Modeling of Compound Concentrations under Various Meteorological Conditions

Air quality dispersion models are used to estimate air pollutant concentrations in the atmosphere. Given information about a source configuration and emission rate, dispersion models can estimate concentrations at any location downwind for any type of meteorological conditions. By running the model for a year’s worth of hourly meteorological data, maximum or worst-case concentrations can be estimated.

An appropriate model and software such as AERMOD will be used to estimate concentrations around the termination manhole at each of the six sites, using the following information:

- Source information: GPS data will be used to locate the terminal manhole on the software UTM coordinate system. Source information (emission rates, flow velocities, temperatures, release heights, and release diameters) measured in Section 5.4.1 will be used as model inputs. The termination manhole will be modeled as a point source. The compound with the highest concentration to Effects Screening Level ratio (https://www.tceq.texas.gov/toxicology/database/tox) will be modeled as a worst case.

- Meteorological data: A year’s worth of hourly meteorological data from the closest available surface and upper air stations will be modeled, to encompass variability in meteorological conditions.

- Building downwash: Dimensions of buildings surrounding the termination manhole will be input into BPIP or similar software to capture plume building downwash effects.

Heights of surrounding buildings will be estimated in Section 5.4.2. Building lengths and widths can be estimated using appropriate aerial photographs and Google Maps.

- Receptor grid and terrain data: A Cartesian receptor grid with 3 m x 3 m spacing will be utilized. The extent of the receptor grid will be large enough to capture maximum plume concentrations. A 7.5-minute digital terrain data will be utilized, covering the extent of the receptor grid.

- Averaging time: A 1-hour averaging time will be selected in the software.

- Output: Model output will include maps showing concentration isopleths superimposed over aerial photographs of the site. In addition, the percent of hours of the meteorological data that result in exceedances of the Effects Screening Level at one or more receptor locations will be provided.

5.6. Determination of Health Risks

Measured and modeled air concentrations from Sections 5.4 and 5.5 will be compared to appropriate health-based action levels, to determine if any potential health risks exist for workers or citizens in the surrounding community. Appropriate health-based action levels include Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs), American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs), Effect Screening Levels and Air Monitoring Comparison Values Texas Commission on Environmental Quality (TCEQ) Texas Air Monitoring Information System (TAMIS) database, and other appropriate values.

5.7. Project Report

The project report will include methods, data collected, analysis, and findings from Sections 5.4 and 5.6 above. In particular, maximum and average concentrations measured at each site will be reported, along with standard deviations.

To determine if any potential ***health risks*** exists for the workers and/or persons in the surrounding community, dispersion model output will be provided, measured and modeled air concentrations from Sections 5.4 and 5.5 will be compared to appropriate health-based action levels. Statistical analyses will be conducted as appropriate.

To determine the ***impact of CIPP installation procedures and pipe characteristics***, concentration measurements will be compared for different CIPP diameters and lengths. In addition, estimates of styrene emissions per pound of resin cured will be compared for the different CIPP pipes studied.

Findings from Sections 5.4 through 5.6 will be compared to findings reported in the literature as per UTA/CUIRE report. The final report should be comprehensive, conclusive and use a scientific/technical methodology to address any further questions and doubts regarding steam-cured CIPP installations. Peer review of the research approach and findings is required. In addition to above, the research team must come up with their own suggestions and testing procedures to properly eliminate any concerns and doubts in this area.

5.8. Cost Estimate

Table 5.1 presents the summary of budget for Phase 2 considering six sites and two options.

Table 5.1. Summary of Budget for Phase 2 Considering 6 Sites

Item	**Option 1**	**Option 2**
	Canister/ Sorbent Tube	**Mobile MS**
Personnel	$62,000	$62,000
Materials and Analyses	$61,000	$21,000
Travel**	$12,000	$12,000
Overhead	$55,400	$33,800
TOTAL*	**$190,400**	**$128,800**

Table Notes:

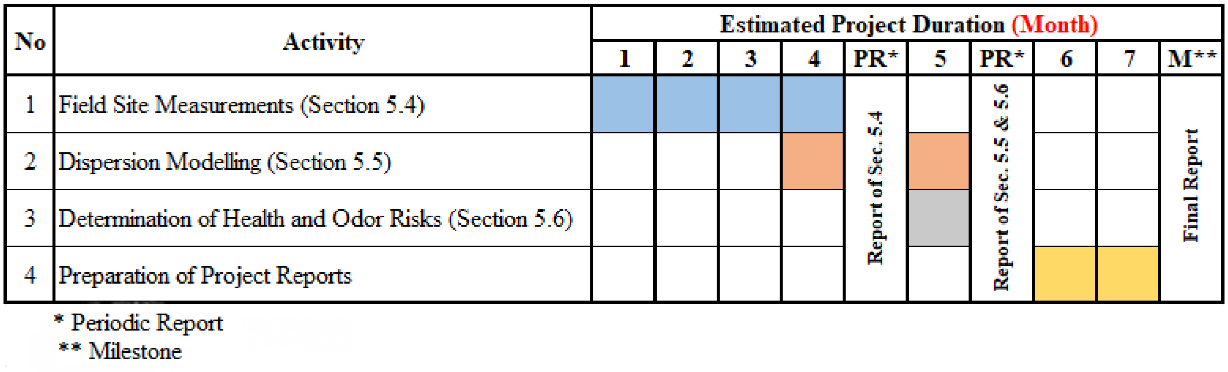
*Total is either $190,400 (<u>$31,700 per site</u>) or $128,800 (<u>$21,500 per site</u>), dependent on whether canister/sorbent tube or mobile MS approach is chosen. Mobile MS option includes rental cost for two portable MS units.

**Additional travel money was included as contingency, since project locations were not determined.

5.9. Schedule

Table 5.2 presents proposed Phase 2 schedule.

Table 5.2. Proposed Phase 2 Schedule



No	Activity	Estimated Project Duration (Month)									
		1	2	3	4	PR*	5	PR*	6	7	M**
1	Field Site Measurements (Section 5.4)	🟦	🟦	🟦	🟦	Report of Sec. 5.4		Report of Sec. 5.5 & 5.6			Final Report
2	Dispersion Modelling (Section 5.5)				🟧		🟧				
3	Determination of Health and Odor Risks (Section 5.6)						▨				
4	Preparation of Project Reports								🟨	🟨	

* Periodic Report
** Milestone

APPENDIX A

CUIRE (U.S.) LITERATURE REVIEWS

Paper No. A1

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

Citation: Sendesi, S., Ra, K., Conkling, E., Boor, B., Nuruddin, M., Howarter, J., Youngblood, J., Kobos, L., Shannahan, J., Jafvert, C. and Whelton, A. (2017)." Worksite Chemical Air Emissions and Worker Exposure during Sanitary Sewer and Stormwater Pipe Rehabilitation Using Cured-in-Place-Pipe (CIPP)." Environmental Science & Technology Letters, 4(8), 325-333.

Part A: Literature 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. Compounds 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. A real-time photoionization detector monitoring showed emissions varied significantly and were a function of location, wind direction, and worksite activity.

Introduction

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. Compounds emitted from the CIPP worksites were condensed and characterized.

Objectives

The main objectives of this report are:

- To conduct real-time emission monitoring using PIDs and videotaping,
- To chemically characterize the uncured resin-impregnated tube,
- To examine the chemical characteristics and toxicological significance of emitted compounds

Methodology

Seven steam-cured CIPP installations were monitored in Indiana and California. Air sampling manifolds were installed to capture materials emitted into the air. PIDs were used for real-time emission monitoring. The condensate cytotoxicity was evaluated for styrene-based CIPP installations in California.

For Indiana, air sampling was conducted during CIPP installation for two 45.7 cm inside diameter vitrified clay sanitary sewer pipes. Chemicals in the uncured resin tube were extracted into methylene chloride and hexane to obtain resin tube extracts that were analyzed by GC/MS. For site 1, a PID was used to monitor chemical emissions at the refrigerated truck that transported the uncured resin tube and near the upstream and downstream manholes. For site 2, the PID was used to measure chemical emissions immediately above a section of uncured resin tube cut from the main pipe segment before curing. The PID did not measure styrene directly, but detected a response to what may have been a mixture of compounds.

For California, CIPPs were installed in one concrete and four corrugated metal pipes at an outdoor research site. One CIPP was manufactured with a low volatile organic compound (VOC) non-styrene resin, and four were manufactured with a styrene-based resin. At each site, air manifolds were set up at an exhaust and fugitive emission point.

Results

In the Indiana investigation of sanitary sewer pipes, uncured resin tube samples were extracted using hexane and methylene chloride from site 2. Hexane extractions showed 67.4 ± 19.7 mg of styrene/gram of tube. Methylene chloride extractions revealed styrene (40.3 ± 8.6 mg/g), butylated hydroxytoluene (BHT) (22.8 ± 14.0 mg/g), and benzaldehyde (2.2 ± 0.7 mg/g). 1-Dodecanol was also detected but not quantified. For the two sites, PID measurements ranged from 0 to 6,231 ppm and were a function of location, type of CIPP activity taking place (tube insertion, steam injection, curing, and venting), wind condition, and vehicle traffic. Site 1 spot PID measurements ranged from 0 to 514 ppm. At site 2, when the PID was located a few centimeters above an excess piece of uncured resin tube, a spot reading of 1,361 ppm was recorded and white material was emitted into the air. A PID response of 6,231 ppm was detected during the curing process. The increase in the magnitude of the PID signal corresponded to the forced introduction of air into the resin tube, before steam was introduced.

In the California Investigation of Stormwater Pipes, styrene was found in greatest abundance compared to other compounds identified. Some condensate compounds were detected in the uncured resin tubes. Non-styrene compounds were likely created during curing and were unreported ingredients in the uncured resin, plastic preliner, plastic coating on the interior of the resin tube, or the polyethylene terephthalate felt. Low-VOC condensate (site 2) contained a quantifiable amount of styrene. Because the uncured low-VOC resin did not contain styrene and Currier found styrene leaching into simulated stormwater from this same CIPP, unintentional contamination by the contractors is suspected. Acetophenone, 4-tert butylcyclohexanol, and 4-tert-butylcyclohexanone were exclusively found in the low-VOC resin condensate. Tripropylene glycol diacrylate (TPGDA) was detected in site 2 and 3 condensates.

The TPGDA flux was greatest for the low-VOC resin site 2 condensate (8.20, 8.99 mg m^{-2} s^{-1}) compared to that of the styrene-based resin site 3 condensate (1.55, 1.59 mg m^{-2} s^{-1}). 4-tert-Butylcyclohexanone and TPGDA were detected only in hexane extracts. Other unidentified compounds were detected in extracts but were not quantified. For the styrene-based resin condensates, no cell viability changes were found for mouse alveolar type II epithelial cells or alveolar macrophages exposed to a diluted condensate with 10 and 100-ppm styrene, but changes were observed for the 1,000-ppm styrene condensate. Differential toxicity between sites indicated toxicity due to non-styrene compounds. Site 4 demonstrated enhanced cytotoxicity compared to that of site 5. These findings support a prior observation that even a dilute condensate (styrene below its Daphnia magna 48 hours LD50) can be acutely toxic.

Conclusions and Recommendations for Future Research

Differential cytotoxicity in alveolar cells occurred even when condensate styrene levels were equivalent and indicated non-styrene compounds contributed to chemical toxicity. The emission of styrene from the non-styrene resin CIPP installation indicated that contractor equipment handling practices affected the resulting chemical emissions. Sampling methods and approaches are needed to better characterize chemical emissions, chemical mixture exposures, and short- and long-term health impacts.

The high temperature, high velocity, and multi-phase emissions posed a challenge in this study. Emission variability was evident by PID readings and video monitoring. Even when the same CIPP contractor used the same resin on the same diameter and type of pipes, the type and amount of chemicals emitted differed. To understand worker chemical exposures and the types and masses of chemicals emitted, their phases, exposure duration and the mixture's toxicological impacts should be investigated. Because there are many resins and CIPP installation variables, and because very few studies have been conducted to characterize air emissions, additional investigations are needed. Limited information exists that enables an understanding of chemical exposure risks to CIPP workers, the public, and the environment.

During this investigation, CIPP workers did not use respirators, resided inside and walked through the chemical plumes and exposures occurred even when plumes were not visible. Contractors also sometimes handled the uncured resin tube and CIPP with their bare hands. Until more CIPP air monitoring and chemical toxicity data are available, it is recommended that persons at or near CIPP sites minimize dermal and inhalation exposures, monitor emissions, use appropriate personal protective equipment, and capture emissions and confirm this by monitoring.

Part B: Reviewer's Critique

Test Methods, Equipment, and Instrumentations Used

Test Methods: PID devices and calibration, gas chromatography/mass spectrometry (GC/MS) methods to analyze uncured resin tube and condensate extracts. Condensate thermal and chemical properties were determined using thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), proton nuclear magnetic resonance (H NMR) spectroscopy and cell cytotoxicity methods are also used.

Equipment and Instrumentation: PID, Tedlar bags, CIA Advantage-Thermal Desorption Unity Series2 instrument, GC/MS instrument

Data and Analysis

QA/QC

- PID sampling done every 2 minutes at Indiana site and every 2 seconds at California site.

- Location of sampling was not uniform for all the sites.

Does the data sample collected represent the whole population?

Data sample represented seven CIPP installation sites. The samples were not representative since the sampling locations and time intervals varied at the two places.

Reporting and detection limits

Not provided

Did the document include employee sampling data from NASSCO companies?

No

CIPP materials used (including resin systems)

L713-LTA (styrene-based resin) and EcoTek (non-styrene-based resin)

Reference Review

Do references support conclusions?

The PID did not measure styrene directly, so comparisons with other studies that measured styrene are not possible.

Peer review documentation of literature or study findings

Peer review of literature

Literature is peer reviewed.

Peer review of findings

Findings are peer reviewed.

Statistical Analysis Presented

What types of models have been used?

No statistical analysis was done.

Were the models used representative, calibrated and validated?

No statistical analysis was done.

Verification of CIPP Product Definition

CIPP product definition is verified for this study.

List of Compounds of Interest

Styrene, benzaldehyde, benzoic acid, BHT, dibutyl phthalate, 1-tetradecanol, phenol, acetophenone, 4-tert-butylcyclohexanol, 4-tert-butylcyclohexanone, and tripropylene glycol

Discussion of Employee/Public Safety and Health Standards and Regulations Including OSHA, ACGIH, NIOSH, and Other Regulatory Limits

The study characterized the chemical emissions for sanitary sewer and stormwater in Indiana and California, respectively. However, no investigation was done to detect and quantify the chemical exposure risks to employees as per the OSHA, ACGIH, NIOSH or any other standards. Styrene was not measured directly, so comparisons with styrene standards cannot be made. The article states the employees were not wearing PPE.

Review of the Data with Respect to Environmental Impacts, Toxicology and Employee Chemical Exposure

As there are many resins and CIPP installation variables, and because very few studies have been conducted to characterize air emissions, additional investigations are needed. Limited information exists that enables an understanding of chemical exposure risks to CIPP workers, the public, and the environment. During this investigation, CIPP workers did not use respirators, resided inside and walked through the chemical plumes and exposures occurred even when plumes were not visible. Contractors also sometimes handled the uncured resin tube and CIPP with their bare hands.

Chemical exposure limits at different locations relative to steam exhaust discharge source

Measurements were not taken at different locations relative to the steam exhaust discharge source.

Determination of Actual Short-Term and Long-Term Health Issues Identified From Odor Complaints As Verified By Professional Medical Personnel

No short term or long-term health issues reported with respect to this study.

Verification of Test methods

Verification of test method in the field

The major field test done was measurement by PID and is a verified method.

Verification of test method in the lab

The analysis in the lab was done using GC/MS with calibration using standards and is verified.

Part C: Overall Review

(Applicability, Originality, Completeness, Limitations, etc. – in own words)

Strengths of the Study

- Measured emissions at 7 sites.
- Measured concentrations real-time using a PID, at exhaust pipe and fugitive emission locations at each site.
- Photographs and graphics provided visual pictures of the CIPP installation and sampling points.

Weaknesses of the Study

- PID response included a number of organics; it was not specific to styrene.
- More sampling locations are required to study downstream wind concentrations of styrene to analyze the impact to public and neighborhood.
- Worker exposure was not measured and no meteorological data was collected.

Paper No. A2

Volatile Organic Compound (VOC) Emission during Cured-in-Place-Pipe (CIPP) Sewer Pipe Rehabilitation

Citation: Ajdari, E. (2016). "Volatile Organic Compound (VOC) Emission during Cured-in-Place-Pipe (CIPP) Sewer Pipe Rehabilitation." thesis, presented to University of New Orleans, LA, in in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Part A: Literature Information

Abstract

Numerous building indoor air contamination incidents indicate that work is needed to understand the magnitude of styrene emission from CIPP sanitary sewer repairs. The main goal of this study was to better comprehend Volatile Organic Compounds emission at three CIPP sanitary sewer installation sites in one U.S. city. Results showed that CIPP chemical emissions might be a health risk to workers and nearby building inhabitants. Additional testing and investigations regarding chemical emissions from CIPP should be commissioned to fill in the environmental and public health knowledge gaps. The acute and chronic chemical exposure risks of CIPP chemical steam constituents and styrene to sensitive populations should be further examined. Other goals of this study were to estimate the magnitude of solid waste generated as well as the amount of certain criteria air pollutants and greenhouse gases emitted from on-site heavy equipment for both CIPP and open-cut sites in a U.S city. The results indicated that the amount of open-cut related solid waste, criteria air pollutants, and greenhouse gases were greater than those during CIPP activities. Additional work is needed to quantify pollutant emissions from CIPP and open-cut activities and consider emissions from a cradle-to-grave standpoint.

Introduction

This study involved measurement of volatile organic compound emissions at three CIPP sanitary sewer installation sites in one U.S. city. It also estimated the magnitude of solid waste generated as well as the amount of certain criteria air pollutants and greenhouse gases emitted from on-site heavy equipment for both CIPP and open-cut sites in a U.S. city.

Objectives

- To chemically identify and quantify VOCs emitted into air at three sites.
- To characterize the steam temperature, flow rate, and velocity from CIPP installation.
- To assess whether potential health impacts may exist.

Methodology

- Sampling equipment used were: Sampler Box (Xitech 1060H high vacuum bag sampler Manufactured by Xitech Instruments, Inc.), 1-L Tedlar Sampling Bag, Pump (flow rate of 3 L/min), LPDE Tubing, Thermometer, Flow Rate and Velocity Meter (VelociCalc Plus model 8384 manufactured by TSI).

- Analysis instruments used were: Gas Chromatography (GC) and Mass Spectrometry (MS) using EPA method 8260B.

- Of 22 pipes in the New Orleans watershed targeted for CIPP, three were chosen for sampling. All three pipes were 8 inches in diameter, and ranged from 235 to 309 feet in length.

- During both curing and cooling procedures, air emissions were observed from two locations per site: manholes and steam hoses. Because the greatest visible amount of chemical steam was emitted through downstream manholes, not upstream manholes, only manholes downstream of each CIPP installation site were sampled for VOC testing. At one site, a sample was also collected on private property near the installation.

- Curing times ranged from 45 to 60 min., followed by 15 min. of cooling time. Samples were collected before curing, during curing, and during cooling.

- 11 air samples were collected among the three sites, including controls. In an effort to limit the potential wind or other uncontrolled environmental conditions that could affect the results, air samples were collected approximately 10 inches inside each manhole. Temperature, flow rate, and velocity were measured exiting the downstream manhole and hose were measured. Air temperature and wind velocity were also measured.

Results

Styrene was the only chemical detected using EPA Method 8260b at any point during the study (out of 67 compounds for which analysis was conducted). Various regulatory styrene exposure limits range from 20 to 700 ppm. Styrene concentrations measured in the manhole exhaust ranged from 250 to 1,070 ppm, indicating that further assessment of potential health risks is warranted. Direct exposure of workers to styrene levels was not measured.

Conclusions and Recommendations for Future Research

Styrene concentrations measured in the manhole exhaust indicated that further assessment of potential health risks is warranted. A follow-up study should be conducted to fully describe chemical emissions during curing and cooling processes and determine if hazards to the CIPP workers and nearby population exist. Real-time air monitoring for styrene and other chemicals should be considered.

Part B: Reviewer's Critique

Test Methods, Equipment, and Instrumentations Used

- Sampling equipment used were: Sampler Box (Xitech 1060H high vacuum bag sampler Manufactured by Xitech Instruments, Inc.), 1-L Tedlar Sampling Bag, Pump (flow rate of 3 L/min), LPDE Tubing, Thermometer, Flow Rate and Velocity Meter (VelociCalc Plus model 8384 manufactured by TSI)

- Analysis instruments used were: Gas Chromatography (GC) and Mass Spectrometry (MS) using EPA method 8260B

- Of 22 pipes in the New Orleans watershed targeted for CIPP, three were chosen for sampling. All three pipes were 8 inches in diameter, and ranged from 235 to 309 feet in length.

- During both curing and cooling procedures, air emissions were observed from two locations per site: manholes and steam hoses. Because the greatest visible amount of chemical steam was emitted through downstream manholes, not upstream manholes, only manholes downstream of each CIPP installation site were sampled for VOC testing. At one site, a sample was also collected on private property near the installation.

- Curing times ranged from 45 to 60 min., followed by 15 min. of cooling time. Samples were collected before curing, during curing, and during cooling.

- Eleven air samples were collected among the three sites, including controls. In an effort to limit the potential wind or other uncontrolled environmental conditions that could affect the results, air samples were collected approximately 10 inches inside each manhole. Temperature, flow rate, and velocity were measured exiting the downstream manhole and hose were measured. Air temperature and wind velocity were also measured.

Data and Analysis

QA/QC

- Calibration of the Xitech 1060H was performed by the rental company before each application.

- Calibration of the VelociCalc Plus model 8384 was performed by the rental company before each usage.

- Control air samples at each job site were also collected before construction activities began.

- For each air sample, a new length of tubing was used to eliminate the potential of sample cross-contamination.

- In an effort to limit the potential wind or other uncontrolled environmental conditions that could affect the results, air samples were collected approximately 10 inches inside each manhole.

- All samples were stored out of sunlight in a cool and dry place.

- GC: internal standards were run.

Does the data sample collected represent the whole population?

Of 22 pipes in the New Orleans watershed targeted for CIPP, three were chosen for sampling. All three rehabilitated pipes in the present study were vitrified clay (VCP). The study does not explain how these 3 pipes were chosen, so it is difficult to determine whether they were representative of the population of pipes.

Reporting and detection limits

Generally 0.5 ppm (during liner inversion and on private property), except for curing and cooling period samples. Specific values are provided in Appendix F of the dissertation for various compounds.

Did the document include employee sampling data from NASSCO companies?

No.

CIPP materials used (including resin systems)

Polyester.

Reference Review

Do references support conclusions?

There were detailed references in the thesis with respect to emissions of styrene air, water & soil. The references support conclusions of this study.

Peer review documentation of literature or study findings

<u>Peer review of literature</u>

The literature in this thesis has its contents from journal articles, and conference. None of them is peer reviewed.

Peer review of findings

The findings are part of a dissertation. The dissertation committee should have reviewed it.

Statistical Analysis Presented

What types of models have been used?

There was no statistical analysis done in this thesis.

Were the models used representative, calibrated and validated?

There was no statistical analysis done in this thesis.

Verification of CIPP Product Definition

CIPP product definition is verified for this study.

List of Compounds of Interest

Styrene was the only chemical detected using EPA Method 8260b at any point during the study.

Discussion of Employee/Public Safety and Health Standards and Regulations Including OSHA, ACGIH, NIOSH, and Other Regulatory Limits

OSHA PEL TWA (8-hour workday); Workers should not experience adverse effect 100 Ceiling Not to be exceeded 200, NIOSH REL TWA (8-10 hour.); Not to be exceeded 50, and STEL TWA (15 min); Not to be exceeded 100.

Review of the Data with Respect to Environmental Impacts, Toxicology and Employee Chemical Exposure

Various regulatory styrene exposure limits range from 20 to 700 ppm. Styrene concentrations measured in the manhole exhaust ranged from 250 to 1,070 ppm, indicating that further investigation of this high reading is required, as it appears that this measurement was taken inside the manhole. The styrene concentration measured on the nearest private property to the downstream manhole at one site was non-detectable.

Chemical Exposure Limits at Different Locations Relative to Steam Exhaust Discharge Source

Chemical exposure at different locations is not available.

Determination of Actual Short-Term and Long-Term Health Issues Identified From Odor Complaints As Verified By Professional Medical Personnel

Health issues due to the CIPP installation pertaining to this study has not been reported.

Verification of Test methods

Verification of test method in the field

- Calibration of the Xitech 1060H was performed by the rental company before each application.
- Calibration of the VelociCalc Plus model 8384 was performed by the rental company before each usage.
- Control air samples at each job site were also collected before construction activities began.
- For each air sample, a new length of tubing was used to eliminate the potential of sample cross-contamination.
- In an effort to limit the potential wind or other uncontrolled environmental conditions that could affect the results, air samples were collected approximately 10 inches inside each manhole.
- All samples were stored out of sunlight in a cool and dry place.

Verification of test method in the lab

For the Gas Chromatograph, internal samples were run to ensure QA/QC.

Part C: Overall Review

(Applicability, Originality, Completeness, Limitations, etc. – in own words)

Strengths of the Study

- The study directly measured styrene and other VOCs from exhaust from steam curing of CIPP at three sites.
- Samples were collected before curing, during curing, and during cooling.
- Sufficient attention was paid to QA/QC.

Weaknesses of the Study

- Exhaust coming directly from the termination manhole was all that was measured (with the exception of one measurement on private property).

- No measurements of direct worker exposure were conducted.

- Concentrations in the surrounding community were only measured in one location at one site.

Paper No. A3

Understanding Environmental Implications of CIPP Rehab Technology

Citation: Kampbell, E. (2009). "Understanding Environmental Implications of CIPP Rehab Technology." Rehabilitation Technology, Underground Technology Cutting Edge Technical Information for Utility Construction and Rehabilitation, 2009.

Part A: Literature Information

Abstract

In May 2008, the Virginia Department of Transportation issued the results of a study (VTRC O8 R16) of which the purpose and scope was "to evaluate the potential for impacts on water quality from use of the steam cured CIPP (cured-in-place pipe) process." Given the potential value of having an independent investigative look at the potential environmental impacts of using styrene-based resin systems in storm water system rehabilitation, the industry looked forward to the gains from such a study, and the potential for having the information available to the consulting engineering community as they continued to increase their usage of CIPP in storm sewer and culvert applications. This article will explore the path of the research, findings of the researchers and their technical conclusions.

Introduction

The Virginia Department of Transportation issued the results of a study of which the purpose and scope was "to evaluate the potential for impacts on water quality from use of the steam cured CIPP (cured-in-place pipe) process." Given the potential value of having an independent investigative look at the potential environmental impacts of using styrenated resin systems in storm water system rehabilitation, the industry looked forward to the gains from such a study, and the potential for having the information available to the consulting engineering community as they continued to increase their usage of CIPP.

Objectives

To explore the path of the research to evaluate the potential for impacts on water quality from use of the steam cured CIPP (cured-in-place pipe) process by the Virginia Department of Transportation (VTRC 08 R16), findings of the researchers and their technical conclusions.

Methodology

- Literature review
- Seven CIPP installation sites monitored, which represented three CIPP installers.
- Samples were tested for the concentration of styrene in the downstream waterway.

Results

The preliminary findings issued in mid-2007 were that the VA DOT should suspend the use of styrene-based CIPP and undertake additional study to understand CIPP; that the DOT should evaluate their contract documents to ensure that CIPP. Contractors are specifically required to prevent the escape or leaching of process residuals (capturing and properly disposing of cure water, steam cure condensate, and escaped resin). If styrene-based CIPP is reinstated, the DOT should ensure that it has proper oversight on hand during the CIPP's installation.

Conclusions and Recommendations for Future Research

It was concluded that "All that CIPP resin systems require is that good housekeeping be practiced by the installation team on the project site." Further, provisions must be made by the contractor in advance for containing any accidental spillage of the resin on the work area. By law. Spills less than the hazardous materials regulated quantity of 1,000 pounds of styrene (2,500 pounds of resin) are to be handled in a responsible manner by the contractor.

It is recommended that the VA DOT perform additional sampling, studies and evaluations of CIPP installations and their effect on the environment, using good sound engineering and testing principles, as follows:

Sanitary Sewers:

- Cure resin system per written curing schedule, and
- Release condensate water directly to receiving sewer while processing

Storm Sewers and Culverts:

- Cure resin system per written curing schedule,
- Based upon receiving waterway's assimilative capabilities:
  - ➢ Detain condensate in a lined holding pond until it cools to ambient,
  - ➢ Discharge water when styrene concentration is confirmed to be less than 25 ppm, or
  - ➢ Retrieve condensate by pumping it into the steam generation truck's reservoir, or
  - ➢ Transport condensate to nearest wastewater treatment facility.

The additional studies should use these defined guidelines in the context of proper installation, following good housekeeping practices to assess the true environmental implications of CIPP rehabilitation technology in culvert and storm sewer rehabilitation.

Part B: Reviewer's Critique

Test Methods, Equipment, and Instrumentations Used

No data available on the test method used.

Data and Analysis

QA/QC

- Timing of the samples taken to measure the styrene content in the downstream waterway was varied; and in some cases, the sampling was delayed until 15 days.
- In several sites, upstream sampling was missed prior to CIPP installation and in several sites, downstream sampling was missed post CIPP installation.

Does the data sample collected represent the whole population?

No, as per the article the data does not represent the whole population.

Reporting and detection limits

Not provided.

Did the document include employee sampling data from NASSCO companies?

No.

CIPP materials used (including resin systems)

Polyester.

Reference Review

Do references support conclusions?

No.

Peer review documentation of literature or study findings

<u>Peer review of literature</u>

The literature was not peer reviewed.

Peer review of findings

The findings were not peer reviewed.

Statistical Analysis Presented

What types of models have been used?

No statistical analysis was presented.

Were the models used representative, calibrated and validated?

No statistical analysis was presented.

Verification of CIPP Product Definition

CIPP product definition was verified.

List of Compounds of Interest

Styrene

Discussion of Employee/Public Safety and Health Standards and Regulations Including OSHA, ACGIH, NIOSH, and Other Regulatory Limits

The maximum limit detected was 44 ppm, which is greater than the limit set by the Safe Drinking Water Act of 0.1 ppm.

Review of the Data with Respect to Environmental Impacts, Toxicology and Employee Chemical Exposure

There was no employee chemical exposure stated in the article. Concentration of styrene pre- and post- CIPP installation was studied. The maximum limit detected was 44 ppm, which is greater than the limit set by the Safe Drinking Water Act of 0.1 ppm. The minimum among the reported value was at site 5, after 30 days, a value of 0.005 ppm.

Chemical Exposure Limits at Different Locations Relative to Steam Exhaust Discharge Source

Chemical exposure at different locations not available.

Determination of Actual Short-Term and Long-Term Health Issues Identified From Odor Complaints As Verified By Professional Medical Personnel

The article does not state any health issue or odor complaints with respect to this study.

Verification of Test methods

Verification of test method in the field

Test method in the field could not be verified due to lack of information.

Verification of test method in the lab

Test method in the lab could not be verified due to lack of information.

Part C: Overall Review

(Applicability, Originality, Completeness, Limitations, etc. – in own words)

Strengths of the Study

Seven sites of steam CIPP installation were studied for styrene concentration in water, with three installers involved in them.

Weaknesses of the Study

- Poor QA/QC.
- No statistical evidence.
- Only steam cured treatment was studied.
- No mention of health impact due to styrene.
- Study does not talk about other water quality analyses and does not focus on soil or air contamination due to CIPP installation.

Paper No. A4

Risk Associated with CIPP Lining of Stormwater Pipes and the Release of Styrene

Citation: Lee, R. K. (2008). "Risk Associated with CIPP Lining of Stormwater Pipes and the Release of Styrene." *Proceedings* of the North American Society for Trenchless Technology (NASTT) NO-DIG Conference, NASTT, Dallas, TX, 2008; Paper E-1-05.

Part A: Literature Information

Abstract

Cured-in-place pipe (CIPP) lining has continued to gain in popularity and use due to the many advantages the technology offers to owners. The speed of installation, the increased social benefits by implementing a trenchless technology, and often the lower construction costs are all very attractive benefits. One of drawbacks, however, is the use of polyester resins in cured-in-place liners that result in the volatilizing of styrene during the curing process. A number of studies in the past have focused on the concentrations of styrene present in the air of residential homes tied to sanitary sewers during pipe lining. However, there has been very few studies done on the impact that styrene has on the environment, especially when lining storm water pipes.

Introduction

In 2006, release of toxic pollutants into the Fairfax County's streams and lakes could have resulted in a fish kill. In this regard, Fairfax County and Malcolm Pirnie decided to undertake a study to determine the concentrations of styrene during and after using CIPP to rehabilitate storm sewers. The first step was to control the discharge of any styrene during installation.

Objectives

This paper discusses the nature of styrene and the impact it has on the environment and the most recent regulatory requirements regarding the release of styrene. The objective of the experimental part of the study was to determine the concentrations of styrene during and after using CIPP to rehabilitate storm sewers.

Methodology

- Precautions were taken to control leaching of styrene resin in to the storm water, and CIPP was flushed twice after cool down process.
- Grab samples were taken by Malcolm Pirnie at various points of CIPP installation.
- Samples were ice packed and sent to TestAmerica for analysis of volatile organic compounds (VOC).
- USEPA SW-846 8260B method was used for testing the Volatile organic compounds.

Results

Results showed that the use of hot water, while controlled, is a longer process and would be the least complete cure. The use of steam as a curing agent, when performed with the proper quality control procedures, should be a complete cure and a lower styrene monomer concentration than a hot water cure is expected. UV, if the light can penetrate the entire thickness of the CIPP, in theory should be the most complete cure. Styrene concentration found on this study for hot water cure after completion of hot water recirculation was 51 mg/L. Hot water cure CIPP after two flushing demonstrated an average styrene concentration of 19 mg/L in storm water. While, a steam cured CIPP installation after two flushing showed an average styrene concentration of 5.5 mg/L in storm water. For both the hot curing process water and steam condensate, the styrene levels are significantly high to cause an impact to wildlife immediately downstream of the rehabilitated storm sewers. In addition, temperature is a pollutant and must be considered. The concentrations of styrene in the flush water after hot water cure are concerning. For example, grab samples from installations of two liners using hot water curing, after flush showed styrene concentration of 21 ppm and 17 ppm.

Conclusions and Recommendations for Future Research

Until regulatory guidelines are clarified and prior to instituting controls on the release of styrene, each municipality should develop site-specific styrene concentrations in accordance with best management practices. This means developing an understanding of what well water users are in the vicinity, determining the types of wildlife that habitat local water bodies, and what concentrations would produce no adverse effect on these species. As for reducing the styrene levels, several options could be tested to determine the styrene reduction effectiveness and the cost effectiveness.

- Add more flushes until the styrene concentrations are at acceptable levels for the specific site being rehabilitated.

- For water cures, consider releasing a higher rate of the cure water into the sanitary sewers as opposed to cycling it through the heater. This could reduce the styrene monomer left in the pipe at the end of the cure.

- Test the effectiveness of a running flush (jet nozzle) versus a volumetric flush.

- Test the effectiveness of using a styrene monomer reducing agent, which polymerizes the residual styrene monomer into inert polystyrene. The polystyrene can be filtered and captured.

Part B: Reviewer's Critique

Test Methods, Equipment, and Instrumentations Used

- Precautions were taken to control leaching of styrene resin in to the storm water, and CIPP was flushed twice after cool down process. Grab samples were taken by Malcolm Pirnie at various points of CIPP installation.

- Samples were ice packed and sent to TestAmerica for analysis of volatile organic compounds (VOC).

- USEPA SW-846 8260B method was used for testing the Volatile organic compounds.

Data and Analysis

QA/QC

- Samples were ice packed which ensured escaping of VOCs from the sample.

- Standard test method used, as per the report.

- No duplicate sample collected nor control samples were collected.

- Grab sample was not collected after a particular time post installation in every case.

- Samples not collected at specific time intervals.

Does the data sample collected represent the whole population?

No, the data sample collected does not represent the whole population, the reason being that the samples were grab sampled and were not done for all the installations.

Reporting and detection limits

No reporting or detection limit was specified in the study.

Did the document include employee sampling data from NASSCO companies?

No

CIPP materials used (including resin systems)

Polyester (Not explicitly mentioned though)

Reference Review

Do references support conclusions?

References talk about the leaching of styrene downstream post CIPP installation and potential environmental impacts. The analysis of grab samples confirmed the leaching of styrene in to storm water. Hence, the references support the conclusion.

Peer review documentation of literature or study findings

Peer review of literature

The literature in the article is peer reviewed.

Peer review of findings

The findings on the article are from the analysis of grab samples. The findings were presented at a conference and not peer reviewed.

Statistical Analysis Presented

What types of models have been used?

No statistical analysis was presented and hence no models.

Were the models used representative, calibrated and validated?

No statistical analysis was presented and hence no models.

Verification of CIPP Product Definition

The CIPP product definition was verified.

List of Compounds of Interest

Styrene was the only compound of interest in this study.

Discussion of Employee/Public Safety and Health Standards and Regulations Including OSHA, ACGIH, NIOSH, and Other Regulatory Limits

Under the Safe Drinking Water Act, the Maximum Contaminant Level permitted for styrene is 0.1 mg/L. However, the average styrene concentration found in this study for hot water cure after completion of hot water recirculation was 51 mg/L. Hot water cure CIPP after two flushings demonstrated an average styrene concentration of 19 mg/L in storm water. A steam-cured CIPP installation after two flushings showed an average styrene concentration of 5.5 mg/L in storm water.

Review of the Data with Respect to Environmental Impacts, Toxicology and Employee Chemical Exposure

A concentration of 9.1 mg/L of styrene is sufficient to kill fish, according to 72 hour and 96 hour tests by the Styrene Producers Association. For hot water cure CIPP after completion of hot water recirculation and hot water cure CIPP after two flushings, both exceeded this value.

Chemical Exposure Limits at Different Locations Relative to Steam Exhaust Discharge Source

There was only a grab sampling done per site and data at different locations is not available.

Determination of Actual Short-Term and Long-Term Health Issues Identified From Odor Complaints As Verified By Professional Medical Personnel

No health issues are reported in the article with respect to the study site.

Verification of Test methods

Verification of test method in the field

Grab sampling with precautions to save volatile compounds from escaping was administered with USEPA SW -846 8260B.

Verification of test method in the lab

The lab method followed for volatile organic compounds was USEPA SW -846 8260B.

Part C: Overall Review

(Applicability, Originality, Completeness, Limitations, etc. – in own words)

Strengths of the Study

- Different types of CIPP installation including water inversion, air inversion and pull-in place, hot water cure, and steam cure were studied with respect to styrene leaching downstream.

- Standard sampling and analysis methods were followed.

Weaknesses of the Study

- Grab sampling done was not at a specific interval or specific time post-CIPP installation.

- Styrene concentrations downstream at different locations were not studied. The grab samples were collected from the CIPP installation site alone and were analyzed.
- No report of control samples or duplicate samples to ensure accuracy and QA/QC.

Paper No. A5

Stormwater Chemical Contamination Caused by Cured-in-Place Pipe (CIPP) Infrastructure Rehabilitation Activities

Citation: Tabor, M., Newman, D., Whelton, A. (2014). “Stormwater Chemical Contamination Caused by Cured-in-Place Pipe (CIPP) Infrastructure Rehabilitation Activities.” Environmental Science & Technology, 2014.

Part A: Literature Information

Abstract

Cured-in-place pipe (CIPP) is becoming a popular U.S. stormwater culvert rehabilitation method. Several State transportation agencies have reported that CIPP activities can release styrene into stormwater, but no other contaminants have been monitored. CIPP’s stormwater contamination potential and that of its condensate waste was characterized. Condensate completely dissolved Daphnia magna within 24 hours. Condensate pH was 6.2 and its chemical oxygen demand (COD) level was 36,000 ppm. D. magna mortality (100%) occurred in 48 hours, even when condensate was diluted by a factor of 10,000 and styrene was present at a magnitude less than its LC50. Condensate and stormwater contained numerous carcinogenic solvents used in resin synthesis, endocrine disrupting contaminants such as plasticizers, and initiator degradation products. For 35 days, COD levels at the culvert outlets and downstream ranged from 100 to 375 ppm and styrene was 0.01 to 7.4 ppm. Although contaminant levels generally reduced with time, styrene levels were greatest 50 ft downstream, not at the culvert outlet. Cured CIPP extraction tests confirmed that numerous contaminants other than styrene were released into the environment and their persistence and toxicity should be investigated. More effective contaminant containment and cleaner installation processes must be developed to protect the environment.

Introduction

Nowadays, cured-in-place pipe (CIPP) technique is being used for the rehabilitation of stormwater culverts in the US. However, several state transportation agencies have reported that CIPP activities can release styrene into stormwater, but no other contaminants have been monitored. Moreover, in situ culvert repair with CIPP is less expensive than open-trench operations and avoids traffic disruption and work zone safety issues.

Objectives

- To characterize the aquatic toxicity and chemical composition of CIPP condensate.
- To identify contaminants released from CIPP materials during a 35-day period.
- To provide recommendations for reducing the stormwater quality impacts of this technology.

Methodology

Two CIPP stormwater culvert installation sites in central Alabama were studied. CIPP at Site 1 had been cured 1 week prior to the research team's arrival (4 ft diameter, 158 ft length, 0.75 in. thick), while Site 2 (4 ft diameter, 235 ft length, 0.75 in. thick) was being prepared for CIPP installation when the research team arrived. Steam curing for the CIPP occurred at 125 °C for approximately 6 to 7 hours. Contractors installed plastic mats upstream and downstream of the culvert to prevent environmental contamination. Three water samples were collected in amber glass bottles with polytetrafluoroethylene (PTFE) lined caps headspace free at the culvert inlet, outlet, and 50 ft downstream. Field and trip blanks were also applied. Grab samples were collected on the water surface from pooled water entering the culvert inlet and downstream. The minimal water flowing out each culvert outlet was completely redirected into the bottle until filled. Onsite water temperature, pH, dissolved oxygen (DO), and turbidity levels were measured. A sample of CIPP condensate waste was also collected. Three large pieces of excess CIPP at Site 2 (3 ft × 4 ft × 0.75 in. thick) were removed from the field and underwent the toxicity characterization leaching procedure (TCLP) at room temperature. A CIPP sample (100 g where 5.08 cm length × 5.08 cm width × 1.9 cm height per CIPP piece) was placed in each extraction vessel along with 2 L of laboratory prepared synthetic stormwater. The CIPP surface area in each vessel was 451.61 square cm/L. TCLP was conducted by applying three 18 hours contact periods.

Water Quality analysis:

- Alkalinity was tested with SM 2320B using sulfuric acid for titration.
- pH was measured using a Fischer Scientific Accumet Basic AB15 Plus pH meter.
- Calcium and magnesium ion concentrations were tested with SM 2340C using EDTA as titrant.
- Chemical oxygen demand (COD) was tested with dichromate colorimetric method, using UV visible spectrophotometer (HACH DR 5000) at 254 nm wavelength. Samples were filtered prior to analysis using Whatman glassfiber filter paper.
- Total organic carbon was studied using Shimadzhu TOC-L analyzer.
- Headspace Solid Phase Micro Extraction Gas Chromatography - Mass Spectrophotometry (SPME GC-MS) was used to characterize aqueous volatile organic compound concentrations.
- Liquid- Liquid Extraction Gas Chromatography - Mass Spectrophotometry (LLE-GC MS) was used to analyze toluene, naphthalene and phenanthrene.
- Metal levels in the condensate samples were analyzed using inductively coupled plasma-mass spectrometry.
- Aquatic toxicity was tested using Daphnia magna as a bioindicator.

- Statistical analysis was performed with 2-factor analysis of variance (ANOVA) and post hoc Turkey- Kramer multiple comparison test.

Results

Raw condensate pH was 6.2 and its chemical oxygen demand (COD) level was 36,000 ppm, which is even higher than a typical landfill leachate COD (22,000- 27,000 ppm). Several VOCs were detected in the diluted CIPP condensate. Many of the chemicals identified are used in polymer resin synthesis are known carcinogens and can be acutely toxic to aquatic organisms. Three degradation products of two initiators used in CIPP formulations were also detected and included acetone, 4-tert-butyl-cyclohexanol, and 4-tert-butylcyclohexanone. Condensate contained various heavy metals at levels greater than those found in stormwater. The as-received condensate completely dissolved Daphnia magna within 24 hours. D. magna mortality (100%) occurred in 48 hours, even when condensate was diluted by a factor of 10,000 and styrene was present at a magnitude less than its LC50. The condensate toxicity was not simply caused by styrene, but there was a mixture of contaminants.

At the culvert outlet, the greatest COD, TOC, and styrene levels were detected immediately after CIPP installation ($p < 0.001$), although equally high styrene concentrations were detected on day 7. Contaminant levels generally reduced with time. However, the highest COD, TOC, and styrene levels were measured 50 feet downstream, rather than in the water exiting the culvert outlet.

Condensate and stormwater contained numerous CIPP solvents such as benzene and styrene, degradation products of Perkadox, dibutyl phthalate, and diisoocytal phthalate, endocrine-disrupting contaminants such as plasticizers, and initiator degradation products. For 35 days, COD levels at the culvert outlets and downstream ranged from 100 to 375 ppm and styrene was 0.01 to 7.4 ppm.

Conclusions and Recommendations for Future Research

This study confirmed that various contaminants other than styrene were released into the environment and there was a need for the investigation of their persistence and toxicity. In addition to this, more effective ways must be developed to handle contaminants and carry out cleaner installation processes in future to protect the environment. It is recommended that any release of styrene and other similar contaminants into the environment should be prevented. Water quality monitoring must be recommended before, during, and after installation to determine if waste was released. If elevated levels of contaminants are found, long-term monitoring should be considered.

Part B: Reviewer’s Critique

Test Methods, Equipment, and Instrumentations Used

Onsite water temperature, pH, dissolved oxygen (DO), and turbidity levels were measured. A sample of CIPP condensate waste was also collected. Three large pieces of excess CIPP at Site 2 (3 ft × 4 ft × 0.75 in. thick) were removed from the field and underwent the toxicity characterization leaching procedure (TCLP) at room temperature. A CIPP sample (100 g where 5.08 cm length × 5.08 cm width × 1.9 cm height per CIPP piece) was placed in each extraction vessel along with 2 L of laboratory prepared synthetic stormwater. The CIPP surface area in each vessel was 451.61 square cm/L. TCLP was conducted by applying three 18 hours contact periods.

Water Quality analysis:

- Alkalinity was tested with SM 2320B using sulfuric acid for titration.
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- Calcium and magnesium ion concentrations were tested with SM 2340C using EDTA as titrant.
- Chemical oxygen demand (COD) was tested with dichromate colorimetric method, using UV visible spectrophotometer (HACH DR 5000) at 254 nm wavelength. Samples were filtered prior to analysis using Whatman glassfiber filter paper.
- Total organic carbon was studied using Shimadzhu TOC-L analyzer.
- Headspace Solid Phase Micro Extraction Gas Chromatography - Mass Spectrophotometry (SPME GC-MS) was used to characterize aqueous volatile organic compound concentration.
- Liquid- Liquid Extraction Gas Chromatography - Mass Spectrophotometry (LLE-GC MS) was used to analyze toluene, naphthalene and phenanthrene.
- Metal levels in the condensate samples were analyzed using inductively coupled plasma-mass spectrometry.
- Aquatic toxicity was tested using Daphnia magna as a bioindicator.
- Statistical analysis was performed with 2-factor analysis of variance (ANOVA) and post hoc Turkey- Kramer multiple comparison test.

Data and Analysis

QA/QC

Standard test methodologies were used for sampling lab analysis as per USEPA guidelines.

- Field and trip blanks were applied during sampling.
- Detailed precautions were taken for preventing VOC escaping after sampling.

- Triplicate sampling was conducted, upstream, at the site, outlet and 50 ft downstream, ensuring representativeness and QC.

- The sampling duration for a minimum of 35 days is reported (as from the objectives & methodology), although there is no note on time interval or how long the sampling was continued in the methodology.

Does the data sample collected represent the whole population?

The three CIPP samples tested were not representative of whole population. Waste CIPP samples are not good candidates for leaching tests because the samples are typically cured outside the host pipe and may not be representative of whole population. Also, these samples may not be fully cured.

It is difficult to determine whether the water quality samples represent the entire population. Only two sites were sampled, and the criteria for selecting these sites was not discussed. In addition, data was only collected at the inlet, outlet, and 50 feet downstream. In some cases, concentrations were greater at 50 feet downstream. This begs the question of whether concentrations at other distances downstream may have been higher than at 50 feet. Furthermore, only three grab samples were collected at each location. These samples may not have been representative in terms of time.

Reporting and detection limits

The article does not mention reporting or detection limits associated with the analyses methods used.

Did the document include employee sampling data from NASSCO companies?

No

CIPP materials used (including resin systems)

Polyester

Reference Review

Do references support conclusions?

This study did not account for toxicity observed in warmer or colder temperatures indicative of waterways or the presence of natural organic matter. Previous studies showed that warmer water can increase chemical toxicity to D. magna, and dissolved organic material had no effect or increases organic contaminant toxicity to this organism.

Peer review documentation of literature or study findings

Peer review of literature

Literature is peer reviewed in this article.

Peer review of findings

Findings are peer reviewed in this article.

Statistical Analysis Presented

What types of models have been used?

Statistical analysis was done with the help of mean and standard deviation values which were calculated for each water quality result. Water quality results were statistically analyzed using a 2-factor analysis of variance (ANOVA) and post hoc Tukey-Kramer multiple comparison test. Type I error of 0.10 was applied for all statistics for null hypothesis rejection. The results claim a significance of $p<0.0001$.

Were the models used representative, calibrated and validated?

There is no further information available on calibration and validation. Hence, we cannot comment on the representativeness of the model as well.

Verification of CIPP Product Definition

This study verified the CIPP product definition.

List of Compounds of Interest

Styrene, 3-heptanol, benzaldehyde, phenol, benzyl alcohol, 3,3,5-trimethyl cyclohexanon, benzene, 4-methylenecyclohexylmethanol, phenyl ethyl alcohol, 4-(1,1-dimethylethyl)-cyclohexanol, 4-(1,1-dimethylethyl)-cyclohexanone, 1-phenyl-2-propanone 1-hydroxy, 4,7-methano-1H-indenol, hexahydro are some of the compounds identified in this study.

Discussion of Employee/Public Safety and Health Standards and Regulations Including OSHA, ACGIH, NIOSH, and Other Regulatory Limits

The Safe Drinking Water Act recommends styrene level not more than 0.1 ppm. However, styrene levels in this study exceeded the threshold (up to 7.4 ppm).

Review of the Data with Respect to Environmental Impacts, Toxicology and Employee Chemical Exposure

DOT and wastewater utility funded studies reported styrene levels to rise from 20 to 500 ppm in the air during and following CIPP installations, respectively. One week after CIPP stormwater culvert installations, styrene levels ranged from less than 0.005 to 22 ppm in downstream waters. As of April 2014, a CIPP restriction remained in place for one CALTRANS region, whereas NYSDOT and VDOT had adopted more precise CIPP culvert construction standards and again permitted CIPP use. Continued concerns expressed by State DOTs about CIPP technology's environmental contamination potential, however, underscored a need to quantify the chemical contamination potential of CIPP infrastructure rehabilitation activities.

Chemical Exposure Limits at Different Locations Relative to Steam Exhaust Discharge Source

The highest COD, TOC, and styrene levels were measured 50 feet downstream, rather than in the water exiting the culvert outlet.

Determination of Actual Short-Term and Long-Term Health Issues Identified From Odor Complaints As Verified By Professional Medical Personnel

No health issues were reported with respect to this particular study site.

Verification of Test methods

Verification of test method in the field

No tests in the field were reported.

Verification of test method in the lab

Test methods in the lab were all in accordance with USEPA stipulations.

Part C: Overall Review

(Applicability, Originality, Completeness, Limitations, etc. – in own words)

Strengths of the Study

- Excellent QA/QC followed.
- Detailed chemical analysis with detailed information reported.
- Statistical analysis was conducted.

Weaknesses of the Study

- As stated by authors, the three CIPP pipe samples tested were not representative. Study did not illustrate as how the measurements were made and samples were collected.
- In terms of water quality, only two sites were sampled, and the criteria for selecting these sites was not discussed.
- Data was only collected at the inlet, outlet, and 50 feet downstream. In some cases, concentrations were greater at 50 feet downstream. This begs the question of whether concentrations at other distances downstream may have been higher than at 50 feet.
- Only three grab samples were collected at each location. These samples may not have been representative in terms of time.
- Since the presence of styrene was found on the 35th day, the study could have been continued for more days.
- Chemical toxicology study was limited to condensate and water quality.
- Although there is a mention of statistical analysis, no further information is available about calibration and validation.

Paper No. A6

Water Quality of Flow through Cured-In-Place Pipe (CIPP)

Citation: Currier, B. (2017). “Water Quality of Flow through Cured-In-Place Pipe (CIPP).” Final Report; Office of Water Programs, California State University Sacramento: Sacramento, CA, 2017 (prepared for California Department of Transportation, Sacramento, CA).

Part A: Literature Information

Abstract

To conservatively measure the water quality impacts of CIPP methods, a small volume of water was introduced immediately after CIPP installations of 11 pipes. Minimizing the volume of water used to flush the pipes theoretically results in higher concentrations of chemical residuals from the CIPP installation materials. Water quality analysis for volatile organic compounds in samples taken from the induced flows demonstrated that adherence to the Caltrans specification for CIPP installation is sufficient to avoid fish kills. Some measured concentrations were above the no observable effect concentration (NOEC) for algae within four days; however, all concentrations were below all other known toxicity thresholds for other test species (e.g., trout). Potential specification improvements may be helpful to further reduce the risk to sensitive species such as algae.

Introduction

Culverts are a vital part of California’s transportation system because they prevent flooding and erosion by channeling stormwater beneath highways. A significant number of culverts rated fair require corrective maintenance through trenchless repair methods. Out of the available methods, CIPP is not only cost saving, but could also have less sediment-based environmental impacts. However, due to concerns about styrene in particular, and its potential environmental impacts and behavior, there is a resulting need to understand the environmental impacts of CIPP installed according to the Caltrans specification and to compare the results with California’s environmental regulations and known toxicity thresholds.

Objectives

To measure the water quality impacts of CIPP method of pipe rehabilitation and determine if the current Caltrans specifications are adequate or if modifications are required.

Methodology

Field vs. Simulated field: A combination of field and simulated field water quality tests were performed on the CIPP rehabilitation system and covered several installation and post-cure treatment scenarios. Field studies are preferable as a test of actual conditions. Simulated studies in a more controlled environment are better suited to comparing test scenarios while controlling all other parameters. Agreement between field and simulated field results indicates that the simulated field results may be extrapolated to field conditions. Three field studies and eight simulated field studies were conducted. The field studies followed test scenarios 1, 3, and 4. The simulated field studies followed all 8-test scenarios. All test scenarios used 18-in. diameter pipe. Field Pipes 1, 10, and 11 had lengths of 37-, 47-, and 59-ft, respectively.

A small volume of water was introduced immediately after CIPP installations of 11 pipes. A very low volume of water was used at a relatively high flow rate for that volume of water. Flow was selected based on Manning's flow calculations to obtain a target flow depth of three to four inches. To ensure the target depth was achieved throughout the length of the pipe, the target flow duration was estimated based on the travel time of the target flow down the length of each test pipe. In practice, the flow was shut off at the occurrence of flow at the downstream end of the pipe. The resulting volume used varied from approximately 200 to 300 gallons.

Induced flow was performed on a schedule based on an increasing geometric progression in an attempt to weight the samples toward the period just at the end of the curing process. To start the schedule, the first sample was taken six hours after cool down. Subsequent sampling for each pipe occurred at 12 hours, 24 hours, 48 hours, and 96 hours after cool down for both field and simulated field studies.

Grab samples were collected from turbulent flow as water discharged from the pipes. Each grab sample was collected in triplicate, as requested by the laboratory. Gas Chromatography/Mass Spectrometry was used to analyze volatile organic content (VOC) in the water samples.

Both field and simulated field tests experienced both saturated and unsaturated soil conditions.

Results

Concentrations of most volatile organic compounds were below reporting limits for most water quality samples taken during the field study and simulated field study. Six and twelve-hour results were excluded since this data was not collected in a consistent manner between field and simulated field test runs. Both field and simulated field test results indicate that styrene continues to diffuse across the inner liner as evidenced by increasing concentrations after flow was induced for the water quality tests.

All field experiments resulted in concentrations that were immediately (without dilution or fate and transport losses) protective of the most sensitive species (algae) within four days. Concentrations varied for Pipe 11 through the 13th day. After Day 13, the concentrations in Pipe 11 decreased linearly to a no detect value at Day 17. For Pipes 1 and 10, concentrations varied until Day 4. After Day 4, the concentrations in Pipes 1 and 10 decreased in a fairly linear fashion to a non-detect value at Day 17. The reason for increased variability in Pipe 11 may be due to high groundwater that caused a greater heat sink during the curing process than what was experienced at Pipes 1 and 10. Similar to Pipe 11, Pipe 10 had dry weather flow that was diverted; however, Pipe 10 did not show evidence of high groundwater. Dry weather flow in the pipe may be from a spring located off the roadway. Initial 6-hour samples for all pipes and the 12-hour samples for

Pipes 1 and 10 were at or near reporting limits due to collection of samples in the quiescent containment systems.

All simulated field experiments resulted in concentrations that would be immediately protective of the most sensitive species (algae) within four days, except for the control (simulated field Pipe 1). The simulated field Pipe 1 had the following combination of site characteristics that was unique among the polyester resin CIPP for both field and simulated field tests:

- Low ambient air temperature (<62°F compared to >75°F for all other styrene-based, steam cured CIPP),

- Saturated embankment and soil moisture (lack of impervious pavement above Simulated Field Experiment), and

- Lower steam temperature (<200°F compared to >240°F for all other styrene-based, steam-cured CIPP)

Steam temperature in Pipes 2, 3, 4, 5, and 8 were in the 240 °F to 250 °F range for the duration of the curing hold time, while the steam temperature in simulated field Pipe 1 ranged from 165 °F to 195 °F, approximately, during the curing hold time. Ambient air temperatures were also cooler during the installation of simulated field Pipe 1.

Conclusions and Recommendations for Future Research

Water quality analysis for volatile organic compounds in samples taken from the induced flows demonstrated that adherence to the Caltrans specification for CIPP installation is sufficient to avoid fish kills. Some measured concentrations were above the no observable effect concentration (NOEC) for algae within four days; however, all concentrations were below all other known toxicity thresholds for other test species (e.g., trout). Potential specification improvements may be helpful to further reduce the risk to sensitive species such as algae.

Part B: Reviewer's Critique

Test Methods, Equipment, and Instrumentations Used

Field vs. Simulated field: A combination of field and simulated field water quality tests were performed on the CIPP rehabilitation system and covered several installation and post-cure treatment scenarios. Field studies are preferable as a test of actual conditions. Simulated studies in a more controlled environment are better suited to comparing test scenarios while controlling all other parameters. Agreement between field and simulated field results indicates that the simulated field results may be extrapolated to field conditions. Three field studies and eight simulated field studies were conducted. The field studies followed test scenarios 1, 3, and 4. The simulated field studies followed all 8-test scenarios. All test scenarios used 18-in. diameter pipe. Field Pipes 1, 10, and 11 had lengths of 37-, 47-, and 59-ft, respectively.

A small volume of water was introduced immediately after CIPP installations of 11 pipes. A very low volume of water was used at a relatively high flow rate for that volume of water. Flow was selected based on Manning's flow calculations to obtain a target flow depth of three to four inches. To ensure the target depth was achieved throughout the length of the pipe, the target flow duration was estimated based on the travel time of the target flow down the length of each test pipe. In practice, the flow was shut off at the occurrence of flow at the downstream end of the pipe. The resulting volume used varied from approximately 200 to 300 gallons.

Induced flow was performed on a schedule based on an increasing geometric progression in an attempt to weight the samples toward the period just at the end of the curing process. To start the schedule, the first sample was taken six hours after cool down. Subsequent sampling for each pipe occurred at 12 hours, 24 hours, 48 hours, and 96 hours after cool down for both field and simulated field studies.

Grab samples were collected from turbulent flow as water discharged from the pipes. Each grab sample was collected in triplicate, as requested by the laboratory. Gas Chromatography/Mass Spectrometry was used to analyze volatile organic content (VOC) in the water samples. Both field and simulated field tests experienced both saturated and unsaturated soil conditions.

Data and Analysis

QA/QC

- Grab samples collected in triplicate.
- Sampling was done in time intervals of geometric progression
- Both field and simulated samples were analyzed.
- One of the simulated installations was validated with the field installation. Originally, field tests were to be performed at sites where CIPP installations took place to corroborate prior simulated field test results. However, due to project scheduling, the field tests occurred first. The research coincided with a field project on SR-50 in Kyburz using steam-cured CIPP (the most commonly used method) where field sample collection was feasible. The simulated field experiments were conducted in an outdoor test environment on the California State University, Sacramento campus.

Does the data sample collected represent the whole population?

The field installation was validated with the simulated installation and sampling was done at definite time intervals. Although the field sampling was reported as downstream, there is no further report of samples being collected from different locations downstream. Hence, the data samples collected may not represent the whole population.

Reporting and detection limits

No data is available with respect to Reporting and detection limits.

Did the document include employee sampling data from NASSCO companies?

No

CIPP materials used (including resin systems)

Polyester, Vinyl ester.

Reference Review

Do references support conclusions?

The references show toxicity in the downstream water after CIPP installation, whereas the study, especially the simulated study, shows no serious toxic effect if CALTRANS specifications are followed. Hence, we can say that references do not support the study's conclusion.

Peer review documentation of literature or study findings

<u>Peer review of literature</u>

Most of the references are from CALTRANS and from journal articles.

<u>Peer review of findings</u>

Not available

Statistical Analysis Presented

What types of models have been used?

Box plot comparing styrene concentrations for dosing systems and source water and box plots comparing field and simulated field styrene data from styrene-based CIPP installations for 24-, 48-, and 96-hour samples are the only statistical analysis in this report.

Were the models used representative, calibrated and validated?

No statistical modeling was done.

Verification of CIPP Product Definition

CIPP product definition is verified.

List of Compounds of Interest

Styrene

Discussion of Employee/Public Safety and Health Standards and Regulations Including OSHA, ACGIH, NIOSH, and Other Regulatory Limits

The maximum reported styrene level post curing is 120 ppb (0.12 ppm), which is slightly more than the limit set by the Safe Drinking Water Act of 0.1 ppm.

Review of the Data with Respect to Environmental Impacts, Toxicology and Employee Chemical Exposure

No employee chemical exposure data is available.

Chemical Exposure Limits at Different Locations Relative to Steam Exhaust Discharge Source

This information is not available in this report.

Determination of Actual Short-Term and Long-Term Health Issues Identified From Odor Complaints As Verified By Professional Medical Personnel

No health issues were reported in this study.

Verification of Test methods

Verification of test method in the field

Grab sampling was done to collect the samples. In addition, a condensate sample was collected for simulated installations. No further information is available on the field test method; hence, it cannot be verified.

Verification of test method in the lab

Gas Chromatography/Mass Spectrometry was used to analyze volatile organic content (VOC) in the water sample. This is a USEPA approved test method and hence is verified.

Part C: Overall Review

(Applicability, Originality, Completeness, Limitations, etc. – in own words)

Strengths of the Study

Well-scheduled sampling was done: to start the schedule, the first sample was taken six hours after cool down. Subsequent sampling for each pipe occurred at 12 hours, 24 hours, 48 hours, and 96 hours after cool down for both field and simulated field studies. Simulated and field studies were done and the simulated study was validated. Different types of post cure treatments were tested, providing more information on how the styrene concentration changes with post cure treatments. Temperature, precipitation and relative humidity data were also recorded.

Weaknesses of the Study

- The study was not done at different locations downstream and hence lacks representativeness.

- No air quality data is available.

- As stated by authors, steam temperature in simulated field Pipe 1 approximately ranged from 165 °F to 195 °F during the curing hold time. However, 165 °F to 195 °F is not steam, and could lead to under cure.

- Humidity will negatively affect volatilization, but this study does not quantify the relationship between humidity, styrene concentration in water, or volatilization into the air within the pipe.

Paper No. A7

Understanding the Environmental Implications of Cured-in-Place Pipe Rehabilitation Technology

Citation: Donaldson, B.M., and Baker, A. (2008). “The Environmental Implications of Cured-in-Place Pipe Rehabilitation.” VTRC 08-CR12, Virginia Transportation Research Council, Charlottesville, 2008.

Part A: Literature Information

Abstract

Cured-in-place (CIPP) rehabilitation is a commonly used technology for pipe repair, and transportation agencies are using CIPP technology to repair damaged pipe culverts. In typical CIPP applications, a lining tube saturated with a thermosetting resin is installed into the damaged pipe and cured with a heat source to form a pipe-within-a-pipe. This study focused on CIPP installations that use forced steam through the lining tube both to press the liner to the inside dimensions of the host pipe and to harden the resin-impregnated liner material. Of the thermosetting resins used in CIPP applications, styrene-based resins are the most common. This research focused on styrene-based CIPP products. To evaluate the potential for impacts on water quality from the steam-cured CIPP process, seven CIPP installations in surface water and stormwater conveyances were identified and observed over the course of a 1-year study in Virginia. Water samples were collected from each project site and analyzed for styrene. The results were then evaluated for compliance with established regulatory standards and published aquatic toxicity criteria.

Water samples collected from pipe outlets at five of the seven CIPP installations showed detectable levels of styrene. Styrene concentrations were generally highest in water samples collected during and shortly following installation. The maximum duration that styrene was detected at any site was 88 days following the CIPP installation. Although the sites in this study were not directly linked to sources of drinking water, styrene levels at five sites were higher than the U.S. Environmental Protection Agency’s maximum contaminant level for drinking water of 0.1 mg/L. Styrene was detected at five sites for a minimum of 5 days to at least 71 days after installation and was detected at these sites up to 40 m downstream. Certain measurements were also found to exceed the values for EC50 (the concentration required to have a defined effect on 50 percent of a study population) or LC50 (i.e., the concentration required to kill 50 percent of a study population) for several freshwater aquatic indicator species. The findings suggest that the elevated styrene levels could have resulted from one or a combination of the following: (1) installation practices that did not capture condensate containing styrene, (2) uncured resin that escaped from the liner during installation, (3) insufficient curing of the resin, and (4) some degree of permeability in the lining material. A summary of the actions taken by the Virginia Department of Transportation (VDOT) in response to the preliminary findings of this study is also provided in this report. VDOT suspended the use of styrene-CIPP for pipes that convey surface or stormwater while further evaluating CIPP repair and subsequently developing new requirements for these installations. The new measures include substantial modifications to VDOT’s CIPP specifications, an inspector training program, increased project oversight, and water and soil testing prior to and

after CIPP installation. Reinstatement of statewide VDOT CIPP installations using the new procedures and specifications was planned for May 2008.

Introduction

Since many pipes and culverts were placed more than 20 years ago, repair or replacement of damaged or worn pipes is becoming a large maintenance concern in the United States. Cured-in-place pipe (CIPP) rehabilitation is one of several “trenchless” pipe repair technologies that allow users to repair existing underground pipes in place rather than using the conventional method of unearthing and replacing sections of damaged pipe.

In typical CIPP applications, a lining tube is saturated with a thermosetting resin, installed into the existing pipeline, and cured into a pipe-within-a-pipe. Generally, curing is conducted by forcing heated water or steam through the pipe, which presses and hardens the resin-impregnated lining tube against the inside of the host pipe.

Despite its widespread and frequent use, little has been investigated regarding the environmental impact of CIPP technology on surface water or aquatic habitat.

Objectives

- To evaluate the potential for impacts on water quality from use of the steam-cured CIPP process. Of the thermosetting resins used in CIPP applications, styrene-based resins are the most common. Thus, this research focused on styrene-based CIPP products.

- To gather information on the methods used in VDOT’s CIPP installations and to analyze the impacts that the process might have on water quality, seven steam-cured CIPP installations in Virginia were identified and observed over the course of a 1-year study.

Methodology

To achieve the purposes of this study, following methodology was adopted:

- Literature review and information gathering

The literature was reviewed for the methods and materials used in CIPP rehabilitation and the impacts of styrene on aquatic organisms. Online databases searched included Aqualine, Biological Sciences, Environmental Sciences and Pollution Management, Toxline, Agricola, Science Direct, and WorldCat, among others. Information was also gathered from the American Society of Testing and Materials’ (ASTM) standards for CIPP rehabilitation, regulatory programs administered by the Virginia Department of Environmental Quality, and other applicable organizations involved with water quality standards. Information on the hazards and regulations for styrene was obtained from the EPA’s website.

- Field monitoring of seven steam-cured CIPP installations in Virginia

Seven CIPP installations were identified within the Piedmont and Blue Ridge Physiographic Provinces of Virginia, and water samples were collected over the course of this 1-year study. The installations were conducted by three primary companies that perform CIPP rehabilitation in Virginia. All project sites were surface water conveyances where the pipe inlet and outlet were exposed with the exception of Site 4, which was an entirely subsurface stormwater conveyance. None of these sites directly links to a source of drinking water.

All samples were collected into 40-ml volatile organic analysis (VOA) vials with hydrochloric acid (HCl) preservative. The samples were packed on ice and sent to the laboratory via an overnight courier service. All samples were analyzed for styrene in accordance with the EPA's SW-846 Method 8260B11 by Microbac Laboratories in Baltimore, Maryland. Samples collected at the last one to two sampling periods from Sites 1, 4, 5, 6, and 7 were also sent to Air, Water, and Soil Laboratories, Inc., in Richmond, Virginia. These samples were also packed on ice and sent to the laboratory via an overnight courier service.

Results

Water samples collected from pipe outlets at five of the seven CIPP installations showed detectable levels of styrene. Styrene concentrations were generally highest in water samples collected during and shortly following installation. The maximum duration that styrene was detected at any site was 88 days following the CIPP installation. Although the sites in this study were not directly linked to sources of drinking water, styrene levels at five sites were higher than the U.S. Environmental Protection Agency's maximum contaminant level for drinking water of 0.1 mg/L. Styrene was detected at five sites for a minimum of 5 days to at least 71 days after installation and was detected at these sites up to 40 m downstream. Certain measurements were also found to exceed the values for EC50 (the concentration required to have a defined effect on 50 percent of a study population) or LC50 (i.e., the concentration required to kill 50 percent of a study population) for several freshwater aquatic indicator species.

Conclusions and Recommendations for Future Research

It can be concluded that the use of styrene-based CIPP technologies may result in detectable levels of styrene at or near the work site of the CIPP installation. The maximum time styrene was detected at any site was 88 days following CIPP installation. Moreover, elevated levels of styrene could have been due to:

- Installation practices that did not capture condensate containing styrene,
- Uncured resin that escaped from the liner during installation,
- Insufficient curing of the resin,
- Some degree of permeability in the lining material.

The following recommendations are offered:

- Once CIPP installations are reinstated, VTRC should evaluate them to determine whether styrene leaches from the “cured” pipe under conditions that ensure strict control of process residuals.

- VTRC should assess the environmental effects, if any, of other trenchless pipe repair technologies frequently used by VDOT.

Part B: Reviewer’s Critique

Test Methods, Equipment, and Instrumentations Used

All samples were collected into 40-ml volatile organic analysis (VOA) vials with HCl preservative. The samples were packed on ice and sent to the laboratory via an overnight courier service. All samples were analyzed for styrene in accordance with the EPA’s SW-846 Method 8260B11 by Microbac Laboratories in Baltimore, Maryland. Samples collected at the last one to two sampling periods from Sites 1, 4, 5, 6, and 7 were also sent to Air, Water, and Soil Laboratories, Inc., in Richmond, Virginia. These samples were also packed on ice and sent to the laboratory via an overnight courier service.

Data and Analysis

QA/QC

- Control sampling was done in sites, 1, 3 and 4, prior to CIPP installation.

- Samples were preserved with HCl and shipped overnight to the laboratories.

- Several samples were sent to a second laboratory to verify results.

- Control samples were not done for all the sites.

- A definite time interval was not followed for sampling.

Does the data sample collected represent the whole population?

No the data sample collected does not represent the whole population. There is no evidence of the basis for selecting the 7 sites or their representativeness. In addition, samples were not collected at the same time post- and pre- CIPP installation.

Reporting and detection limits

Reporting limit for styrene by the laboratory according to this report is 0.005 mg/L.

Did the document include employee sampling data from NASSCO companies?

No

CIPP materials used (including resin systems)

The type of CIPP material used in this study is not stated.

Reference Review

Do references support conclusions?

The references report fish kills due to styrene in water post CIPP installations. This study also found high concentrations of styrene in water due to CIPP installation.

Peer review documentation of literature or study findings

<u>Peer review of literature</u>

The literature is based on online databases Aqualine, Biological Sciences, Environmental Sciences and Pollution Management, Toxline, Agricola, Science Direct, and WorldCat, among others. Information was also gathered from the American Society of Testing and Materials' (ASTM) standards for CIPP rehabilitation, regulatory programs administered by the Virginia Department of Environmental Quality, and other applicable organizations involved with water quality standards. Information on the hazards and regulations for styrene was obtained from the EPA's website. All of these are peer reviewed.

<u>Peer review of findings</u>

The findings in this report do not claim to be peer reviewed.

Statistical Analysis Presented

What types of models have been used?

No statistical modeling has been done in this study.

Were the models used representative, calibrated and validated?

No statistical modeling has been done in this study.

Verification of CIPP Product Definition

The CIPP product definition is verified.

List of Compounds of Interest

Styrene

Discussion of Employee/Public Safety and Health Standards and Regulations Including OSHA, ACGIH, NIOSH, and Other Regulatory Limits

Styrene concentrations in water samples ranged from <0.005 mg/L to 77 mg/L, whereas the permissible level of styrene in water as per the Safe Drinking Water Act is 0.1 mg/L.

Review of the Data with Respect to Environmental Impacts, Toxicology and Employee Chemical Exposure

There is no employee chemical exposure reported. At certain times after CIPP installation, styrene concentrations exceeded the MCL for drinking water at five of the seven study sites and exceeded the EC50 or LC50 values of the water flea6 and the rainbow trout9 (common indicator species) at four of the monitored project sites. Concentrations exceeded the MCL for drinking water for at least 5 days after installation at five sites and for at least 44 to 71 days at three of these sites. Concentrations above the MCL were detected up to 40 m downstream. The sample results from five of seven sites exceeded one or more aquatic toxicity criterion for styrene, and concentrations exceeding these values were detected as far as 10 m downstream. Styrene concentrations at one site exceeded the EC50 value for the water flea and the LC50 value for the rainbow trout at the sampling period of 24 days following installation.

Chemical Exposure Limits at Different Locations Relative to Steam Exhaust Discharge Source

There is no chemical exposure study in this report. The study pertains to styrene concentration in water post-CIPP installation.

Determination of Actual Short-Term and Long-Term Health Issues Identified From Odor Complaints As Verified By Professional Medical Personnel

No health issues were reported in this study.

Verification of Test methods

Verification of test method in the field

Sample collection in the field was followed by preservation with HCl and ice packing. Overnight shipping to laboratories was done taking into consideration VOC analysis. The field test method was not verified, however.

Verification of test method in the lab

All samples were analyzed for styrene in accordance with the EPA’s SW-846 Method 8260B, which is verified.

Part C: Overall Review
(Applicability, Originality, Completeness, Limitations, etc. – in own words)

Strengths of the Study

- Real-world samples were collected following CIPP installation at 7 sites.
- USEPA method was followed for laboratory analysis.
- Several samples were sent to a second laboratory to verify results.
- Recommendations were made for reducing water quality impacts of CIPP installation.

Weaknesses of the Study

- Because the CIPP installations observed continued up to 30 consecutive hours and because of the distance between the project sites, the authors could not be present to collect samples at consistent intervals during and after all installations.
- The type of CIPP material used for CIPP is not stated in this study.
- Control samples were not done for all the sites.
- The study could have been more organized to collect samples at uniform distances from steam exhaust and at consistent time intervals.

Paper No. A8

The Influence of Rehabilitated Stormwater Infrastructure on Water Quality and Daphnia magna Toxicity: A Field and Laboratory Investigation

Citation: Tabor, M. L. (2014). "The Influence of Rehabilitated Stormwater Infrastructure on Water Quality and Daphnia magna Toxicity: A Field and Laboratory Investigation." Master's Thesis, University of South Alabama.

Part A: Literature Information

Abstract

Trenchless rehabilitation is becoming more widely used as an option for repair of aging stormwater conveyance and sewer infrastructure. One of the most popular stormwater culvert repair technologies is cured-in-place pipe (CIPP). CIPP involves the installation of an in-situ polymer liner within a structurally compromised pipe. However, near CIPP installation sites in North America, there is growing evidence of odor complaints, interference with activated sludge wastewater treatment systems, increased styrene levels in stormwater, and fish kills. The objectives of this research were to determine the water quality impacts of CIPP installed at two Alabama stormwater culverts, characterize wastewater generated by CIPP operations, and develop a laboratory leaching method that predicts water quality and aquatic toxicity impacts of newly installed CIPP material. CIPP wastewater was found to be acutely toxic to Daphnia magna within 24 hours. The wastewater's pH was 6.2, but 36,000-ppm chemical oxygen demand (COD), elevated styrene levels, and numerous solvents (endocrine-disrupting chemicals and carcinogens) were also detected. Results from field stormwater sampling demonstrated that organic and inorganic contaminants were imparted by two newly installed CIPP for five weeks.

Introduction

One million miles of stormwater culverts currently require repair (Hunt et al., 2010; Thornton et al., 2005) and Department of Transportation (DOT) agencies across the US are seeking inexpensive and reliable methods for their rehabilitation. Trenchless technology rehabilitation materials such as cured-in-place-pipe (CIPP) are becoming popular among DOTs because of their versatility and ease of installation (Torres and Ruiz, 2011; Davies, 2013). However, anecdotal reports and a few state-funded DOT studies have demonstrated that some CIPP installation activities released chemicals into the environment during and following installation, causing damage (Whelton et al, 2013; O'Reilly, 2008; Donaldson and Baker, 2008). To reduce the potential that DOTs will approve infrastructure rehabilitation products that cause environmental damage, a pre-approval water quality impact test method is needed.

Objectives

The objectives of this study were:

1. To determine the water quality impacts of CIPP installed at two Alabama stormwater culverts,

2. To characterize wastewater generated by CIPP operations, and

3. Develop a laboratory leaching method that predicts water quality and aquatic toxicity impacts of newly installed CIPP material.

Methodology

- Field Sites and Sample Collection:

Two CIPP installation sites in central Alabama were studied. Stormwater quality was monitored one day after installation. At Site 1, natural creek water was flowing through the one-week-old CIPP. Water samples were collected at multiple locations. At Site 2, due to the lack of recent precipitation, deionized water (10 L) was poured into Site 2's newly installed CIPP 11 at the inlet and water was collected as it exited the pipe.

Onsite water quality measurements included water temperature, pH, dissolved oxygen (DO) concentration, and turbidity. Water samples were also collected in amber 1 L glass bottles with polytetrafluoroethylene (PTFE)-lined caps headspace free, for subsequent laboratory analysis of alkalinity, chemical oxygen demand (COD), calcium and magnesium ion concentrations, total organic carbon, volatile organic compounds, and Daphnia magna Toxicity Testing. A sample of CIPP installation condensate waste was also collected at Site 2.

In addition, three large (0.75 in. x 3 ft x 4 ft) pieces of CIPP at Site 2 were removed from the field using a diamond tipped saw to undergo chemical extraction testing, as described later.

- Water Quality Analysis Methods:

Alkalinity concentration was determined in accordance with Standard Method (SM) 2320B (APHA et al. 1995). Sulfuric acid (0.025 N) was used for endpoint titration. Water pH was measured using a Fisher Scientific Accumet® basic AB15 plus pH meter. Calcium and magnesium ion concentrations were determined by titration using ethylenediaminetetraacetic acid (EDTA) in accordance with SM 2340C. HACH® digestion reagent vials were used to facilitate the closed reflux, dichromate colorimetric method for quantifying chemical oxygen demand (COD) in accordance with the US Environmental Protection Agency (EPA) reaction digestion method 8000 and SM 5220D.

Digestion reagent vials were heated per method instructions (150 ˚C/2 h) in a HACH® DRB 200™ digital reactor block and the COD colorimetric determinations were made using a HACH® DR 5000™ UV-VIS Spectrophotometer. Aromatic organic constituent concentrations were analyzed by ultraviolet (UV) absorbance at 254 nm with a HACH® DR 5000™ UV-VIS spectrophotometer. Prior to UV 254 absorbance characterization, all field water samples were filtered according to SM 5910B due to the turbidity of the samples that affected the accuracy of the spectrophotometer. Total organic carbon (TOC) concentration was characterized using a Shimadzu TOC-L TOC analyzer following SM 5310A. A 1,000-ppm TOC standard solution (Aqua Solutions, Deer Park, TX) was diluted in deionized water to produce 0 ppm, 2 ppm, 4 ppm, and 5 ppm calibration standards.

- Headspace Solid Phase Micro-Extraction Gas Chromatography-Mass Spectrometry (Headspace SPME GC-MS)

Headspace SPME GC-MS was applied to characterize volatile organic compound (VOC) concentrations in sample waters. The applied protocol was similar to the method developed by Silva et al. (2000). An Agilent Technologies 7890A GC system with a 5975C inert mass selective detector (MSD) multi-purpose sampler was used.

- Liquid-Liquid Extraction Gas Chromatography-Mass Spectrometry (LLE GC-MS)

Two hundred milliliters of field water sample per field sampling location was extracted using 20 mL of dichloromethane (DCM) following methods optimized by Koch (2004). Each extraction was performed thrice and dried over anhydrous sodium sulfate. Rotary evaporation (rotovap) at 300 mb pressure and room temperature was applied to reduce the extracted sample size from approximately 60 mL to 0.5 mL. Each 0.5 mL sample was then directly injected into the GC-MS port. The GC oven program utilized helium as a carrier gas at a rate of 2 mL/min. The GC oven temperature was held at 40 ˚C for 4 min. and ramped to 300 ˚C at a rate of 12 ˚C per min. Temperature was held at 300 ˚C for 10 min. The injector was in splitless mode and held at 280 ˚C. A percent recovery of toluene, naphthalene, and phenanthrene for the LLE method was determined with three replicates to be 93.0 + 19.4%, 73.2 + 15.5%, and 84.1 + 14.5%, respectively.

CIPP condensate from the curing process was also characterized by a commercial laboratory to describe VOC and metal levels. Samples were analyzed using the purge and trap method coupled with gas chromatography-mass spectrometry (GC-MS) in accordance with EPA method 8260 (EPA, 1996). The metal levels were analyzed using the EPA method 200.7 and 200.8 using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) (EPA, 1994; EPA, 2007).

- Daphnia magna Toxicity Testing:

Daphnia magna served as the aquatic toxicity bioindicator. Daphnia cultures were raised in laboratory prepared stormwater based on US EPA protocol 600/8-87/011 (EPA, 1987). Adult daphnia (20-25 per beaker) were placed in 2 L beakers containing 1.6 L of laboratory prepared stormwater. Daphnia, trout food, and algae were purchased from Aquatic Biosystems, Inc. (Fort Collins, CO). Only broods less than 24 hours old and were from generations 2 to 6 were used for the toxicity testing. Water changes and feeding occurred three times a week. Daphnia were maintained at 20 ± 2 °C and were exposed 16 hours photo periods.

- Statistical Analysis:

Mean and standard deviation values were calculated for each water quality result. Water quality results were statistically analyzed using the Tukey-Kramer multiple comparison test. Type I error was applied for all statistics ($\alpha = 0.10$) for null hypothesis rejection. The alternative hypothesis was that the sample water quality characteristic statistically differed from other solutions.

- Development of a laboratory leaching method that predicts water quality and aquatic toxicity impacts of newly installed CIPP material:

The ability of three laboratory-based material leaching methods to predict stormwater chemical levels exiting a newly installed steam-cured CIPP culvert was evaluated. Samples of CIPP, which had been collected from the field, were tested using three leaching agitation methods: (1) Static, (2) Stirbar, and (3) mTLCP approaches. All CIPP leaching tests were conducted at room temperature for three subsequent 18 hours periods for a total of 54 hours per method. Water that contacted CIPP underwent chemical analysis and aquatic toxicity testing using standard methods. Water quality was described using COD, UV visible spectroscopy, and GC-MS methods. Daphnia magna was the indicator organism applied to examine aquatic toxicity.

Results

Results showed that the CIPP activity impacted stormwater quality for 35 days following installation and collected condensate was acutely toxic to D. manga. Stormwater COD levels ranged from 100 ppm to 375 ppm and styrene ranged from 0.01 ppm to 7.4 ppm. While contaminant levels generally reduced with time, the greatest COD and styrene levels were detected 50 ft downstream of each installation site, not at the culvert outlet. The CIPP condensate collected by the installers and stored for disposal contained a pH of 6.2, 36,000 ppm COD, and a styrene level near 310 ppm. The as-collected condensate dissolved D. magna organisms within 24 hours. When condensate was diluted by a factor of 10,000, 100% D. magna mortality occurred. Results implied that contaminants other than styrene may contribute to daphnid mortality. Laboratory material extraction tests of the cured CIPP confirmed this finding. Results demonstrated that contaminants other than styrene were released into the environment and more work is needed to understand the impact of CIPP formulations and curing conditions on the environmental impacts of this activity. Condensate copper, and zinc levels were greater than background levels commonly found in surface and ground waters (0.030, and 1.01 ppm, respectively).

Static and stirbar methods of TCLP procedure demonstrated a poor ability to predict field water quality at the CIPP site. The mTCLP protocol most closely predicted field stormwater quality. However, after the first 18 h leaching period the COD, UV254 absorbance, and styrene levels observed by mTCLP testing were only 8%, 2%, and 29% of the levels observed in the field. Over the entire 54 h exposure period, the styrene level was nearly 95% of field observed styrene, although the mTCLP method only observed COD levels that were 21% of the field observations. Differences between styrene and COD levels likely relate to the varied types of organic contaminants present in the water in addition to styrene. UV254 absorbance results support this conclusion.

Various factors influenced the chemical characteristics of extraction waters. The method of agitation proved to be an important factor as did the duration of water contact. The finding that CIPP samples gain weight when in contact with water supports the conclusion that contaminants are being released from the sample as the water was being sorbed. The greatest change in sample weight occurred during the first 18 hours exposure period, which correlated to the largest COD concentration, UV254 absorbance and styrene concentration. Interestingly, CIPP sample stored for 70 days at room temperature released fewer chemicals into water when compared to freshly cured CIPP possibly due to volatilization and continuation of the curing process.

Laboratory leaching protocols examined in this study have several limitations. First, no methods accounted for any materials released into the environment during CIPP installation. These materials include raw uncured resin, CIPP cut shavings the project team observed downstream, or mist observed at the entry and exit to the culvert during installation. Second, the CIPP specimen only represented one curing condition, formulation, and one installation site. The GC-MS analytical and DCM extraction methods applied may not have extracted and detected all contaminants present because they were optimized for nonpolar organic contaminant extraction, not polar organic chemicals. In absence of a laboratory based material leaching protocol, the water quality impact of infrastructure repair material can only be determined by field stormwater testing at each installation site per material. This approach is expensive and cost prohibitive for DOTs. Moreover, as new infrastructure rehabilitation materials are introduced into the trenchless rehabilitation market, costs associated with evaluating each installation site separately will grow exponentially.

Four tentatively identified chemicals were detected in both the laboratory and field-testing, including styrene, benzene, 4-(1,1-dimethyl)- cyclohexanol, and 4-(1,1-dimethyl)- cyclohexanone. Several (18) contaminants found in field stormwater were not detected during laboratory material leaching tests. None of the extractant waters was acutely toxic to D. magna for any exposure period.

Conclusions and Recommendations for Future Research

CIPP activity impacted stormwater quality for 35 days following installation and collected condensate was acutely toxic to D. manga. Results demonstrated that contaminants other than styrene were released into the environment, and more work is needed to understand the impact of CIPP formulations and curing conditions on the environmental impacts of this activity. More investigation is needed to enable utilities and DOTs to develop construction specifications that minimize the environmental impacts of infrastructure rehabilitation materials.

Results demonstrated that the mTLCP method was the best performing protocol particularly for styrene release. Further work is necessary to determine the ability of the mTCLP method to predict field stormwater levels at multiple installation sites, for broader range of materials, and evaluate additional water quality indicators. Future work should focus on evaluating the ability of the mTLCP method to predict chemical levels observed in the field at multiple stormwater culvert rehabilitation sites.

Part B: Reviewer’s Critique

Test Methods, Equipment, and Instrumentations Used

- Field Sites and Sample Collection:

Two CIPP installation sites in central Alabama were studied. Stormwater quality was monitored one day after installation. At Site 1, natural creek water was flowing through the one-week-old CIPP. Water samples were collected at multiple locations. At Site 2, due to the lack of recent precipitation, deionized water (10 L) was poured into Site 2’s newly installed CIPP 11 at the inlet and water was collected as it exited the pipe.

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- Statistical Analysis

Mean and standard deviation values were calculated for each water quality result. Water quality results were statistically analyzed using the Tukey-Kramer multiple comparison test. Type I error was applied for all statistics (α = 0.10) for null hypothesis rejection. The alternative hypothesis was that the sample water quality characteristic statistically differed from other solutions.

- Development of a laboratory leaching method that predicts water quality and aquatic toxicity impacts of newly installed CIPP material:

The ability of three laboratory-based material leaching methods to predict stormwater chemical levels exiting a newly installed steam-cured CIPP culvert was evaluated. Samples of CIPP which had been collected from the field were tested using three leaching agitation methods: (1) Static, (2) Stirbar, and (3) mTLCP approaches. All CIPP leaching tests were conducted at room temperature for three subsequent 18 h periods for a total of 54 h per method. Water that contacted CIPP underwent chemical analysis and aquatic toxicity testing using standard methods. Water quality was described using COD, UV visible spectroscopy, and GC-MS methods. Daphnia magna was the indicator organism applied to examine aquatic toxicity.

Data and Analysis

QA/QC

- All water quality analysis followed standard test procedures.
- Sample preservation was done after sampling.
- Control sampling was done only for one site out of two.

Does the data sample collected represent the whole population?

There were only two sites that was studied for water quality post CIPP installation. Although the water samples were collected at various locations, the data sample collected does not represent the whole population.

Reporting and detection limits

Reporting limit and detection limits are not available.

Did the document include employee sampling data from NASSCO companies?

No

CIPP materials used (including resin systems)

Polyester, Vinyl ester

Reference Review

Do references support conclusions?

There have been references from existing literature regarding the environmental impacts of CIPP, which implied that styrene was responsible for aquatic toxicity incidents. Results obtained in the present work indicate that other contaminants might also contribute to the toxicity.

Peer review documentation of literature or study findings

<u>Peer review of literature</u>

The literature used in this report are from journal articles and from various states' transportation department reports. All the journal articles are peer reviewed, while peer review information on DOTs reports is not available.

<u>Peer review of findings</u>

Peer review information on this report is not available.

Statistical Analysis Presented

What types of models have been used?

No statistical modeling was done. However, the results were statistically analyzed. Mean and standard deviation values were calculated for each water quality result. Water quality results were statistically analyzed using the Tukey-Kramer multiple comparison test. Type I error was applied for all statistics ($\alpha = 0.10$) for null hypothesis rejection. The alternative hypothesis was that the sample water quality characteristic statistically differed from other solutions.

Were the models used representative, calibrated and validated?

A model was not validated or calibrated. Only statistical significance was tested.

Verification of CIPP Product Definition

CIPP product definition was verified.

List of Compounds of Interest

Styrene, benzene, 4-(1,1-dimethyl)- cyclohexanol, and 4-(1,1-dimethyl)- cyclohexanone.

Discussion of Employee/Public Safety and Health Standards and Regulations Including OSHA, ACGIH, NIOSH, and Other Regulatory Limits

Styrene levels exceeded the Safe Drinking Water Act levels of 0.1 mg/L near the outlets as well as downstream, although the concentration reduced over time to 0.01 ppm. The levels were found to be extremely toxic to D. magna.

Review of the Data with Respect to Environmental Impacts, Toxicology and Employee Chemical Exposure

The CIPP condensate collected by the installers and stored for disposal contained a pH of 6.2, 36,000 ppm COD, and a styrene level near 310 ppm. Dibutyl phthalate and diisoocytal phthalate were found downstream of the CIPP installation and are known endocrine disrupting chemicals. These chemicals can disrupt normal function of the endocrine system in aquatic organisms, which inhibits development and reproduction. Results implied that contaminants other than styrene might contribute to daphnid mortality.

Chemical Exposure Limits at Different Locations Relative to Steam Exhaust Discharge Source

Styrene levels exiting the culvert after installation were 7.43 ppm, but by week 4 and week 5, styrene levels were found range from 1.24 ppm to 1.27 ppm.

Determination of Actual Short-Term and Long-Term Health Issues Identified From Odor Complaints As Verified By Professional Medical Personnel

No odor complaints or health issues were reported in this study.

Verification of Test methods

Verification of test method in the field

Water sample collection in the field was as per protocol for sample collection for volatile organic compounds.

Verification of test method in the lab

All lab tests were following USEPA standard test methods.

Part C: Overall Review

(Applicability, Originality, Completeness, Limitations, etc. – in own words)

Strengths of the Study

- First characterization of CIPP condensate
- Toxicity Characteristic Leaching Procedure was done to learn the leaching of chemicals post CIPP installation.
- Toxicity to D. Magna was studied.
- A laboratory leaching method that predicts water quality and aquatic toxicity impacts of newly installed CIPP material was tested.

Weaknesses of the Study

- Of the two sites included in this study, one site was spanning 158 ft and the other 235 ft. This should have made considerable difference in the styrene concentration, as the same water flows through a longer distance in one pipe than in other. However, it did not seem to make a difference.
- Full modeling and statistical analysis would have helped in predicting the contaminants in the future.
- As stated by authors, at Site 2, deionized water (10 L) was used, which is very corrosive.

Paper No. A9

A Comprehensive Review on the Challenges of Cured-in-Place Pipe (CIPP) Installations

Citation: Das, S., Bayat, A., Gay, L., Salimi, M., & Matthews, J. (2016). “A Comprehensive Review on the Challenges of Cured-in-Place pipe (CIPP) Installations.” Journal of Water Supply: Research and Technology-Aqua, 65(8), 583-596.

Part A: Literature Information

Abstract

This paper outlines the issues and challenges associated with cured-in-place pipe (CIPP) rehabilitation projects of sewer mains, water mains, and service laterals. Common problems and challenges are first reviewed from the available literature and CIPP installation site visits. These obstacles and risks are classified into five different categories: pipe condition and configuration, pre-installation, challenges during installation, post-installation, and environmental challenges. In addition, this paper discusses relevant measures adopted in the current practices to mitigate these challenges. The main purpose of this paper is to provide a concise but comprehensive summary of all information needed by researchers and engineers to understand the obstacles and challenges that may arise during CIPP rehabilitation work. Meanwhile, much effort is made to identify future research needed to better understand how the current practice deals with such issues and to find better solutions to current challenges.

Introduction

A large proportion of current North American underground infrastructure was installed in the 1950s and 1960s during a period of rapid economic growth in Canada and the United States. Today, these aging systems have exceeded their design lives and have deteriorated to the point that failures are commonplace (Hashemi et al., 2011). Renewal of this aging and deteriorating underground infrastructure is a major obstacle faced by municipalities. Open-cut excavation methods are utilized for traditional replacement or renewal, which can be costly and disruptive to the surrounding environment, particularly in highly populated areas and locations with problematic ground and site conditions. In contrast, trenchless rehabilitation technologies employ innovative methods, materials, and equipment that require minimum surface excavation and access.

Among the different trenchless pipe rehabilitation techniques, cured-in-place pipe (CIPP) is considered a safe, cost-effective, efficient, and productive alternative. However, relining using CIPP is not a straightforward process and has a number of issues and challenges. Risks and/or deficiencies in a CIPP project may result in a direct economic loss to the industry. For instance, deficiencies such as uncured linings must be fixed using spot repair or a full removal and replacement of the liner, causing a significant cost impact.

As a result, CIPP industries and municipalities are constantly concerned about probable issues in any relining project. Sterling (2010) briefly summarized the challenges for new trenchless installation techniques, such as inspection, location, condition assessment and asset management methods, as well as the challenges for renewal, including repair, rehabilitation, and replacement technologies. Later, Selvakumar & Tafuri (2012) discussed the separate issues for water and wastewater systems and showed the major issues and key challenges faced in terms of accelerating rehabilitation efforts in the most commonly used current technologies. In addition, Selvakumar et al. (2012) provided a review of quality assurance and quality control (QA/QC) practices and summarized information on the installation and QA/QC practices for the trenchless rehabilitation of sewer and water transmission mains.

However, the literature provides limited information on issues and complications encountered during CIPP rehabilitation processes. This paper provides a review of the obstacles and risks faced in CIPP projects. Those challenges have been organized into five different categories with respect to various underground infrastructure systems (sewer main, water main, and service lateral). Finally, concluding remarks are provided based on the findings and suggestions for future research on this topic.

Objectives

The objective of this paper is to present a review and provide a summary of problems and challenges in CIPP installation, as well as relevant measures adopted in current practice to resolve these issues.

Methodology

Information used in this paper was collected from academic publications, industrial guidelines, and specifications from various practitioners specializing in CIPP installation. Site visits to CIPP installation projects, performed in different municipalities by specialized CIPP providers, also produced a portion of the information. The approach taken (literature review, industry information, and site visits) is intended to provide a comprehensive overview of the topic.

Results

Relining using CIPP may be accompanied by a number of issues and challenges and hence many potential advancements in the application of CIPP technology remain to be developed.

- Aging and deteriorating infrastructure conditions are significant concerns for the cleaning step in the CIPP process. These conditions include cracks, internal corrosion, grease build-up, root intrusion, joint misalignment, separation, leakage, excessive pipe deflection, and lateral connection leakage. Cleaning of severely corroded concrete sewers and tuberculated water mains is a major challenge. Further emphasis should be put on introducing more innovative cleaning equipment.

- No specific North American design standard exists for CIPP installations in sewers with non-circular sections. Currently, there are some European standards, which are not followed in North American countries.

- Lateral CIPP rehabilitation is always challenging due to small diameters, sharp bends, transitions, root intrusion, legal jurisdiction, and other issues. Future research is recommended to make the lateral CIPP process more efficient and effective.

- Due to tidal and groundwater fluctuations and high flow, more work may be conducted on temporary bypass designs, drainage plans, and pre-liner installation or chemical grouting of pipe joints in advance of the CIPP lining for pipes subjected to infiltration/inflow (I/I).

- Installing CIPP for large diameter sewers involves special problems such as onsite wet out, site access, equipment layout, long installation, and curing time. Adequate planning and careful attention are required to ensure proper and timely preparation in advance of the lining equipment set-up, site access and layout.

- During liner installation by air inversion, finding an appropriate installation pressure is a key issue. For pull-in-place installation, it is necessary to maintain a good balance between installation temperatures and pull rate.

- Another significant challenge in lateral liner installation is to monitor the curing temperature in both upstream and downstream sections of the pipe. Readings are typically taken at the cleanout only. There are now sensors available to mitigate this issue.

- Different post-installation liner deficiencies such as folds, liner peeling, wrinkles, or bubbles are common in CIPP projects. Further research may be conducted to investigate these problems and find effective ways to mitigate them.

- For storm sewers, potential environmental impacts of chemical emissions derive from the resins and effluent leaked or discharged to downstream water sources. The major concern is styrene, which is one of the most significant resin components of polyester resin and vinyl ester resin. Therefore, during the CIPP rehabilitation of culvert or storm water drainage pipes that convey streams or storm waters to downstream water sources, effective measures are needed to prevent styrene release. Non-styrene-based resins are likely to become more widely used in the future.

Conclusions and Recommendations for Future Research

This paper provided a concise but comprehensive summary of information needed by researchers and engineers to understand challenges that may arise during CIPP installation work. This review may benefit trenchless CIPP companies, water distribution and wastewater municipality sectors.

Part B: Reviewer’s Critique

Test Methods, Equipment, and Instrumentations Used

Information used in this paper was collected from academic publications, industrial guidelines, and specification from various practitioners specializing in CIPP installation. Site visits to CIPP installation projects, performed in different municipalities by specialized CIPP providers, also produced a proportion of the information. The approach taken (literature review, industry information, and site visits) is intended to provide a comprehensive overview of the topic.

Data and Analysis

QA/QC

Six journal articles were reviewed with respect to environmental impact due to CIPP installation. However, all available resources on environmental impacts due to CIPP installation were not reviewed. Additional theses and reports, which could have given more information. The review paper could give insights on styrene emissions, presence of other toxic chemicals, high chemical oxygen demand (COD), and heavy metal concentrations associated with CIPP installation.

Does the data sample collected represent the whole population?

No, the data sample collected does not represent the whole population since all the available resources were not reviewed in this study.

Reporting and detection limits

Not applicable for this review.

Did the document include employee sampling data from NASSCO companies?

No

CIPP materials used (including resin systems)

Not an experimental study.

Reference Review

Do references support conclusions?

Yes, references support conclusions. The article reviewed possible impacts on the environment due to CIPP installation and concludes the environmental impact is due to the resin used during CIPP installation.

Peer review documentation of literature or study findings

Peer review of literature

All literature in this article is peer reviewed.

Peer review of findings

All findings in this article were peer reviewed.

Statistical Analysis Presented

What types of models have been used?

There is no mention of any statistical analysis used in this study.

Were the models used representative, calibrated and validated?

There is no mention of any statistical analysis used in this study.

Verification of CIPP Product Definition

CIPP product definition has been verified for the articles cited.

List of Compounds of Interest

Styrene, ethyl ketone, isopropyl benzene, n-propyl benzene, 1, 3, 5-trimethyl benzene acetone, 4-tert-butyl-cyclohexanol, and 4-tert-butylcyclohexanone**.**

Discussion of Employee/Public Safety and Health Standards and Regulations Including OSHA, ACGIH, NIOSH, and Other Regulatory Limits

According to NAASCO, air emission of 0.5-ppm styrene is typical during CIPP activity, and styrene emitted by the CIPP process is far below the styrene exposure limits for healthy adults (20–25 ppm). The highest concentration of styrene in water was reported as 77 mg/L post installation, whereas 0.1 mg/L is the Safe Drinking Water Act limit.

Review of the Data with Respect to Environmental Impacts, Toxicology and Employee Chemical Exposure

It was reported that the styrene concentration exceeded the 48-hour effective concentration (EC50) and 96-hour lethal concentration (LC50) values of the water flea and the rainbow trout, respectively, at four of the monitored project sites by the VDOT.

Chemical Exposure Limits at Different Locations Relative to Steam Exhaust Discharge Source

Not applicable to this article

Determination of Actual Short-Term and Long-Term Health Issues Identified From Odor Complaints As Verified By Professional Medical Personnel

- During a CIPP application in Birmingham, UK, nearby residents were complaining about noxious fumes inside their homes. Results from an indoor air test in one house showed styrene levels of 200 ppm, and CIPP contractors advised some residents to evacuate their homes.

- Whelton et al. (2012) stated that they compiled numerous indoor air contamination anecdotal reports from building residents near the CIPP sites, and they claim that the highest indoor air styrene concentration was found to be 500 ppm. However, the 500-ppm value came from a newspaper article (Gowen, 2004), in which the concentration was reported to have been measured from a piece of hose lying at the jobsite. No information was provided about how the measurement was obtained, or whether it was representative. Reporting the 500-ppm as an indoor measurement is incorrect, because the hose was lying outside. A major finding of the Whelton study was that indoor air contamination incidents have occurred, but quantitative air-monitoring data are lacking.

Verification of Test methods

Verification of test method in the field

Not applicable to this study

Verification of test method in the lab

Not applicable to this study

Part C: Overall Review

(Applicability, Originality, Completeness, Limitations, etc. – in own words)

Strengths of the Study

The review article talks about technical challenges faced during the CIPP installation, as well as the environmental challenges.

Weaknesses of the Study

Although there were six articles that were reviewed with respect to the environmental impacts, not all available resources were reviewed. In addition, the review, cites a study by Whelton et al. (2012), in which a 500-ppm measurement was incorrectly reported as an indoor measurement. In actuality, the 500-ppm value was reported in a newspaper article (Gowen, 2004) as measured from a hose left at the jobsite. No information, however, is provided about how the concentration was measured.

Paper No. A10

Impact of Infrastructure Coating Materials on Storm-Water Quality: Review and Experimental Study

Citation: Whelton, A. J., Salehi, M., Tabor, M., Donaldson, B., and Estaba, J. (2012). "Impact of Infrastructure Coating Materials on Storm-Water Quality: Review and Experimental Study." Journal of Environmental Engineering, 139(5), 746-756.

Part A: Literature Information

Abstract

A literature review and 30-day leaching regime were conducted to determine the extent that storm-water infrastructure coatings affect water quality. Newly installed polymer-enhanced cement mortar (PECM) and poly (etherurethane urea) (PEUU) storm-water pipe coatings were removed from the field and underwent 10 three-day water immersion periods. For both materials, the greatest water quality alterations occurred during the first water contact period, followed by significant reductions in water quality alterations. Mineral release from PECM consistently elevated pH from 7.1 to 10.1–11.8 throughout the entire study. Organic contaminant release (total organic carbon (TOC) and UV254) was also detected for PECM during the first two water contact periods only. Alkalinity increased by 534 mg/L as calcium carbonate because of the first contact period, and 18–50 mg/L as calcium carbonate for each remaining period. Isocyanate resin from PEUU lowered water pH by 1.0 to 1.2 pH units during the early contact periods and by lesser magnitude for the remaining exposure period. Chemical oxygen demand (COD), TOC, and UV254 results showed that organic contaminants were released from PEUU. A limited quantity of organic contaminants released by PEUU was biodegradable. Nitrogen compounds were detected only during the first PEUU water contact period.

Introduction

In the present study, a literature review and polymer-enhanced cement mortar (PECM) and PEUU coating leaching experiment were conducted to identify the water quality impacts of storm-water pipe coating materials. Because of unpublished environmental and safety concerns, the California Transportation Agency (CALTRANS) effectively banned the use of coatings that contain isocyanate materials, including PEUU. While transportation agencies have begun to assess and respond to water quality impacts resulting from CIPP installations, no studies were found that documented water quality impacts caused by PECM or PEUU materials.

Objectives

- To quantify water quality alterations caused by newly installed PECM and PEUU storm-water pipe coatings,
- To characterize inorganic and organic contaminants imparted to water over a 30-day exposure period,

- To identify actions to minimize environmental impacts.

Methodology

A literature review followed by polymer-enhanced cement mortar (PECM) and PEUU coating leaching experiment were conducted to identify the water quality impacts of storm-water pipe coating materials.

Experimental: Polymer enhanced cement mortar and PEUU coating samples were removed 24 hours after their installation on metallic storm-water pipes in Virginia in the spring of 2012. These cured materials were not rinsed before or after removal. The nominal specimen surface area was 145.6 cm^2 (PECM) and 920.2 cm^2 (PEUU). Specimens were stored in sealed plastic bags with a damp cloth at 4°C until tested. Samples were damp at the time of testing.

Immersion Testing: a static closed-system testing procedure was applied. Ten days after specimen removal from the field, samples were immersed in pre-cleaned glass jars (that contained synthetic water (pH 7.1) with an alkalinity concentration of 47 mg/L as calcium carbonate (CaCO3)), covered with a glass plate (headspace free). Immersion testing involved 10 consecutive 3-day static exposure periods (22°C). Contact water was prepared using Type I Millipore water, sodium bicarbonate, and hydrochloric acid. After each 3-day contact period, water was removed and characterized. Triplicate samples were taken and analyzed for each water-sampling period. After each 3-day period, newly prepared synthetic water replaced the water in each container. A surface area to water volume ratio (SA/V) of 1.0 cm^2/mL was desired, but the CM sample provided was not in great enough quantity. The SA/V for each test was 0.16 cm^2/mL (PECM), 1.04 cm^2/mL (PEUU), and 0 cm^2/mL (control vessel).

Water Quality Analysis: Analyses were carried out according to approved standard methods (SM) [American Public Health Association (APHA) et al., 2000]. Water pH was analyzed using a research-grade Accumet AB15 pH meter (Fisher Scientific, Pittsburgh, Pennsylvania) according to SM 4500 − Hþ. Alkalinity concentration was measured by end point titration (pH 4.5) using 0.025 N sulfuric acid according to SM2320B. Turbidity was quantified using a DR 2000 direct-reading HACH spectrophotometer (Loveland, Colorado) (Standard Method 2130). A HACH DR 5000™ UV–VIS spectrophotometer was used to characterize ultraviolet (UV) absorption at 254 nm and total nitrogen (TN) concentration (after sample digestion). Total nitrogen was quantified in 2 mL samples after persulfate digestion at 105°C. Nitrogen standards [Ammonia–p–Toluenesulfonate (PTSA), Glycine–PTSA, and Nicotinic–PTSA] demonstrated 98–99% recovery. Standard method 5310A was followed to determine aqueous total organic carbon TOC concentration. Chemical oxygen demand was quantified according to the U.S. EPA reactor digestion method using 2 mL aliquots (APHA et al., 2000). A 5-day biochemical oxygen demand (BOD5) was conducted according to SM 5210B for water from the first 3-day exposure period. Biochemical oxygen demand dilution water was seeded with 24 hours stabilized primary influent from a local activated sludge wastewater treatment facility.

Statistical Analysis: Mean and standard deviation values were calculated for each water quality characteristic. Results were statistically analyzed using two approaches. A two-way analysis of variance was applied to determine if there was a significant variance between contact waters of PECM, PEUU, and the control. The Tukey–Kramer multiple comparison test was carried out using results of each source. The Type I error applied for all statistics was 0.10 for rejection of the null hypothesis. The alternative hypothesis tested for each sampling period was that contact water quality for each material differed from the control solution after the 3-day exposure.

Results

Literature review: It can be concluded from the literature review that contaminants released into waters are specific to the ingredients and impurities of each material. Generally, the greatest water quality alterations (e.g., pH, COD, TOC, metals) have been reported for waters that contact new coatings. Those alterations decrease during multiple water contact periods. Cement mortar coatings release inorganic contaminants that increase water pH, alkalinity, hardness, TDS, and metals concentrations. Epoxy and PU coatings primarily release organic contaminants (e.g., COD, TOC, UV254) and include resins, hardeners, additives, and ingredient degradation compounds. The water pH reduction unique to PU is attributable to reaction of its isocyanate resin with water. Prior investigations into the water quality impacts caused by PEUU and PU/PEUU blend coatings were not found in the literature.

Experimental tests: For both materials (PECM and PEUU), the greatest water quality alterations occurred during the first water contact period, followed by significant reductions in water quality alterations. Mineral release from PECM consistently elevated pH from 7.1 to 10.1–11.8 throughout the entire study. Organic contaminant release (total organic carbon (TOC) and UV254) was also detected for PECM during the first two water contact periods only. Alkalinity increased by 534 mg/L as $CaCO_3$ because of the first contact period, and 18–50 mg/L as $CaCO_3$ for each remaining periods. Isocyanate resin from PEUU reacted with water and reduced water pH by 1.0 to 1.2 pH units during the early contact periods, and lesser magnitude for the remaining exposure period. Chemical oxygen demand (COD), TOC, and UV254 results showed that organic contaminants were released from PEUU. A limited quantity of organic contaminants released by PEUU was biodegradable. Nitrogen compounds were detected only during the first PEUU water contact period, but their exact source(s) could not be determined.

Conclusions and Recommendations for Future Research

This work demonstrates that inorganic and organic contaminants can be released from storm-water infrastructure coatings into waters they contact. Future work is necessary to document water quality alterations caused by materials consisting of different formulations and installation conditions (e.g., curing time, temperature, ingredient-mixing ratios). Additional effort should include elucidating short- and long-term aquatic toxicity for rinse waters. Development of a dynamic storm-water coating-leaching test would allow infrastructure managers to select low-leaching materials and design specifications that limit environmental impacts of rehabilitation operations.

For rinse waters suspected to contain elevated levels of contaminants, water collection, testing, and proper disposal is recommended. In addition, if water quality testing is considered, knowledge of material ingredients is necessary to effectively select the water quality characteristics to monitor.

Part B: Reviewer's Critique

Test Methods, Equipment, and Instrumentations Used

A literature review followed by polymer-enhanced cement mortar (PECM) and PEUU coating leaching experiment were conducted to identify the water quality impacts of storm-water pipe coating materials.

Experimental: Polymer enhanced cement mortar and PEUU coating samples were removed 24 hours after their installation on metallic storm-water pipes in Virginia in the spring of 2012. These cured materials were not rinsed before or after removal. The nominal specimen surface area was 145.6 cm^2 (PECM) and 920.2 cm^2 (PEUU). Specimens were stored in sealed plastic bags with a damp cloth at 4°C until tested. Samples were damp at the time of testing.

Immersion Testing: a static closed-system testing procedure was applied. Ten days after specimen removal from the field, samples were immersed in pre-cleaned glass jars, covered with a glass plate (headspace free) that contained synthetic water (pH 7.1) with an alkalinity concentration of 47 mg/L as calcium carbonate ($CaCO_3$). Immersion testing involved 10 consecutive 3-day static exposure periods (22°C). Contact water was prepared using Type I Millipore water, sodium bicarbonate, and hydrochloric acid. After each 3-day contact period, water was removed and characterized. Triplicate samples were taken and analyzed for each water-sampling period. After each 3-day period, newly prepared synthetic water replaced the water in each container. A surface area to water volume ratio (SA/V) of 1.0 cm^2/mL was desired, but the CM sample provided was not in great enough quantity. The SA/V for each test was 0.16 cm^2/mL (PECM), 1.04 cm^2/mL (PEUU), and 0 cm^2/mL (control vessel).

Water Quality Analysis: Analyses were carried out according to approved standard methods (SM) [American Public Health Association (APHA) et al., 2000]. Water pH was analyzed using a research-grade Accumet AB15 pH meter (Fisher Scientific, Pittsburgh, Pennsylvania) according to SM 4500 − Hþ. Alkalinity concentration was measured by end point titration (pH 4.5) using 0.025 N sulfuric acid according to SM2320B. Turbidity was quantified using a DR 2000 direct-reading HACH spectrophotometer (Loveland, Colorado) (Standard Method 2130). A HACH DR 5000™ UV–VIS spectrophotometer was used to characterize ultraviolet (UV) absorption at 254 nm and total nitrogen (TN) concentration (after sample digestion). Total nitrogen was quantified in 2 mL samples after persulfate digestion at 105°C. Nitrogen standards [Ammonia–p–Toluenesulfonate (PTSA), Glycine–PTSA, and Nicotinic–PTSA] demonstrated 98–99% recovery. Standard method 5310A was followed to determine aqueous total organic carbon TOC concentration. Chemical oxygen demand was quantified according to the U.S. EPA reactor digestion method using 2 mL aliquots (APHA et al., 2000). A 5-day biochemical oxygen demand (BOD5) was conducted according to SM 5210B for water from the first 3-day exposure period. Biochemical oxygen demand dilution water was seeded with 24 h stabilized primary influent from a local activated sludge wastewater treatment facility.

Statistical Analysis: Mean and standard deviation values were calculated for each water quality characteristic. Results were statistically analyzed using two approaches. A two-way analysis of variance was applied to determine if there was a significant variance between contact waters of PECM, PEUU, and the control. The Tukey–Kramer multiple comparison test was carried out using results of each source. The Type I error applied for all statistics was 0.10 for rejection of the null hypothesis. The alternative hypothesis tested for each sampling period was that contact water quality for each material differed from the control solution after the 3-day exposure.

Data and Analysis

QA/QC

- Specimen Collection: There was only minimum sample available for testing and hence QA/QC on specimen collection was not great.

- Immersion Testing: Triplicate samples were taken and analyzed for each water sampling period. After each 3-day period, newly prepared synthetic water replaced the water in each container. Synthetic water preparation had definite protocols with respect to pH & alkalinity to replicate stormwater.

- Water Quality Analysis: Standard methods were used for all laboratory analysis.

Does the data sample collected represent the whole population?

The data sample collected does not represent the whole population since the specimen of PECM and PEUU was collected from just one site, although there was a broad leaching study done with those specimens.

Reporting and detection limits

No detection limit or reporting limit reported.

Did the document include employee sampling data from NASSCO companies?

No

CIPP materials used (including resin systems)

Epoxy, Polymer enhanced cement mortar, Poly Urea coatings.

Reference Review

Do references support conclusions?

Yes, the references support conclusions. As per references, the water in contact with PECM showed increase in the pH and the water in contact with PEUU showed reduction in pH. This was proved in this leaching study, too. In addition, the total organic carbon and total nitrogen were high during the initial days as per references. This was also found true.

Peer review documentation of literature or study findings

Peer review of literature

The literature comes from various sources such as journal articles, Department of Transportation reports, etc. Except for the journal articles, other sources cannot be confirmed to be peer reviewed.

Peer review of findings

All the findings in this article were peer reviewed since it is a journal publication.

Statistical Analysis Presented

What types of models have been used?

A two-way analysis of variance was applied to determine if there was a significant variance between contact waters of PECM, PEUU, and the control. The Tukey–Kramer multiple comparison test was carried out using results of each source. The Type I error applied for all statistics was 0.10 for rejection of the null hypothesis. The alternative hypothesis tested for each sampling period was that contact water quality for each material differed from the control solution after the 3-day exposure.

Were the models used representative, calibrated and validated?

There was no modeling done although analysis of variance was done. Hence, there is no calibration or validation.

Verification of CIPP Product Definition

The study is about polymer-based spray on coating applied on pipes as a rehabilitation technique, which essentially is cured in place. However, this does not verify CIPP product definition.

List of Compounds of Interest

Polyoxpropylenediamine, diethyltoluenediamine, and unspecified, polyamines, 4,4′–diphenylmethane diisocyanate.

Discussion of Employee/Public Safety and Health Standards and Regulations Including OSHA, ACGIH, NIOSH, and Other Regulatory Limits

Not applicable

Review of the Data with Respect to Environmental Impacts, Toxicology and Employee Chemical Exposure

Not applicable

Chemical Exposure Limits at Different Locations Relative to Steam Exhaust Discharge Source

Not applicable

Determination of Actual Short-Term and Long-Term Health Issues Identified From Odor Complaints As Verified By Professional Medical Personnel

No health issues reported.

Verification of Test methods

Verification of test method in the field

There were no test methods in the field.

Verification of test method in the lab

All test methods in the lab were pertaining to standard methods by APHA and is hence verified.

Part C: Overall Review

(Applicability, Originality, Completeness, Limitations, etc. – in own words)

Strengths of the Study

- This experimental study appear to be the first documented water quality impacts of storm-water pipe coating materials using a static leaching experiment.

- This work demonstrates that inorganic and organic contaminants can be released from storm-water infrastructure coatings into waters they contact.

Weaknesses of the Study

- Specimens collected do not represent the whole population; it seems to be an individual case study.

- A regression model could have been done on the data collected, since there was so much correlation between water quality parameters.

Paper No. A11

Influence of Temperature on Styrene Emission from a Vinyl Ester Resin Thermoset Composite Material

Citation: Crawford, S., & Lungu, C. T. (2011). “Influence of Temperature on Styrene Emission from a Vinyl Ester Resin Thermoset Composite Material.” Science of the Total Environment, 409(18), 3403-3408.

Part A: Literature Information

Abstract

Composite materials made with vinyl ester resins (VER) are lighter, stronger and more corrosion resistant compared to most metals, and are increasingly being used as building materials and in public transportation. Styrene monomer is used as both a diluent and strengthener in the production of vinyl ester resin (VER) composites. Some researchers contend that free styrene in VER composites is available to diffuse out of the material into air, perhaps leading to adverse health effects via inhalation exposures in humans. Yet, there is no known data on styrene emissions from these materials in the literature. In this study, a typical VER composite made with resin containing 38% by weight styrene, reinforced with E-glass fiber and formed using a vacuum assisted resin transfer method, was characterized for styrene emissions by environmental test chamber (ETC) methodology. Styrene concentrations in the ETC were measured over a temperature range of 10 to 50 °C. Initial evaporative styrene emissions increase with increasing temperature. There is a nearly linear relationship in the total mass of styrene emitted and emission factor as emissions increase with increasing temperature. Styrene emission factors appear to vary for different materials, which could indicate processes that are more complex or the influence of material physical properties on emission rates. These results can be used to validate and improve mass transfer emission models for the prediction of volatile organic compound concentrations in indoor environments.

Introduction

Vinyl ester resins are one of the materials used for CIPP technique. Styrene emissions post-CIPP installation is a hot topic of research, and it is important to know about effect of temperature on styrene emissions from vinyl ester resins. Change in temperature has been seen as one of the most important factors influencing the diffusion and partitioning of volatile organic compounds (VOCs) from dry building materials (Zhang et al., 2007; Deng et al., 2009). To date, there is no known research in the scientific literature examining the effect of temperature on styrene emissions from finished vinyl ester resin (VER) material. Moreover, some researchers contend that free styrene in VER composites is available to diffuse out of the material into air, perhaps leading to adverse health effects via inhalation exposures in humans; yet, there is no known data on styrene emissions from these materials in the literature. Therefore, this paper investigates the influence of temperature on styrene emission from a vinyl ester resin thermoset composite material.

Objectives

- To characterize, over a temperature range, styrene emissions from a vinyl ester resin thermoset composite material (VERTCM) using environmental test chamber methodology

- To quantify emission factors for points along the temperature range

Methodology

In this study, vinyl ester resin thermoset composite material (VERTCM) panels were prepared. The resin used consisted of Derakane 510A-40 (Ashland Chemical) containing 38% styrene by weight mixed with promoter Trigonox 239 (AkzoNobel Polymer Chemicals), accelerator (Cobalt Nap-all, Ashland Chemical), and inhibitor (acetylacetone +99%, Sigma-Aldrich) in ratios 0.015, 0.002 and 0.001, respectively, per gram of resin. The cured panels were prepped for the environmental chamber. The final cured panel thickness measured approximately 0.55 cm and panel width ranged from 19.2 to 26.0 cm. After cutting, all four edges of the test panels were sealed with a non-VOC emitting metallic tape. Individual panels were immediately wrapped in two layers of heavy-duty aluminum foil, double-bagged in sealed 4 MIL polyethylene sheeting, marked with identification numbers, and stored at −80 °C. The environmental test chamber had a humidity chamber and was air-tight. An air-mixing test was performed. Styrene concentrations in the ETC were measured over a temperature range of 10 to 50 °C and with air exchange rate of one air change per hour (ACH).

The experiment start time began immediately upon closing the chamber door. Interior chamber air was sampled at 1, 2, 4, 6, and 12 hours the first day, as well as on days 2, 3, 4, 5, 8, 9, 10, 11 and 12, for a total of 14 sample points over 264 hours. Three simultaneous samples of chamber air were collected on SKC 226-01 (Lot 2000) charcoal sorbent tubes using SKC AirChek XR5000 personal sampling pumps pre-calibrated to 1.0±0.05 L per minute for a minimum 12 L air sample. The pumps were post-calibrated to average sampling flow rate. Chamber inlet flow, temperature and humidity were monitored and recorded for the duration of each test. Chamber air analysis for styrene was conducted using gas chromatography with flame ionization detector and 1.9 min of elution time for styrene. Internal standards were checked. Emission factors were calculated as amount of styrene emitted from exposed surface area of a material over time.

Results

The maximum initial concentration of styrene measured in the chamber air increased with increased temperature. In the first 48 hours, the styrene concentration profile was predominantly representative of an evaporative emission process, while after 48 hours the emissions were expected to become more diffusion driven. The total mass of styrene emitted and emission factor both increased with increasing temperature. The emission factor increased nearly linearly between 10 °C and 50 °C (R^2=0.997), while the total mass of styrene emitted appeared to increase linearly (R^2=0.993) over the temperature range as well. At 48 hours after test initiation, the average styrene concentrations for all the three tests were less than 0.20 mg/m^3. Chamber air styrene concentrations converged for all test temperatures at approximately 192 hours.

Preliminary analysis of the vinyl ester resin thermoset composite material (VERTCM) emission properties using high surface area loading at the highest emission factor (0.025 mg/m^2/h). A conservative air exchange rate (1 ACH) indicated that indoor air concentrations of styrene emitted from VERTCM would not likely exceed Agency for Toxic Substances and Disease Registry's (ATSDR) chronic exposure guidelines (0.25 mg/m^3). The total styrene amount emitted was 6.37 mg at 23 °C and 7.39 mg at 35 °C. The highest styrene concentration measured in the chamber was 1.4 mg/m^3 at the lowest temperature and 1.6 mg/m^3 at the highest temperature. The average emission factor was determined to be 0.66 mg/m^2/h at 23 °C and 0.91 m/m^2/h at 35 °C.

In the preliminary study of Kevlar™ VERTCM, the emission factor for styrene was determined to/be much greater than that described in this study. Analysis of the porosity and density of the Kevlar™ VERTCM and E-glass VERTCM showed the Kevlar™ VERTCM to be less dense and more porous than the E-glass VERTCM.

The emission factor (EF) for styrene emitted from VERTCM at 23 °C correlated well with one EF derived for styrene from a carpet backing adhesive sample in a previous study, but did not correlate well with the EF derived for another carpet backing adhesive sample, or with an EF for styrene from a carpet adhesive in another study.

Conclusions and Recommendations for Future Research

It can be concluded that total mass of styrene emitted and styrene emission factor increased with increasing temperature in the chamber. Given this chamber data for styrene emissions from a thermoset composite material, the mass transfer models and other physical-based emission models constructed at 23 °C can be validated against the data derived here. In addition, these models can be modified and improved to scale over a temperature range such that volatile emissions from dry building materials can be better anticipated, modeled and controlled.

It is recommended that additional potential confounders such as density and porosity of the material, which may account for differences in emission factor of styrene reported in the literature, to be considered. Ultimately, a functional model that can be scaled not only to the amount of exposed material, room size and air exchange rate, but also to other material properties and conditions over a temperature range, will be useful for controlling indoor air quality complaints and perhaps protecting humans from unhealthy levels of volatile organic compounds in indoor environments.

Part B: Reviewer’s Critique

Test Methods, Equipment, and Instrumentations Used

In this study, Vinyl ester resin thermoset composite material (VERTCM) panels were prepared. The resin used consisted of Derakane 510A-40 (Ashland Chemical) containing 38% styrene by weight mixed with promoter Trigonox 239, (AkzoNobel Polymer Chemicals), accelerator (Cobalt Nap-all, Ashland Chemical) and inhibitor (Acetylacetone +99%, Sigma-Aldrich) in ratios of resin of 0.015, 0.002 and 0.001, respectively, per gram of resin. The cured panels were prepped for environmental chamber. The final cured panel thickness measured approximately 0.55 cm and panel width ranged from 19.2 to 26.0 cm. After cutting, all four edges of the test panels were sealed with a non-VOC emitting metallic tape. Individual panels were immediately wrapped in two layers of heavy-duty aluminum foil, double-bagged in sealed 4-mil polyethylene sheeting, marked with identification numbers, and stored at -80 °C. The environmental test chamber hence constructed had a humidity chamber and was airtight. Air mixing test was performed. Styrene concentrations in the ETC were measured over a temperature range of 10 to 50 °C and with air exchange rate of one air change per hour (ACH).

The experiment start time began immediately upon closing the chamber door. Interior chamber air was sampled at 1, 2, 4, 6, and 12 hours the first day, as well as on days 2, 3, 4, 5, 8, 9, 10, 11 and 12, for a total of 14 sample points over 264 hours. Three simultaneous samples of chamber air were collected on SKC 226-01 (Lot 2000) charcoal sorbent tubes using SKC AirChek XR5000 personal sampling pumps pre-calibrated to 1.0±0.05 L per minute for a minimum 12 L air sample. The pumps were post-calibrated to average sampling flow rate. Chamber inlet flow, temperature and humidity were monitored and recorded for the duration of each test. Chamber air analysis for styrene was conducted using gas chromatography with flame ionization detector and 1.9 min of elution time for styrene. Internal standards were done. Emission factors were calculated as amount of styrene emitted from exposed surface area of a material over time.

Data and Analysis

QA/QC

- QA/QC was followed while constructing the environmental testing chamber such as testing well-mixed flow of air, testing airtight condition, etc.

- Internal standards were run prior to analysis in gas chromatography

Does the data sample collected represent the whole population?

The data collected cannot represent the whole population, since it is a simulated condition. Actual styrene emissions during curing may get diluted with available air. However, this study helps us to expect the maximum styrene that can be emitted due to increase in temperature.

Reporting and detection limits

Not specified.

Did the document include employee sampling data from NASSCO companies?

No

CIPP materials used (including resin systems)

Vinyl ester

Reference Review

Do references support conclusions?

References suggest increase of styrene emissions with temperature and this study concluded the same. Hence, references support conclusion.

Peer review documentation of literature or study findings

<u>Peer review of literature</u>

All literature in this journal article has been peer reviewed.

<u>Peer review of findings</u>

All findings in this study have been peer reviewed since it was published in a journal.

Statistical Analysis Presented

What types of models have been used?

There is no mention of statistical modeling. However, there seem to be good correlation of emission factor and maximum styrene emission to increase in temperature. Hence, it could be modeled.

Were the models used representative, calibrated and validated?

No modeling was done, and hence no calibration or validation.

Verification of CIPP Product Definition

This was not a CIPP study. Hence, CIPP product definition is not verified.

List of Compounds of Interest

Styrene

Discussion of Employee/Public Safety and Health Standards and Regulations Including OSHA, ACGIH, NIOSH, and Other Regulatory Limits

The maximum concentration of styrene reported in the chamber was 0.345 ppm (1.47 mg/m^3), which is lower than the safe inhalation limit suggested by OSHA (8-hour STEL ceiling) of 50 ppm. The average of the styrene emitted for the temperature was 0.047 ppm (0.2 mg/m^3), which is also lower than the OSHA limit.

Review of the Data with Respect to Environmental Impacts, Toxicology and Employee Chemical Exposure

The 8-hour time weighted average exposure for styrene as per OSHA is 100 ppm. The maximum and average concentrations observed in the chamber are both lower than that.

Chemical Exposure Limits at Different Locations Relative to Steam Exhaust Discharge Source

Not applicable to this study.

Determination of Actual Short-Term and Long-Term Health Issues Identified From Odor Complaints As Verified By Professional Medical Personnel

Not applicable to this study.

Verification of Test methods

Verification of test method in the field

The environmental test chamber construction was as per standard methods.

Verification of test method in the lab

The analysis of styrene by gas chromatography was as per standard method with calibration and internal samples run.

Part C: Overall Review

(Applicability, Originality, Completeness, Limitations, etc. – in own words)

Strengths of the Study

- First ever study to examine the effect of temperature on styrene emissions from finished vinyl ester resin thermoset composite material or other dry building material.

- Insightful study, which can help in forecasting the emissions that can occur in extreme hot summer when resins get cured on-site like in CIPP.

Weaknesses of the Study

- Field validation was not done to check the styrene emissions due to vinyl ester at different temperatures.

- Statistical modeling was not done in spite of excellent correlation between styrene emission factor and increase in temperature.

Paper No. A12

Styrene Removal Adds to the Challenges of Rehabilitating Sewer Pipeline in Reno, Nevada

Citation: Loendorf, T., & Waters, D. (2009). “Styrene Removal Adds to the Challenges of Rehabilitating Sewer Pipeline in Reno, Nevada.” *Proceedings* of the North American Society for Trenchless Technology (NASTT) No-Dig Conference. Liverpool, NY: NASTT.

Part A: Literature Information

Abstract

In 2007, the City of Reno (City) asked Brown and Caldwell to design rehabilitation of approximately 26,000 linear feet of sewer pipeline using CIPP. Because of concerns raised by the local wastewater treatment facility, styrene levels in all water used during the lining process would be restricted to levels less than 2 milligrams per liter upon discharge into the sewer system. One of the eight project areas included 10,200 lf of pipeline 30 to 42-inch in diameter installed adjacent to the Truckee River through the center of Reno. The City has developed the land around the river into a vibrant public area with parks, shopping, and walkways heavily utilized by City residents and visitors. The river is a recreational hub for activities, including a whitewater kayak course. Another 6,800 linear feet of 66 to 72-inch pipeline was installed along a waterway and across a golf course with limited access. The waterway has a bike trail along its bank used daily by local residents. In addition to the normal requirements associated with all CIPP lining work, styrene removal adds multiple elements to each installation: longer bypass requirements in both time and length, greater traffic control needs, increased duration of each lining shot due to treatment process, larger footprint required for additional equipment and laboratory testing requirements. This paper will discuss the issues that were encountered due to the location of the sewer pipeline, public involvement, and the affect styrene removal had on the project.

Introduction

The City of Reno (City) has a current population of approximately 220,000. During the last 10 years, the City has seen a large increase in population, leading to increased flows within their collection system. The community is served by a wastewater collection system that consists of over 700 miles of 8 to 72-inch diameter pipelines. The collection system varies in age, with some of the oldest pipes dating back to 1870’s. The City operates and maintains the system to assure system operation and to prevent sanitary sewer overflows. The City initiated a sewer rehabilitation program in 1995 with an annual budget of two million dollars. Over the past five years, studies were conducted that identified the need to increase the annual rehabilitation budget to nineteen million dollars annually. The City has been renewing and/or replacing approximately 35,000 linear feet of sewers each year.

Brown and Caldwell has worked with the City for over five years developing rehabilitation design plans and providing construction management and inspection.

The 2007 rehabilitation project consists of approximately 26,000 linear feet of sewer pipe, ranging in size from 8-inch to 72-inch. In addition to the usual Cured-In-Place-Pipe (CIPP) method of rehabilitation requirements, the City set a discharge limit on styrene at 2 mg/L. The discharge limit on styrene was imposed when the local wastewater treatment facility expressed concerns that styrene may cause a loss of beneficial bacteria needed for their treatment process. The work involved eight separate project areas around the City and required the contractor to schedule work around events that bring large groups of conventions/ tourists to town. Two of these project areas required the contractor to become creative due to limited space, access, and time.

Objectives

The objective of this paper is to discuss the issues that were encountered due to the location of the sewer pipeline, public involvement, and on-site treatment of discharged water to bring styrene levels to less than 2 mg/L.

Methodology

Vipel® L704-FAP Polyester resin manufactured by AOC was used on this project and Installation utilizing water inversion. Water cure was used for all pipes greater than 18-inches in diameter. Steam was used during installation of the smaller diameter pipelines. Capture and treatment of the condensate was also required. A granulated activated carbon (GAC) system was designed to treat process water used during inversion, curing and cooling to reduce styrene levels below the required 2 mg/L. The system included coarse sand pre-filters and granular activated carbon (GAC) tanks, all designed for automatic backwash.

Results

Depending on the installation and curing methodology, the levels of styrene vary in samples collected. Installation using steam produced only a small amount of condensate but contained higher levels of styrene. Water samples collected during CIPP installation had levels of styrene in the 60-70 mg/L range for non-treated process water. After the GAC filtration of process water, analytical results showed that all samples collected were well below 2 mg/L for styrene; most were non-detect. Some samples collected from long reaches where large volumes of water were treated did have very low levels (<1 mg/L) of styrene.

Conclusions and Recommendations for Future Research

It can be concluded that the no-dig technology of pipeline rehabilitation will continue to use CIPP as our aging infrastructure deteriorates. The benefits of the CIPP method of pipeline rehabilitation should not outweigh the potential impact to the environment. One method of dealing with the styrene issue associated with CIPP installations is the use of GAC treatment for all process water. With the proper filtration and treatment equipment, even the toughest installations can be completed successfully, while reducing the amount of styrene released.

Part B: Reviewer's Critique

Test Methods, Equipment, and Instrumentations Used

GAC was used to filter the condensate and initially discharged water from the CIPP. There is no information available on test methods, equipment or instruments used to collect or analyze the water samples.

Data and Analysis

QA/QC

There is no information to verify that QA/QC was followed.

Does the data sample collected represent the whole population?

The data collected represent the whole population, assuming the GAC filtration of process water and steam condensate was done throughout the project (although, there is no information available to confirm this).

Reporting and detection limits

There is no reporting or detection limits stated in this study.

Did the document include employee sampling data from NASSCO companies?

No

CIPP materials used (including resin systems)

Polyester

Reference Review

Do references support conclusions?

The references talk about styrene concentration post-CIPP and the newly set city limit of styrene (2 mg/L). The study concludes that applying GAC filtration can reduce the concentration of styrene in process water below 2 mg/L. The references support the conclusion and vice-versa.

Peer review documentation of literature or study findings

Peer review of literature

The literature in this article may not be peer reviewed.

Peer review of findings

The findings in study were presented at a conference, but does not seem to be peer reviewed.

Statistical Analysis Presented

What types of models have been used?

There were no statistical models used in this study.

Were the models used representative, calibrated and validated?

No statistical models were used.

Verification of CIPP Product Definition

The CIPP product definition has been verified for this study.

List of Compounds of Interest

Styrene

Discussion of Employee/Public Safety and Health Standards and Regulations Including OSHA, ACGIH, NIOSH, and Other Regulatory Limits

The styrene concentration in the process water was below 2 mg/L, which is safe for discharging into the sanitary sewer system.

Review of the Data with Respect to Environmental Impacts, Toxicology and Employee Chemical Exposure

There is no information available in the article related to environmental impacts, toxicology, or employee chemical exposure.

Chemical Exposure Limits at Different Locations Relative to Steam Exhaust Discharge Source

Chemical exposure limits at different locations are not available, since the water was not discharged directly to the sewer.

Determination of Actual Short-Term and Long-Term Health Issues Identified From Odor Complaints As Verified By Professional Medical Personnel

Not applicable for this study.

Verification of Test methods

Verification of test method in the field

The field test method of using GAC for filtration of process water post-CIPP installation has been verified.

Verification of test method in the lab

There is no information on lab test method and hence cannot be verified.

Part C: Overall Review

(Applicability, Originality, Completeness, Limitations, etc. – in own words)

Strengths of the Study

This study seem to be innovative in the fact that the styrene levels in process water post-CIPP installation could be brought below 2 mg/L through GAC filtration. This could be extended to bring the styrene levels to those required by the Safe Drinking Water Act.

Weaknesses of the Study

- There is no information on the following facts:
  - Sampling method for process water,
  - Lab analysis for styrene,
  - Study on condensate post CIPP installation,
- There is no evidence on QA/QC being followed.

Paper No. A13

Water Quality Implications of Culvert Repair Options: Vinyl Ester Based and Ultraviolet Cured-in-Place Pipe Liners

Citation: Donaldson B. (2012). “Water Quality Implications of Culvert Repair Options: Vinyl Ester Based and Ultraviolet Cured-in-Place Pipe Liners.” Virginia Center for Transportation Innovation & Research, Virginia, 2012.

Part A: Literature Information

Abstract

Specifications of the Virginia Department of Transportation (VDOT) allow for the use of several “trenchless” pipe or culvert repair technologies whereby existing underground culverts are repaired in place rather than by the use of the conventional method of unearthing and replacing damaged sections. However, water quality implications of these trenchless alternatives are not completely understood. A previous evaluation found water quality impacts from installations of conventional cured-in-place pipe (CIPP). This trenchless rehabilitation technology includes saturating a flexible liner with a styrene-based resin and curing the liner on site with steam or hot water. VDOT subsequently implemented new specifications for styrene-based CIPP to prevent water quality impacts from its installation or use.

The current study included an environmental evaluation of two unconventional CIPP technologies available for use by VDOT: vinyl ester based (styrene-free) CIPP and styrene-based ultraviolet (UV) CIPP. To evaluate the potential for vinyl ester based and UV CIPP technologies to impact water quality, water samples were collected from field installations and simulations for up to 120 days. Samples were analyzed for product constituents listed in material safety data sheets. Results were then compared with established regulatory standards and published toxicity criteria for aquatic species.

For the vinyl ester based CIPP evaluated, concentrations of the primary resin constituent exceeded toxicity thresholds for aquatic species for vinyl ester monomers in six subsequent water sampling events. Adherence to VDOT’s CIPP specifications for styrene-based liners is expected to minimize contaminant leaching from the installation and use of this product. Following UV CIPP installations, no water quality impacts were documented from culvert outlets with water flow but styrene concentrations following one of the installations exceeded toxicity thresholds for aquatic species in standing water. The study recommends that VDOT consider revising its current CIPP specifications such that styrene-based CIPP requirements also apply to non–styrene-based CIPP installations. The water quality evaluations conducted in this study could not capture the range of potential field scenarios and installation variables. The VDOT specification that requires the collection and analyses of water and soil samples following CIPP installations would provide VDOT with additional sampling results from liners installed in varying field conditions and help ensure that VDOT is using this lining technology with appropriate environmental safeguards.

Introduction

CIPP rehabilitation technologies (i.e., UV and vinyl ester based) were introduced to VDOT after the development of the conventional CIPP specifications. Thus, they do not apply to styrene-based repair methods and were written without any evaluation. A determination of the potential water quality implications of the previously mentioned CIPP technologies is needed to ensure that VDOT is continuing to be a responsible user of all CIPP technologies with respect to environmental factors.

Objectives

The objectives of this study were as follows:

- To provide VDOT with information on two CIPP rehabilitation technologies, i.e., vinyl ester based CIPP and UV-cured CIPP, for their potential to contaminate water to a degree that exceeds the toxicity thresholds for aquatic species.

- To investigate whether adherence to or modification of VDOT's existing styrene based CIPP specifications would be expected to mitigate any adverse impacts on water quality.

Methodology

The methodology for the present study was as follows:

- A literature review was conducted for information regarding the material and installation procedures and relevant water quality standards and toxicity studies of aquatic species for the chemicals that comprise each of the two technologies, i.e., vinyl ester based CIPP and UV CIPP.

- Vinyl ester-based and two UV CIPP installations were observed and methods or incidents that might pertain to water quality were documented.

- Analyses were done for vinylic monomer and acrylate monomer in CIPP that was used vinyl ester resin (with sampling frequency 7, 14, 21 60, 90, 120 days). The analysis method, however, was not reported. Styrene was analyzed for vinyl ester resin CIPP, which was UV, cured (with sampling frequency 1, 2, 3, 7, 14, 21). 10.5 gal of water was poured through the vinyl ester liner pipe and 5 gallons of water was poured through the two UV cured pipes. For the UV cured pipes, samples were collected at the outlet for company A's installation and at the outlet and 10 m downstream for company B's installation.

  The water was captured in 40-ml sampling vials as it flowed out of the outlet. These simulations were designed to replicate a worst-case field scenario with low water flow with little dilution potential. For Company B's UV CIPP installation in a culvert with natural stream flow, water flow varied from low to heavy. Control samples were also collected at each sampling event. Control samples at the installation with continual stream flow (UV CIPP, Company B) were taken at the outlet of the host culvert prior to liner installation and just upstream from the inlet following installation. Control samples at installations with simulated water flow were taken from the same water source that was used to flush the culvert for the purpose of water sampling.

For immersion testing, for each tested liner, an open 5-gal glass tank was filled with 2 gal of tap water. A control sample was collected from each tank into 40-ml vials. Within 2 hours following installation of the Company A and Company B liners, a cut section of liner (12 x 7 x 0.25 in.) was immersed in the tank. Each sampling day, water samples were collected from the tank into 40-ml vials. Fresh water with an equivalent volume to that removed for sampling was then poured into the tank with the remaining water and the liner section.

- Results were evaluated from first three tasks to determine whether adherence to or modification of VDOT's current styrene-based CIPP specifications would be expected to mitigate any adverse impacts to water quality.

Results

The maximum concentration of the vinylic monomer was 87 mg/L, which is up to 200 times greater than the toxicity thresholds for the golden orfe fish (a common indicator species). Toxicity thresholds of this contaminant were exceeded for six subsequent sampling events. Acrylate monomer concentrations did not exceed toxicity thresholds.

Styrene concentrations in all water samples taken following Company A's two liner installations were below 0.001 mg/L. Following Company B's installation, although styrene was detected in samples of flowing water, styrene concentrations did not exceed the toxicity thresholds for aquatic species in any of the eight samples collected at the outlet from the flowing water test. These thresholds were exceeded in five subsequent samples of standing water from the immersion test, with a maximum styrene concentration of 12.9 mg/L. These results indicated that styrene leaching from the liner was mitigated by water flow.

Conclusions and Recommendations for Future Research

It can be concluded that concentrations of a vinylic monomer in water samples collected following the installation of a vinyl ester based CIPP exceeded the toxicity thresholds for aquatic species for up to 90 days following installation, or six subsequent sampling events. Adherence to VDOT's CIPP specifications (which are currently limited to styrene-based installations) is expected to reduce the high contaminant concentrations found following installation of a vinyl ester based CIPP. Styrene concentrations in water samples collected following UV based CIPP installations exceeded the toxicity thresholds for aquatic species in standing water but were below toxicity thresholds in flowing water. Styrene concentrations in water samples collected from flowing water tests and standing water tests of Company A's liner were below 0.001 mg/L. In water samples collected following Company B's liner installation, residual styrene accumulated in standing water (up to 12.9 mg/L), but concentrations in all eight water samples (collected up to 21 days following installation) at a culvert with water flow were below the toxicity thresholds for aquatic species. Adherence to VDOT's existing CIPP specifications is expected to mitigate any adverse impacts on water quality from UV CIPP installations. For both styrene-based and styrene-free CIPP installations, adherence to VDOT's CIPP specification that requires the collection and analyses of water and soil samples following installation would provide VDOT with additional sampling results from liners installed in varying field conditions, and help ensure that VDOT's CIPP specifications sufficiently mitigate risks to water quality.

A modification to the specification's sampling requirement that is specific to vinyl ester based liners would be necessary to ensure that samples are analyzed for the appropriate chemical.

Part B: Reviewer's Critique

Test Methods, Equipment, and Instrumentations Used

The methodology for the present study was as follows:

- A literature review was conducted for information regarding the material and installation procedures and relevant water quality standards and toxicity studies of aquatic species for the chemicals that comprise each of the two technologies, i.e., vinyl ester based CIPP and UV CIPP.

- Vinyl ester based, two UV CIPP installations were observed, and methods or incidents that might pertain to water quality were documented.

- Analysis were done for vinylic monomer and acrylate monomer in CIPP that used vinyl ester resin (with sampling frequency 7, 14, 21 60, 90, 120 days). Styrene was analyzed for vinyl ester resin CIPP, which was UV, cured (with sampling frequency 1, 2, 3, 7, 14, 21). 10.5 gal of water was poured through the vinyl ester liner pipe and 5 gallons of water was poured through the two UV cured pipes. For the UV cured pipes, samples were collected at the outlet for company A's installation and at outlet and 10 m downstream for company B's installation.

  The water was captured in 40-ml sampling vials as it flowed out of the outlet. These simulations were designed to replicate a worst-case field scenario with low water flow with little dilution potential. For Company B's UV CIPP installation in a culvert with natural stream flow, water flow varied from low to heavy. Control samples were also collected at each sampling event. Control samples at the installation with continual stream flow (UV CIPP, Company B) were taken at the outlet of the host culvert prior to liner installation and just upstream from the inlet following installation. Control samples at installations with simulated water flow were taken from the same water source that was used to flush the culvert for the purpose of water sampling.

  For immersion testing, for each tested liner, an open 5-gal glass tank was filled with 2 gal of tap water. A control sample was collected from each tank into 40-ml vials. Within 2 hours following installation of the Company A and Company B liners, a cut section of liner (12 x 7 x 0.25 in.) was immersed in the tank. Each sampling day, water samples were collected from the tank into 40-ml vials. Fresh water with an equivalent volume to that removed for sampling was then poured into the tank with the remaining water and the liner section.

- Results were evaluated from first three tasks to determine whether adherence to or modification of VDOT's current styrene-based CIPP specifications would be expected to mitigate any adverse impacts to water quality.

Data and Analysis

QA/QC

- Control samples were also collected at each sampling event for water quality analysis. Control sampling was also done for immersion testing.

- No QA/QC in sampling. Sampling duration was different for each of the three pipes.

Does the data sample collected represent the whole population?

The data sample collected does not represent the whole population. The sampling was done at different frequencies for each pipes. One pipe was studied for vinyl ester type resin and two for UV cure. This cannot be considered to represent whole population.

Reporting and detection limits

There is no reporting limit stated in this article. Detection limit has been reported as 0.001 mg/L.

Did the document include employee sampling data from NASSCO companies?

No

CIPP materials used (including resin systems)

Vinyl ester

Reference Review

Do references support conclusions?

The references support conclusions. As per the references, the styrene levels were found to exceed the threshold for aquatic organism's post-CIPP installation for vinyl ester resins. The study concluded the same.

Peer review documentation of literature or study findings

Peer review of literature

The literature review in this article comes from various reports and journal articles. The peer review of all reports cannot be confirmed. However, the literature from all journal articles should be peer reviewed.

Peer review of findings

The findings from this study are not peer reviewed as per available information.

Statistical Analysis Presented

What types of models have been used?

There was no statistical model presented.

Were the models used representative, calibrated and validated?

There was no statistical model presented.

Verification of CIPP Product Definition

CIPP product definition was verified.

List of Compounds of Interest

Styrene, vinylic monomer and acrylate monomer

Discussion of Employee/Public Safety and Health Standards and Regulations Including OSHA, ACGIH, NIOSH, and Other Regulatory Limits

The maximum concentration of the vinylic monomer was 87 mg/L and the maximum concentration of styrene for UV cured CIPP installation was 12.9 mg/L. The styrene levels for the flowing water tests were less than the Safe Drinking Water Act threshold level of 0.1 mg/L.

Review of the Data with Respect to Environmental Impacts, Toxicology and Employee Chemical Exposure

The maximum concentration of the vinylic monomer was 87 mg/L, which is up to 200 times greater than the toxicity thresholds for the golden orfe fish (a common indicator species). Toxicity thresholds of this contaminant were exceeded for six subsequent sampling events. Acrylate monomer concentrations did not exceed toxicity thresholds.

Chemical Exposure Limits at Different Locations Relative to Steam Exhaust Discharge Source

Only one pipe was sampled 10 m from the outlet and hence much information is not available with respect to this.

Determination of Actual Short-Term and Long-Term Health Issues Identified From Odor Complaints As Verified By Professional Medical Personnel

No information on health issues or odor complaints is available with respect to this study.

Verification of Test methods

Verification of test method in the field

Flowing water test and immersion test were the two field tests that were performed and the test method has been verified.

Verification of test method in the lab

Information concerning lab analysis is not available and hence cannot be verified.

Part C: Overall Review

(Applicability, Originality, Completeness, Limitations, etc. – in own words)

Strengths of the Study

- The tests were performed with respect to the concentrations of actual monomers in the water post-CIPP installation, which no other study has done.

- Immersion test and flowing water test were performed on-site, which gives more insight towards variation of the styrene concentration with change in resin and curing type.

Weaknesses of the Study

- The actual methodology of analysis for the styrene and the resin monomers is not reported.

- There was no QA/QC followed for sampling.

Paper No. A14

Odor Control-More than Sewage When Installing Cured-In-Place Sewer Pipe Liners

Citation: Bauer, G., and McCartney, D. (2004). “Odor Control-More than Sewage When Installing Cured-In-Place Sewer Pipe Liners.” *Proceedings* of the North American Society for Trenchless Technology (NASTT) No-Dig Conference, New Orleans, LA.

Part A: Literature Information

Abstract

Over the last few decades, trenchless technologies in North America have evolved to become a viable, cost effective alternative to open cut methods of infrastructure renewal. Trenchless technologies have gone through many growing pains, and while the industry has made considerable strides, as evidenced by expanded use of trenchless solutions, some aspects remain less well documented, such as the construction impacts of some cured-in-place products. Many cured-in-place pipe resins use styrene as a major component in the curing process. Styrene can give off a pungent odor at concentrations of only a few parts per million. Alternatives to styrene are considerably more costly, and thus styrene remains the product of choice for cured-in-place pipe. However, the odor and chemical composition of styrene are of considerable concern to the public, and thus must be addressed during liner installation, particularly within residential areas. This paper presents knowledge gained during a cured-in-place installation in the City of Ottawa. Styrene levels were monitored throughout the pipe lining process, and the results are presented and a successful odor control strategy explained. Understanding how and why these odors are generated will allow pipe renewal groups to better control and address the construction impacts of cured-in-place pipe liners.

Introduction

Rehabilitation of infrastructure has become an integral part of maintaining municipal assets, providing a cost effective solution to repair and extend their life expectancy in today’s fiscal restraint. Cured-in-place pipe (CIPP) forms one of a number of important rehabilitations initiatives and will continue to do so. As with most trenchless technology methods, modifications will occur to improve its performance and/or cost effectiveness. This paper presents knowledge gained during a CIPP installation in the City of Ottawa. It explains a successful odor control strategy as how and why styrene odors were generated during the CIPP activity.

Objectives

The objective of this study is to allow pipe renewal groups to better control and address the odor impacts of cured-in-place pipe liners by monitoring the air quality and simultaneously fixing the odor-causing problems.

Methodology

Styrene levels were monitored throughout the pipe lining process. Monitoring stations were decided in consultation with the testing agency. Locations for both the case studies were typically downstream of the installation, as the wind flow was in the same direction. Air monitoring was carried out using a photoionization air monitor, PE Photovac model 2020. For each section being lined, the calibration was carried out for the air monitor using two-point calibration procedure. Zero point was calibrated using medical air, and high point was calibrated using 101-ppm isobutylene. At times, the monitoring device was moved from access points to record street level values also.

For the case study 1 and 2, the sewer was monitored for styrene levels by a team at an access structure (detailed as one of the best locations for monitoring the CIPP exhaust, since the venting fan was placed there). For Case Study 1, the air monitor was set up at approximately 70 m from the tail end of the CIPP installation length and in a perpendicular direction. For case study 2, the monitor was set up in line with the CIPP installation length at 79.4 m distance from the tail end of installation. Variation of styrene over the installation period was monitored and effectiveness of the venting system was judged.

Results

The results indicated that styrene levels vary during the liner installation and with the amount of resin used. The liner installed on the Pinecrest Collector Sewer (Case Study 1) was four times longer than the liner installed on the Stittsville Trunk Sewer (Case Study 2) and resulted in much higher styrene levels.

Case Study 1:

The air monitoring started 5 minutes after the inversion of the liner started. The peak styrene level recorded without venting was 110 ppm, almost about an hour and 45 minutes after the inversion started. Cooking of the liner started at the third hour and fan venting started almost at the completion of 5 hours. The styrene levels went down from 60 ppm to 10 ppm when the venting started. Cooling down of the liner was complete after 18 hours from the begin time. During this time, the styrene levels increased to about 40 ppm. Two hours later, the liner structure was cut to drain of the water, during which the styrene levels were 60 ppm. An hour later, it decreased to zero. Three hours later, the fan was removed and the styrene level rose to 12 ppm for a short period and then decreased to zero.

Case Study 2:

There was a 25-minute delay in starting the monitoring after the installation started. Styrene levels went up to 17 ppm until the venting started. An hour later, the venting started, and the styrene levels fell to 1 ppm gradually. Even when the heating started after the inversion, the levels continued to drop to zero (probably the liner was blocking the air movement and hence not being monitored). Gradually as the heating continued, styrene levels went up to 20 ppm and then dropped to 1 ppm and rebounded back to 13 ppm an hour later. Half an hour later, the styrene levels never exceeded 3 ppm and gradually dropped to zero.

Conclusions and Recommendations for Future Research

The CIPP process used in the linings described in this paper used styrene as a major component in the resin. The odor produced during the lining installation was the result of varying levels of styrene. The monitored results indicate that precautions should be taken to protect the worker in all installations and where warranted, the public, typically in older areas with internal plumbing deficiencies. Moreover, venting is an effective method of reducing styrene levels. From the air monitoring data, it is suggested that the venting should be in place and operational before the lining installation starts. Some of the highest levels recorded occurred during the initial stages of the installation.

It is recommended that an investigation of the system be completed before installation in order to determine the potential for odor to enter buildings. If the potential exists, plan ahead by developing a flexible venting and monitoring program that can be changed quickly to react to changes as they occur. This can only be accomplished if proper investigations have occurred, which produce accurate mapping of the sewer system.

Part B: Reviewer’s Critique

Test Methods, Equipment, and Instrumentations Used

Styrene levels were monitored throughout the pipe lining process. Monitoring stations were decided in consultation with the testing agency. Locations for both the case studies were typically downstream of the installation as the wind flow was in the same direction. Air monitoring was carried out using a photoionization air monitor, PE Photovac model 2020. For each section being lined, the calibration was carried out for the air monitor using two-point calibration procedure. Zero point was calibrated using medical air and high point was calibrated using 101 ppm isobutylene. At times, the monitoring device was moved from access points to record street level values, also.

For the case study 1 and 2, the sewer was monitored for styrene levels by a team at an access structure (detailed as one of the best location for monitoring the CIPP exhaust, since the venting fan was placed there). For case study 1, the air monitor was set up at approximately 70 m from the tail end of the CIPP installation length and in a perpendicular direction. For case study 2, the monitor was set up in line with the CIPP installation length at 79.4 m distance from the tail end of installation. Variation of styrene over the installation period was monitored and effectiveness of venting system was judged.

Data and Analysis

QA/QC

- For each section being lined, the calibration was carried out for the air monitor using a two-point calibration procedure.

- The working of air monitoring device was verified intermittently by taking it to streets and measuring air quality.

- Airflow direction was considered for air monitoring.

Does the data sample collected represent the whole population?

The data sample collected was for two of the liner stretches where odor complaints occurred. Even the two cases studied here show high variations in styrene levels throughout the process. Hence, the data sample collected cannot be said to represent the whole population.

Reporting and detection limits

Reporting limit was 101 ppm and detection limit was 0 ppm (as per calibration data).

Did the document include employee sampling data from NASSCO companies?

No

CIPP materials used (including resin systems)

Polyester

Reference Review

Do references support conclusions?

The references state that styrene produces a strong pungent odor at a few ppm. This was proved when air monitoring was done at houses that had odor complaints, and they detected the styrene level as 2.5 ppm.

Peer review documentation of literature or study findings

<u>Peer review of literature</u>

There is not much literature available in this report. Most of the literature refers back to materials safety data sheet.

<u>Peer review of findings</u>

Peer review of findings was not done.

Statistical Analysis Presented

What types of models have been used?

There were no statistical models used in this study.

Were the models used representative, calibrated and validated?

There were no statistical models used in this study.

Verification of CIPP Product Definition

CIPP product definition has been verified.

List of Compounds of Interest

Styrene

Discussion of Employee/Public Safety and Health Standards and Regulations Including OSHA, ACGIH, NIOSH, and Other Regulatory Limits

The highest concentration of styrene was 110 ppm in the Case Study 1. The time-weighted average as per ACGIH is 20 ppm and the short-term exposure limit is 40 ppm. In both the case studies, the styrene level exceeded this limit several times. It is essential to consider employee/public safety during CIPP.

Review of the Data with Respect to Environmental Impacts, Toxicology and Employee Chemical Exposure

The employee chemical exposure is not reported in this report. However, according to the air monitoring data, a study is required to learn employee chemical exposure and toxicology data.

Chemical Exposure Limits at Different Locations Relative to Steam Exhaust Discharge Source

The data was monitored at only one place for both the case studies. Hence, this data is not available.

Determination of Actual Short-Term and Long-Term Health Issues Identified From Odor Complaints As Verified By Professional Medical Personnel

There were odor issues reported in both the case studies, which was related to poor plumbing connections in the sewers. The highest level of styrene recorded in homes in this study was 2.5 ppm, which could be sensed by human beings.

Verification of Test methods

Verification of test method in the field

Field air monitoring was done using a portable air monitor device. This monitor underwent 2-point calibration before monitoring.

Verification of test method in the lab

There were no lab studies according to this report.

Part C: Overall Review

(Applicability, Originality, Completeness, Limitations, etc. – in own words)

Strengths of the Study

- Air monitoring was conducted and odor complaints were addressed.
- Calibration and verification of air monitor was done intermittently.

Weaknesses of the Study

- Air monitoring did not start prior to the CIPP installation, and was delayed.

Paper No. A15

Environmental Effects of Cured-in-Place Pipe Repairs

Citation: Caltrans Division of Research and Innovation-Preliminary Investigation (2012). "Environmental Effects of Cured-in-Place Pipe Repairs." Produced by CTC & Associates LLC, August 2012.

Part A: Literature Information

Abstract

To rehabilitate culverts without disrupting highway corridors and causing long delays and significant added costs, Caltrans will need to use cured-in-place pipe (CIPP) repairs, a method of completely relining culverts using a thermosetting, resin-impregnated flexible tube that is inflated and cured with hot water or steam.

The North Coast Regional Water Quality Board (NCRWQB) is currently not permitting use of CIPP because of concerns that it negatively affects water quality. These concerns are based predominantly on a study by the Virginia Department of Transportation (DOT), which showed that CIPP sometimes caused residual styrene concentrations in the stormwater that were above the U.S. Environmental Protection Agency's maximum contaminant level for drinking water, and led to a moratorium on the use of CIPP in Virginia. However, subsequent Virginia DOT studies showed that the release of styrene was caused by poor CIPP installation practices, and implementing new specifications could eliminate these problems. With the new specifications in place, Virginia DOT has resumed its use of CIPP, and Caltrans has revised its CIPP specifications to take into account lessons learned by Virginia DOT. The NCRWQB uses Virginia DOT's earlier study to justify its restrictions on CIPP, not taking into account further developments in Virginia, and has made styrene effluent limits so low that using CIPP is impossible even with new installation practices. The NCRWQB is also requiring Caltrans to conduct a pilot study that would be cumbersome and impractical to perform.

Caltrans is interested in adopting a more scientific approach to the regulatory standards that will allow for continued use of CIPP. This Preliminary Investigation presents the results of a review of completed research and a survey of state practices addressing the use of CIPP in an environmentally safe manner. To gather information for this investigation, we:

- Conducted a literature search about the effects of CIPP on the environment, and responsible methods and practices for using CIPP with a focus on finding related studies by or on behalf of other state transportation agencies.

- Contacted Insituform Technologies, a CIPP manufacturer, regarding the environmental impacts of using CIPP.

- Performed a brief survey of members of the AASHTO Standing Committee on the Environment regarding DOT use of CIPP, asking whether they have faced water quality

problems and how they have addressed them. After the survey, we conducted follow-up phone interviews with four of the participating DOTs: New York, Oregon, Virginia and Washington.

Introduction

This investigation presents the results of a review of completed research and a survey of state practices addressing the use of CIPP in an environmentally safe manner.

Objectives

The objective of the study was to evaluate the environmental effects of cured-in-place pipe (CIPP) repairs and to have a more scientific approach to the regulatory standards to allow for continued use of CIPP.

Methodology

The methodology of the study was as follows:

- Conducted literature search about the effects of CIPP on the environment, and responsible methods and practices for using CIPP with a focus on finding related studies by or on behalf of other state transportation agencies,

- Contacted Insituform Technologies, a CIPP manufacturer, regarding the environmental impacts of using CIPP,

- Performed a brief survey of members of the AASHTO Standing Committee on the Environment regarding DOT use of CIPP, asking whether they have faced water quality problems and how they have addressed them,

- Conducted follow-up phone interviews with four of the participating DOTs: New York, Oregon, Virginia and Washington.

Results

The literature review found that there was no additional published research about the environmental effects of CIPP installation, beyond the reports referred to in Caltrans’ request. In addition to the literature review, a survey was also distributed to members of the AASHTO Standing Committee on the Environment. Staff at 14 state DOTs and the Canadian province of Alberta responded to this survey. Follow-up interviews with four states (New York, Oregon, Virginia and Washington) were also conducted. Arkansas State Highway and Transportation Department did not respond to email or phone inquiries. The survey and follow-up interviews confirmed the lack of research into the environmental effects of CIPP installations, although two states, New York and Oregon, noted that they had done some water quality testing of CIPP installations. Further, Virginia DOT completed some recent testing of a CIPP repair (using new specifications) that showed the installation to have no water quality issues.

While 11 of 15 respondents said they use CIPP, only four states, namely New York, Oregon, Virginia and Washington, reported water quality issues that had the following consequences:

- New York: Revised its specifications and was confident that installations could be done without negative environmental impacts.

- Oregon: As the contractor in this case used steam instead of hot water for curing, due to which there was styrene discharge into the river, it was hopeful that this scenario was a rare exception and specifications call for all wastewater to be contained.

- Virginia: found the installation to be very clean. Samples were collected at the outlet a few days following installation and about 10 m downstream, with results showing styrene levels of 0.294 mg/L at the outlet and 1.34 mg/L downstream. These levels are below the toxicity thresholds for rainbow trout (a common indicator species). In August 2012 the agency will release reports on water quality testing results for both ultraviolet (UV)-based CIPP repairs and polyurea and cementitious spray-on liners.

- Washington: the agency recommends that culverts be replaced rather than relined in most cases; when relining is used, water should be diverted around the pipe being relined. Seven of the 11 respondents using CIPP provided specifications; Maryland and Washington noted that they do not have CIPP specifications.

Conclusions and Recommendations for Future Research

It can be concluded that published research available on the environmental impacts of CIPP repairs was limited to the Virginia Transportation Research Council (VTRC) study. Further, only Virginia DOT had conducted water quality testing on a carefully controlled CIPP installation to evaluate the effectiveness of more stringent specifications. A number of states are planning to provide CIPP specifications but were unable to meet the deadline for this study.

It can be recommended in this investigation that Caltrans:

- Contact New York State DOT and Virginia DOT for water quality testing results of CIPP installations

- Follow up with Virginia DOT for forthcoming reports on the water quality effects of repairs using UV-cured CIPP and spray-on liners

- Follow up with Insituform Technologies on the results of internal inquiries about the environmental effects of CIPP repairs

- Contact Oregon DOT for further information about the use of CIPP in that state. If necessary, conduct further studies on the water quality effects of CIPP installations.

Part B: Reviewer's Critique

Test Methods, Equipment, and Instrumentations Used

- Conducted literature search about the effects of CIPP on the environment, and responsible methods and practices for using CIPP with a focus on finding related studies by or on behalf of other state transportation agencies,

- Contacted Insituform Technologies, a CIPP manufacturer, regarding the environmental impacts of using CIPP,

- Performed a brief survey of members of the AASHTO Standing Committee on the Environment regarding DOT use of CIPP, asking whether they have faced water quality problems and how they have addressed them,

- Conducted follow-up phone interviews with four of the participating DOTs: New York, Oregon, Virginia and Washington.

Data and Analysis

QA/QC

- All the available research reports were reviewed.

- Follow up was conducted with states, which did not respond to the survey.

Does the data sample collected represent the whole population?

The data sample collected is from literature and surveys from 15 states and from the analysis they have done. This does not represent the whole population.

Reporting and detection limits

Not applicable for this study.

Did the document include employee sampling data from NASSCO companies?

No

CIPP materials used (including resin systems)

Polyester, Vinyl ester and Epoxy.

Reference Review

Do references support conclusions?

The references do not support conclusions. There are references of Arkansas DOT and other DOT studies; however, weightage was given to VDOT studies. VDOT has definitely done an extensive research on effect of CIPP on water quality. Other DOTs have done so also.

Peer review documentation of literature or study findings

Peer review of literature

The literature review is from journal articles and is peer reviewed.

Peer review of findings

The findings of this study is the survey results and literature review. Findings were not peer reviewed.

Statistical Analysis Presented

What types of models have been used?

There were no models used in this study.

Were the models used representative, calibrated and validated?

There were no models used in this study.

Verification of CIPP Product Definition

CIPP product definition has been verified for the literature referred in this study.

List of Compounds of Interest

Styrene

Discussion of Employee/Public Safety and Health Standards and Regulations Including OSHA, ACGIH, NIOSH, and Other Regulatory Limits

Not applicable.

Review of the Data with Respect to Environmental Impacts, Toxicology and Employee Chemical Exposure

Not applicable.

Chemical Exposure Limits at Different Locations Relative to Steam Exhaust Discharge Source

Not applicable.

Determination of Actual Short-Term and Long-Term Health Issues Identified From Odor Complaints As Verified By Professional Medical Personnel

Not applicable.

Verification of Test methods

Verification of test method in the field

Not applicable for this study

Verification of test method in the lab

Not applicable for this study

Part C: Overall Review

(Applicability, Originality, Completeness, Limitations, etc. – in own words)

Strengths of the Study

Detailed study with respect to effect of CIPP on water quality was probed.

Weaknesses of the Study

- The survey was concentrated on water quality only. Questions pertaining to air quality and soil contamination due to CIPP were not asked or reviewed in the literature.

- Not all states were surveyed.

Paper No. A16

Industrial Hygiene Evaluation: CIPP – Styrene Exposure

Citation: Willett, M. (2017). "Industrial Hygiene Evaluation: CIPP-Styrene Exposure." Prince William County Service Authority, Woodbridge, VA.

Part A: Literature Information

Abstract

Industrial hygiene sampling of Prince William County Service Authority (PWCSA) employees during contractor installation of cured-in-place piping (CIPP) was conducted in an effort to obtain initial styrene exposure data on two employees working with two different contractors working in neighborhoods serviced by PWCSA. Sampling included one personal real-time gas monitor and one passive monitoring badge on each of the two employees. Briefly, results of the air sampling found exposure levels below the detection limit for both passive badges. The real-time gas monitors picked up spikes in exposure when employees walked near the open truck, which hauled the lining, and when walking near the installation, especially near the exhaust end of the line. Even with these periodic exposures, average exposures (both time weighted averages and short-term exposure limits) were below recommended standards.

Introduction

Prince William County Service Authority (PWCSA) is an independent public body responsible for providing and operating a comprehensive drinking water and water reclamation system serving a quarter of a million customers. The PWCSA currently operates two wastewater facilities and maintains several field facilities. They also oversee third-party contractors doing construction on their infrastructure. In this study, industrial hygiene sampling of PWCSA employees during contractor installation of cured-in-place piping (CIPP) was conducted in an effort to obtain initial styrene exposure data on two employees working with two different contractors working in neighborhoods serviced by PWCSA.

Objectives

The objective of this study was to provide initial industrial hygiene exposure data to styrene for employees overseeing installation projects using cured-in-place-piping (CIPP), which will assist PWCSA in adequately protecting employees and ensuring compliance with the OSHA regulatory requirements.

Methodology

The PWCSA Safety and Security Program Manager and Circle Safety & Health Consultants devised a sampling strategy and measured both time weighted average (TWA) exposures, as well as ceiling and STELs. Air samples were taken in the breathing zone of the employee in order to estimate the amount of contaminant that would enter the body via the lungs without respiratory protection. Organic vapor badges were used for measuring styrene TWA exposure. A Honeywell ToxiRAE Pro PID (photoionization detector) single gas monitor with the correction factor set for styrene was used to measure averages, STELs and peaks/ceiling levels of for organic vapors. (Styrene is assumed but other organic vapors can be detected by this instrument.) The monitoring devices were placed on the employee at the beginning of the shift at the shop and removed in the field after approximately seven hours. One of the gas monitors turned itself off due to low battery prior to pick up.

Employee Sampled: Air sampling was conducted on Employee 1 and Employee 2 from the Infiltration and Flow Department. Employee 1 worked with AM-Liner installing 353 feet of liner on Gordon Drive. Employee 2 worked with Insituform Technologies installing 248, 272 and 124 ft of liner on Millwood Drive and Wildwood Court.

Analysis: The organic vapor air sampling badges were analyzed for styrene by SGS Galson Laboratories of East Syracuse, New York. SGS Galson is accredited by the American Industrial Hygiene Association and is ISO/IEC 17025:2005 certified. The samples were preserved and analyzed in accordance with the NIOSH 1501 sampling and analytical method. The ToxiRAE Pro was calibrated and the styrene correction factor set by the Pine Environmental office located in Richmond, VA. It was fresh-air calibrated in the field prior to use.

Results

Results of the air sampling found exposure levels below the detection limit for both passive badges. The real-time gas monitors picked up spikes in exposure when employees walked near the open truck, which hauled the lining, and when walking near the installation, especially near the exhaust end of the line. Even with these periodic exposures, average exposures (both time weighted averages and short-term exposure limits) were below recommended standards.

The styrene badge on Employee 2 showed levels less than 0.4 ppm and on Employee 1 showed styrene levels less than 0.3 ppm. Peak exposure occurred when Employee 2 walked near the exhaust end of the project at the beginning of the steaming/curing process. The second highest peak of 11.5 ppm occurred when he examined the truck loaded with liners used for this project. The average values varied from 0.004 to 0.077 ppm.

Conclusions and Recommendations for Future Research

It can be concluded that:

- Full-shift time weighted average exposures to styrene for PWCSA employees’ were negligible during the sampling day. The employees protected themselves with distance, as their presence close to the source of the chemical exposure was not necessary for any extended periods.

- The highest exposures occurred when the employee walked near the exhaust end of the line while it was curing with steam; the second highest exposure occurred while looking into the truck containing the liners. Even with these brief exposures, employees' exposures to styrene were below the OSHA and ACGIH STELs and ceiling limits.

- A concern for the CIPP procedure was the possibility of residual chemical releases. A particular concern raised by the California CIPP Alert is the potential for the migration of vapors into buildings and potential impacts on indoor air quality and exposures to the occupants of affected buildings. The PID monitor used during this industrial hygiene-sampling project worked well for detecting the off-gassing chemicals.

It can be recommended that a hand-held PID monitor may be a useful tool for locating sources of chemicals that may migrate into buildings via dry traps, compromised plumbing connections, etc.

Part B: Reviewer's Critique

Test Methods, Equipment, and Instrumentations Used

A sampling strategy was devised by the PWCSA Safety and Security Program Manager and Circle Safety & Health Consultants to measure both time weighted average (TWA) exposures as well as ceiling and STELs. Air samples were taken in the breathing zone of the employee in order to estimate the amount of contaminant that would enter the body via the lungs without respiratory protection. Organic vapor badges were used for measuring styrene TWA exposure. A Honeywell ToxiRAE Pro PID (photoionization detector) single gas monitor with the correction factor set for styrene was used to measure averages, STELs and peaks/ceiling levels of for organic vapors (Styrene is assumed but other organic vapors can be detected by this instrument). The monitoring devices were placed on the employee at the beginning of the shift at the shop and removed in the field after approximately seven hours. One of the gas monitors turned itself off due to low battery prior to pick up.

Employee Sampled: Air sampling was conducted on Employee 1 and Employee 2 from the Infiltration and Flow Department. Employee 1 worked with AM-Liner installing 353 feet of liner on Gordon Drive. Employee 2 worked with Insituform Technologies installing 248, 272 and 124 feet of liner on Millwood Drive and Wildwood Court.

Analysis: SGS Galson Laboratories of East Syracuse, New York, analyzed the organic vapor air sampling badges for styrene. SGS Galson is accredited by the American Industrial Hygiene Association and is ISO/IEC 17025:2005 certified. The samples were preserved and analyzed in accordance with the NIOSH 1501 sampling and analytical method. The ToxiRAE Pro was calibrated and the styrene correction factor set by the Pine Environmental office located in Richmond, VA. It was fresh-air calibrated in the field prior to use.

Data and Analysis

QA/QC

- The samples were preserved and analyzed in accordance with the NIOSH 1501 sampling and analytical method. The ToxiRAE Pro was calibrated and the styrene correction factor set by the Pine Environmental office located in Richmond, VA. It was fresh-air calibrated in the field prior to use.

Does the data sample collected represent the whole population?

No, the sample collected does not represent the whole population. The styrene badges were worn by only two employees. In addition, on one of the employees the monitor turned off due to low battery, not recording complete data.

Reporting and detection limits

No reporting limit or detection limit was specified in this report.

Did the document include employee sampling data from NASSCO companies?

Yes

CIPP materials used (including resin systems)

Not specified in the report.

Reference Review

Do references support conclusions?

No references were quoted in this report.

Peer review documentation of literature or study findings

Peer review of literature

Not applicable.

Peer review of findings

Peer review of the findings is not reported.

Statistical Analysis Presented

What types of models have been used?

No statistical analysis was stated in this study.

Were the models used representative, calibrated and validated?

No statistical analysis was stated in this study.

Verification of CIPP Product Definition

CIPP product definition is verified for this study.

List of Compounds of Interest

Styrene

Discussion of Employee/Public Safety and Health Standards and Regulations Including OSHA, ACGIH, NIOSH, and Other Regulatory Limits

PWCSA employees' full-shift time weighted average exposures to styrene were negligible during the sampling day. Only one time a peak of 104 ppm was detected, which is greater than the OSHA regulatory levels of 100 ppm.

Review of the Data with Respect to Environmental Impacts, Toxicology and Employee Chemical Exposure

The average chemical exposure by employees were much less than the OSHA regulatory requirement.

Chemical Exposure Limits at Different Locations Relative to Steam Exhaust Discharge Source

Chemical exposure at different locations relative to steam exhaust is not available.

Determination of Actual Short-Term and Long-Term Health Issues Identified From Odor Complaints As Verified By Professional Medical Personnel

There was high odor issue reported in this study.

Verification of Test methods

Verification of test method in the field

PID was given to the employees to wear on them, to monitor the air quality they inhale in. Field test method is verified in this study.

Verification of test method in the lab

Lab analysis were conducted as per NIOSH regulations and hence is verified.

Part C: Overall Review

(Applicability, Originality, Completeness, Limitations, etc. – in own words)

Strengths of the Study

- QA/QC is reported for the lab analysis.
- Weather data was collected.
- Employee exposure of styrene due to CIPP was studied.

Weaknesses of the Study

- The study was restricted to two locations.
- The PC monitor turned off due to low battery, without recording entire data. Hence, the study may not be conclusive.

APPENDIX B

IKT (EUROPEAN) LITERATURE REVIEWS

Paper No. B1

Investigation of Styrene Emissions Occurring During Pipe Rehabilitation with CIPP[1]

Part A: Literature Information

Abstract

Styrene is an important component of the polyester resins used in the CIPP lining process. Concerns have been raised about the possible release of styrene into sewer water, groundwater, soil and air. In the past, there have been some incidents in the wastewater treatment plant in Bielefeld during the installation of CIPP in the sewer network of this city that forced the responsible persons to investigate the reasons for this. Members of the staff and residents recognizes some odor perception. Therefore, a research project was launched and a team of experts accompanied 24 rehabilitation projects. Additionally a test rig was designed that enables the city of Bielefeld prior to rehabilitation of sewer network to find out how much styrene will be released from the applied CIPP technique in advance.

Introduction and Objectives

In this research project, (funded by the Ministry of the Environment of North Rhine-Westphalia, see appendix 01) about 24 rehabilitation projects (total length: 4900 m) were tested for emissions of styrene to water and air in the period from 2001 to 2004. In addition, a test stand for CIPP-liners was developed and tested, which can be used for emission measurements of styrene into soil, groundwater and air.

Methodology

About 24 rehabilitation projects (total length: 4900 m) were tested for emissions of styrene to water and air in the period from 2001 to 2004. At this project, a certain quality assurance (e.g., DIBt approval for the liner, ISO 9000 ff. certified company and other today generally applied requirements) was applied to reduce the release of styrene. In addition, a test rig for CIPP-liners was developed and tested (see Figure B1), which can be used for emission measurements of styrene into soil, groundwater and air at different CIPP techniques prior to their application in the sewer network.

Results

The study shows that no contamination by styrene in soil and groundwater could be detected. Regarding measured styrene emissions into the air, it recommends that unauthorized persons should not approach within 5 m. By applying the corresponding quality assurance, the risk for the local residents is restricted to perception of odors. It was recommended to drain process water in to the sanitary or combined water sewer after a certain period. Within the project, condensation water was discharged.

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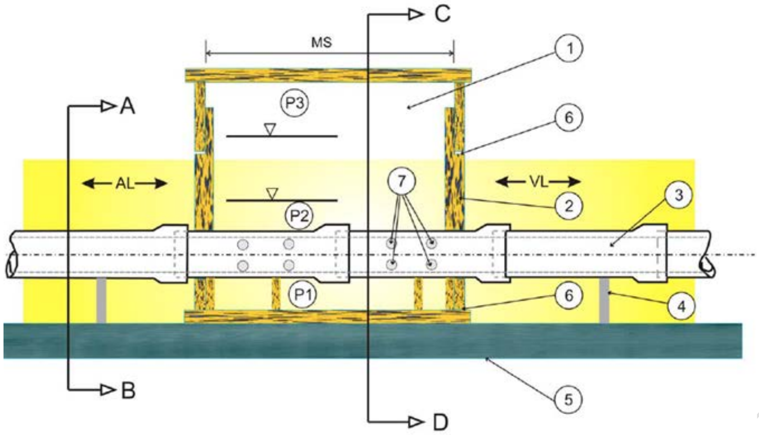
[1] In this paper, the mg/kg is mg of styrene per kg of resin cured.

The study was undertaken for CIPP-Lining with steam, water and UV cure. A subdivision of the statements concerning styrene emission for each method is not made clear in the report. Furthermore, there is no Information about measurement methods applied, instruments used and individual measured values.

It recommends a limit of residual styrene content of 400 mg/kg after curing the CIPP-Liner in the test stand. For rehabilitation projects, a limit value of 500 mg/kg (up to a diameter DN600) and 1,000 mg/kg (from a diameter DN600) is indicated.



1: encapsulation
2: hole for pipe with diameter DN 600 with aperture for pipe with diameter DN 300
3: test pipe
4: support for test pipe
5: ground (concrete or asphalt)
6: lock and seal
7: drill hole / opening to simulate damage
MS: measuring section
P1-P3: sampling points

Figure B1. Test Stand

Conclusions and Recommendations for Future Research

Regarding measured styrene emissions into the air, it recommends that unauthorized persons should not approach within 5 m. By applying the corresponding quality assurance, the risk for the local residents is restricted to perception of odors. It is recommended to drain process water in to the sanitary or combined water sewer after a certain period.

It recommends a limit of residual styrene content of 400 mg/kg after curing the CIPP-Liner in the test stand. For rehabilitation projects, a limit value of 500 mg/kg (up to a diameter DN600) and 1,000 mg/kg (from a diameter DN600) is indicated.

Part B: Reviewer's Critique

Test Methods, Equipment, and Instrumentations Used

Equipment and Instrumentation for rehabilitation projects: not specified

Twenty-four rehabilitation projects (total length: 4900 m) were tested for emissions of styrene to water and air in the period from 2001 to 2004. In addition, a test stand for CIPP-liners was developed and tested, which can be used for emission measurements of styrene into soil, groundwater and air.

Detailed information about the results for each project or about the used equipment and instrumentation are not available.

Data and Analysis

QA/QC

There are no information available about any QA/QC during the project.

Does the data sample collected represent the whole population?

As there are no detailed information available for the 24 tested projects the study does not represent the whole population.

Reporting and detection limits

No reporting limit or detection limit are specified in this report.

Did the document include employee sampling data from NASSCO companies?

No

CIPP materials used (including resin systems)

Polyester

Reference Review

Do references support conclusions?

No

Peer review documentation of literature or study findings

<u>Peer review of literature</u>

Not Available

<u>Peer review of findings</u>

Not Available

Statistical Analysis Presented

What types of models have been used?

No statistical analysis was stated in this study.

Were the models used representative, calibrated and validated?

No statistical analysis was stated in this study.

Verification of CIPP Product Definition

Not Available

List of Compounds of Interest

Styrene

Discussion of Employee/Public Safety and Health Standards and Regulations Including OSHA, ACGIH, NIOSH, and Other Regulatory Limits

That study did not detect contamination by styrene in soil and groundwater. Regarding measured styrene emissions to air, it recommends preventing unauthorized persons approaching within 5 m of the lining work. For local residents the pollution of the air can be reduced to odor perception only by corresponding quality assurance.

Analyzes of the process water show that this can be only drained in to the sanitary or combined water sewer after a certain period and if necessary dilution. Collected condensation water was disposed.

Review of the Data with Respect to Environmental Impacts, Toxicology and Employee Chemical Exposure

That study did not detect contamination by styrene in soil and groundwater. Regarding measured styrene emissions to air, it recommends preventing unauthorized persons approaching within 5 m of the lining work. For local residents the pollution of the air can be reduced to odor perception only by corresponding quality assurance.

Analyzes of the process water show that this can be only drained in to the sanitary or combined water sewer after a certain period and if necessary dilution. Collected condensation water was disposed.

Chemical Exposure Limits at Different Locations Relative to Steam Exhaust Discharge Source

Not Available

Determination of Actual Short-Term and Long-Term Health Issues Identified From Odor Complaints As Verified By Professional Medical Personnel

No complaints were recorded.

Verification of Test methods

Verification of test method in the field

Not Available

Verification of test method in the lab

Not Available

Part C: Overall Review

(Applicability, Originality, Completeness, Limitations, etc. – in own words)

Strengths of the Study

In this project, a test stand was developed which was the basis for further tests later.

Weaknesses of the Study

The study covered CIPP lining with steam, water and UV cure. A subdivision of the statements concerning styrene emission was not made clear in the report. Furthermore, there were no information about measurement methods applied, instruments and individual measured values.

Paper No. B2

Styrene Emissions during Installation of a CIPP

Part A: Literature Information

Abstract

A city of North-Rhine Westfalia (anonymized) has a dumping ban on styrene in the public sewer system. In order to avoid time-consuming and cost-intensive monitoring during the renovation work on the site, it must be demonstrated in advance for each CIPP system used, that any proceeding polymerization of styrene contained in unsaturated polyester resin takes place in polystyrene and that after curing requirements for residual styrene content in the CIPP are complied with. Therefore the specific developed test rig is used which was developed and tested in a research project

Introduction

A city of North-Rhine Westfalia (anonymized) has a dumping ban on styrene in the public sewer system. In order to avoid time-consuming and cost-intensive monitoring during the renovation work on the site, it must be demonstrated in advance for each CIPP system used, that any proceeding polymerization of styrene contained in unsaturated polyester resin takes place in polystyrene and that after curing requirements for residual styrene content in the CIPP are complied with.

For this purpose, two CIPP (DN300 and DN600) were installed in a specially developed test rig. During installation, potential styrene emissions were determined in the surrounding media – groundwater, soil and the overlying air. The purpose of this was to prove that the correct use of the CIPP systems examined minimizes the risk of contamination. After completion of the tests, samples were taken from the CIPP and the residual styrene content was determined. In order to be able to evaluate the quality of the installed CIPP, the mechanical properties of the installed CIPP were also determined.

Objectives

To investigate and demonstrate measured readings from a CIPP installation in a certain test rig to show the applicability of the used curing technique with view of the styrene release.

Methodology

Test rig:

The test rig comprised a wooden box (W x L x H = 1.4m x 2.65m x 2.0m) enclosing a joint of two concrete pipes (Figure B2) (test rig for diameter DN 600 and a test rig for diameter DN 300). The pipes were completely embedded in sand, so that there was a layer of sand about 25 to 30 cm thickness above and below the pipe. By adding water to the surface of the sand bedding, a high water content was set in the soil up to the level of the pipe invert. The moisture content of the soil above and below the pipe were recorded to confirm this. Above the sand layer was an air layer, which was enclosed by the cover of the box, which was almost airtight.

Five concrete pipe sections were laid in the longitudinal direction and held together by straps. To simulate leaks in the pipe and in the area of a fitting joint, eight holes of 50 mm diameter were drilled in the pipe section within the box and a gap of 50 mm width was left in the joint (Figure B4). The holes were located halfway between the springing line and the crest or invert of the pipe, with a horizontal distance of approximately 1.0 m between the holes. In order to prevent the test soil from trickling into the pipes during installation, the holes were covered with a fleece (Figure B3).

Figure B2. Test Rig

Figure B3. Simulated Damage (Under Fleece)

Figure B4. Simulated Damage to Pipe

Installation of CIPP:

A CIPP of unsaturated polyester resins with glassfiber base material was installed by UV-curing in the two test pipes. Both CIPP had a pre-liner and an integrated outer foil (Figures B5, B6 and B7).

The CIPP for the first test in the nominal size DN 600 should, according to the factory certificate, was made with a composite thickness of 7.2 mm and a total thickness of 7.7 mm. For the second test with a nominal diameter of DN 300, a composite thickness of 3.7 mm and a total thickness of 4.2 mm was used.

Figure B5. Liner (DN 600)

Figure B6. Liner (DN 300)

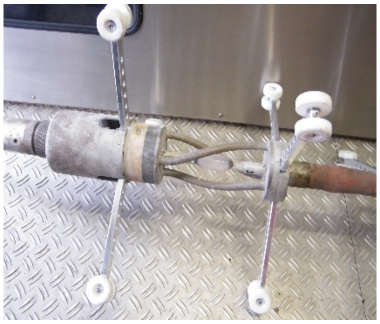


Figure B7. UV Lamp

Air sampling:

For sampling the air layer in the test rig above the sand filling, 50 liters of air were sucked out of the interior through a hole in the bulkhead of the test rig and passed over adsorption material (activated charcoal tubes) using an automatic sampler (Figures B8 and B9). In the opposite bulkhead, another hole allowed pressure equalization during suction by the automatic sampler. Both holes were 300 mm below the upper edge of the test rig and 300 mm away from the longitudinal wall. So that no styrene from the surrounding atmosphere (ambient air) could enter the test rig, the supply air hole was equipped with an adsorbent material (an A-carbon tube) (Figure B10).

Before the installation of the liner, the air layer inside the rig and surrounding the ambient air, were sampled to establish a baseline against which to measure any subsequent styrene contamination from the CIPP production.

The styrene contamination of the ambient air was detected by a second automatic sampler on the cover of the test rig (Figure B10).

As soon as the CIPP was cured and the cooling phase started, the measurement of the ambient air began. After airtight sealing of the sampling points used for soil sampling, sampling of the air from the test rig was undertaken. Suction of 50 liters air took about 25 minutes.

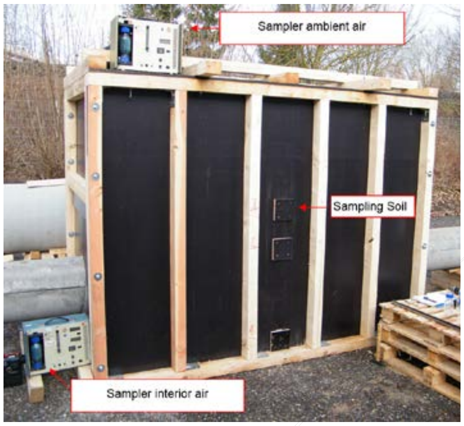


Figure B8. Sampler Positions for Air and Soil

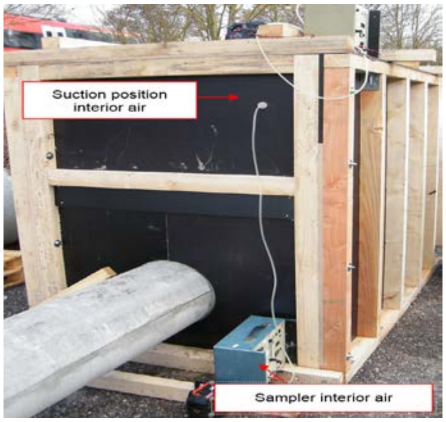


Figure B9. Sampler Position for "Interior Air"

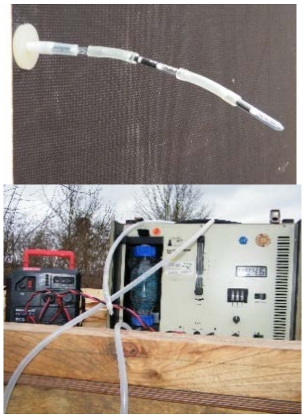


Figure B10. A-Carbon Tube (above), Sampler for Ambient Air (below)

Results

Styrene emission in air from the test rig:

The background load, or diffuse background pollution, of the atmosphere due to styrene emissions was determined by means of test tubes equipped with activated carbon (A-carbon) as the adsorption material. In each case, a second A-carbon tube was installed in line after the main one order to subsequently check that adsorption capacity of the main sampling tube was not exceeded during sampling.

The analyzes of ambient air data in the run-up to each test, to indicate styrene emissions in the vicinity of the test rig, were measured prior to installation and during installation of the CIPP-liners. The concentration for the first installation was between <0.001 mg styrene/m³ and 0.002 mg styrene /m³ in ambient air, and for the second (conducted the next day) was between 0.019 mg styrene/m³ and 0.035 mg styrene/m³. The partially tested second adsorption tubes gave no measurable levels, proving that the capacity of the first A-carbon absorber-tubes were not exceeded.

In the air layer above the sand layer of the test rig, closed and sealed against the ambient air, values between <0.001 mg/m³ styrene and 0.026 mg/m³ styrene were recorded before installation of the CIPP-liners (baseline measurement). During the first test (diameter DN 600), there was no enrichment of styrene in the air layer of the test rig. The enrichment rate in the air layer during the second test (diameter DN 300) was 0.016 mg/m³. The maximum value of 0.043 mg/m³ was obtained during the same tests done by IKT in 2008, UV-cured CIPP DN600.

The styrene concentrations observed in air were, in all cases, considered to be safe (all IKT-studies 2007, 2008, 2011) as they fell below the air limit value or occupational exposure limit of 86 mg/m³ with a high safety margin.

Conclusions and Recommendations for Future Research

The analyzes of ambient air data in the run-up to each test, to indicate styrene emissions in the vicinity of the test rig, were measured prior to installation and during installation of the CIPP-liners. The concentration was up to 0.035 mg styrene/m³ (maximum).

The styrene concentrations observed in air of the closed test rig during installation of UV-cured CIPP was, in all cases, considered to be safe (IKT-studies 2007, 2008, 2011) as they fell below the air limit value or occupational exposure limit of 86 mg/m³ with a high safety margin.

Part B: Reviewer’s Critique

Test Methods, Equipment, and Instrumentations Used

For sampling the air layer in the test rig above the sand filling, 50 liters of air were sucked out of the interior through a hole in the bulkhead of the test rig and passed over adsorption material (activated charcoal tubes) using an automatic sampler. In the opposite bulkhead, another hole allowed pressure equalization during suction by the automatic sampler. So that no styrene from the surrounding atmosphere (ambient air) could enter the test rig, the supply air hole was equipped with an adsorbent material (an A-carbon tube).

Before the installation of the liner, the air layer inside the rig and surrounding the ambient air, were sampled to establish a baseline against which to measure any subsequent styrene contamination from the CIPP production.

A second automatic sampler on the cover of the test rig detected the styrene contamination of the ambient air. After extraction of the styrene from the sorbent tubes, the content of styrene was measured with a gas chromatograph.

Data and Analysis

QA/QC

Specific QA/QC for the sorbent tubes (activated charcoal tubes) are not available. All chemical analysis were made by Hygiene Institut des Ruhrgebiets (Institute for Environmental Hygiene and Toxicology). Staff of this Institute accompanied all tests. The Institute is accredited for the performed chemical analysis.

Does the data sample collected represent the whole population?

Only the installation of two UV-cured liners was monitored. The study does not represent the whole population in terms of various diameters, lengths, curing method, etc.

Reporting and detection limits

No reporting limit or detection limit was specified in this report.

Did the document include employee sampling data from NASSCO companies?

No

CIPP materials used (including resin systems)

Polyester

Reference Review

Do references support conclusions?

All three performed test in the years 2007, 2008 and 2011 come to the same conclusion. The styrene concentrations observed in air of the closed test rig during installation of UV-cured CIPP was, in all cases, considered safe.

Peer review documentation of literature or study findings

Peer review of literature

Not Available.

Peer review of findings

Not Available.

Statistical Analysis Presented

What types of models have been used?

No statistical analysis was stated in this study.

Were the models used representative, calibrated and validated?

No statistical analysis was stated in this study.

Verification of CIPP Product Definition

Not Available.

List of Compounds of Interest

Styrene

Discussion of Employee/Public Safety and Health Standards and Regulations Including OSHA, ACGIH, NIOSH, and Other Regulatory Limits

The styrene concentrations observed in the air of the closed test rig during installation of UV-cured CIPP were, in all cases, considered to be safe (IKT-studies 2007, 2008, 2011) as they fell below the air limit value or occupational exposure limit of 86 mg/m³ with a high safety margin.

The analyzes of ambient air data in the run-up to each test, to indicate styrene emissions in the vicinity of the test rig, were measured prior to installation and during installation of the CIPP-liners. The concentration was up to 0.035 mg styrene/m³ (maximum) and can be considered safe as well (less than 86 mg/m³).

Review of the Data with Respect to Environmental Impacts, Toxicology and Employee Chemical Exposure

The styrene concentrations observed in the air of the closed test rig during installation of UV-cured CIPP were, in all cases, considered to be safe (IKT-studies 2007, 2008, 2011) as they fell below the air limit value or occupational exposure limit of 86 mg/m³ with a high safety margin.

The analyzes of ambient air data in the run-up to each test, to indicate styrene emissions in the vicinity of the test rig, were measured prior to installation and during installation of the CIPP-liners. The concentration was up to 0.035 mg styrene/m³ (maximum) and can be considered safe as well (less than 86 mg/m³).

Chemical Exposure Limits at Different Locations Relative to Steam Exhaust Discharge Source

Not Available.

Determination of Actual Short-Term and Long-Term Health Issues Identified From Odor Complaints As Verified By Professional Medical Personnel

No customer complaints regarding styrene levels were recorded during the three studies.

Verification of Test methods

Verification of test method in the field

Not Available.

Verification of test method in the lab

Not Available.

Part C: Overall Review

(Applicability, Originality, Completeness, Limitations, etc. – in own words)

Strengths of the Study

The study measured the release of styrene into the air above a buried pipe during installation of a UV-cured CIPP in a specific test rig. It also delivers ambient air data during the installation of the liner. The results are compared to German Standards (Occupational Exposure Limits).

Weaknesses of the Study

- The study only covered CIPP lining with UV cure.
- The transferability of the results to real rehabilitation projects in public sewers is not secured.

Paper No. B3

Styrene Measurement in a City of the Ruhr Area (anonymized)

Part A: Literature Information

Abstract

The curing of liners made of unsaturated polyester resin (UP resin) with steam causes emissions of styrene to be released into the ambient air with the steam. In order to determine the content of styrene in the ambient air in the vicinity of the steam outlet, a City of the Ruhr Area (anonymized) commissioned IKT – Institute for Underground Infrastructure to create a test concept and to carry out appropriate measurements during steam curing. The measured values of styrene at the street were compared to the German air pollution control regulation titled "Technical Instructions on Air Quality Control" ("Technische Anleitung zur Reinhaltung der Luft"). The allowed release of 50 mg/m³ according to this Technical Instruction is lower than the occupational exposure limit of 86 mg/m³.

Introduction

For the implementation of a test concept to measure the styrene release during installation of a steam-cured liner, a city in the Ruhr Area (anonymized) selected the renovation of a sewer with a nominal diameter of 400 mm. Only one installation of a steam-cured CIPP was analyzed. Figures B11 through B14 illustrate site conditions.

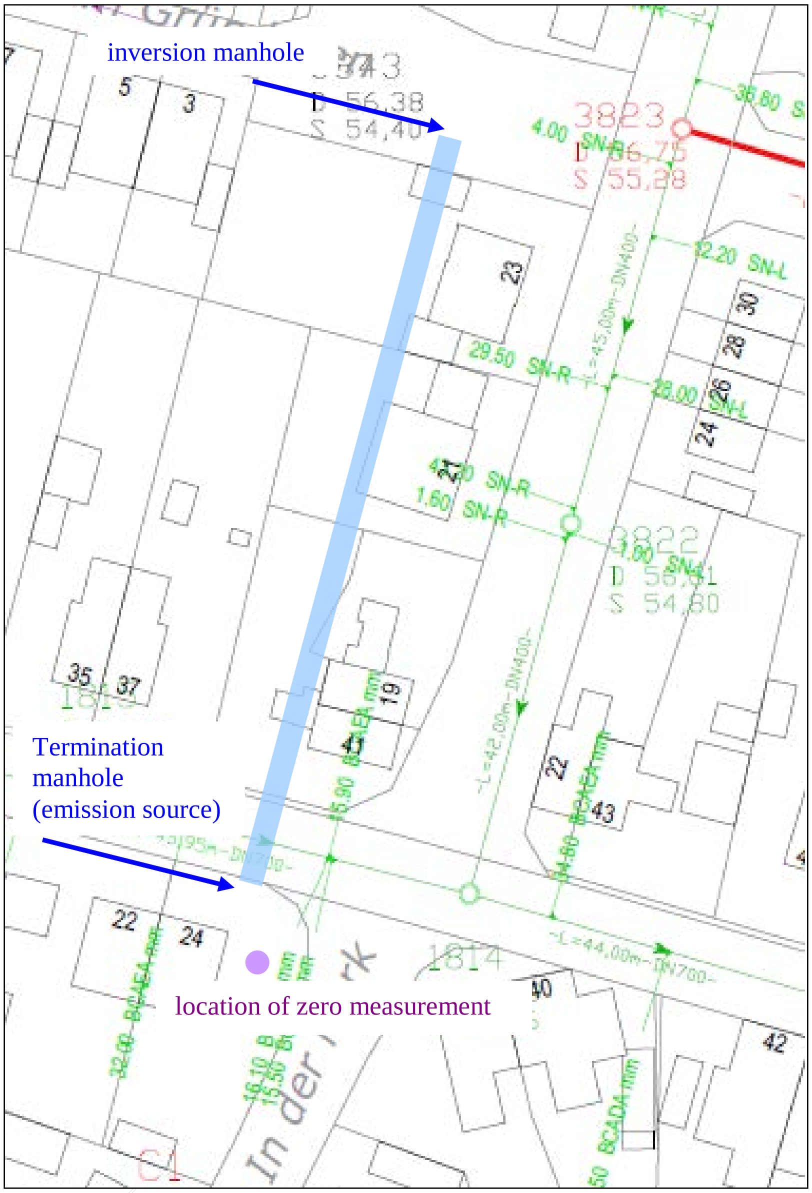


Figure B11. Location of CIPP Sewer Rehabilitation

Figure B12. Inversion Manhole (3823) Looking Towards Termination Manhole

Figure B13. Position of Termination

Figure B14. View from Termination Manhole (1814) In the Wind Direction to Lakestraße

Objectives

To investigate and demonstrate measured readings from realized CIPP sewer relining within a city in the Ruhr Area.

Methodology

Starting from the point of the steam outlet at the termination manhole (emission source), measuring points were marked out at 5-m intervals up to a distance of 20 m from the emission source. Measurement of styrene concentration was conducted in the ambient air, in the wind direction on both the Lakestrasse and the street marked "In der Mark" (see Figure B15). Due to the very weak wind from the west or southwest, the vent steam was distributed on both roads. Styrene measurements were made every 5 minutes, between the curb and the middle of each road at a height of approximately 1.5 m above the road surface.

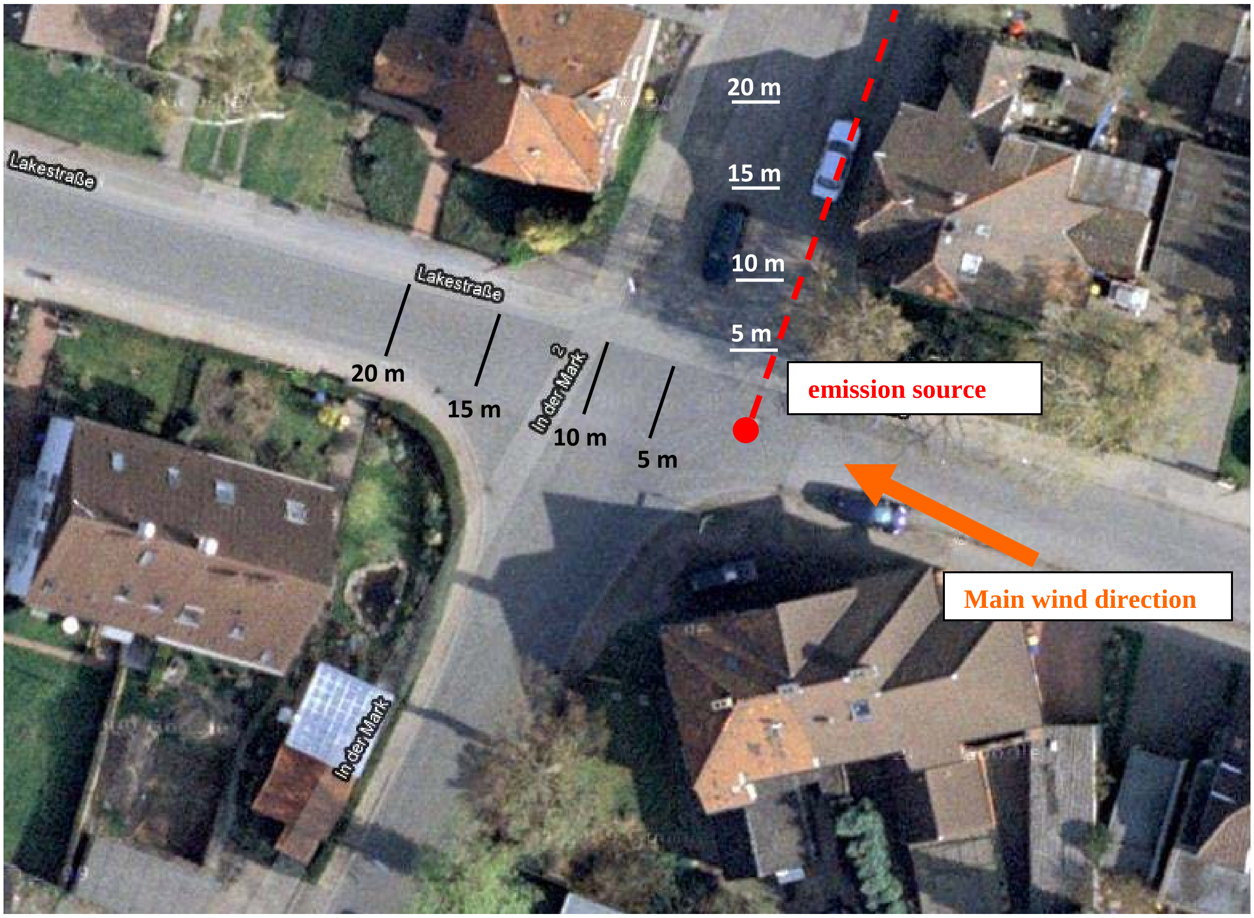


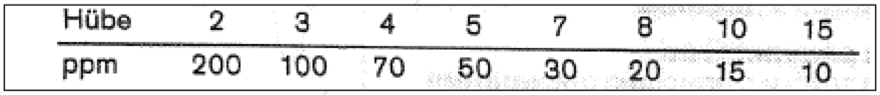
Figure B15. Position of Measuring Points and Emission Source
Source: Google Maps

A DRÄGER Accuro gas detection pump (see Figure B16) was used to determine the concentration of styrene in the air. These measurements were based on 15 pump strokes and observing any change of the white indicator layer, in the middle of the measuring tube, to a light yellow color.

Figure B16. DRÄGER Accuro Gas Detection Pump

Figure B17: DRÄGER Measuring Tubes

Figure B18 describes the relationship.



Hübe	2	3	4	5	7	8	10	15
ppm	200	100	70	50	30	20	15	10

Figure B18. Extract from Operating Instructions for the Measuring Tubes
Source: Dräger Safety AG & Co. KG

Before start of curing, a baseline measurement of the styrene concentration was carried out at a distance of 4 m from the emission source in the wind direction. This measurement recorded no color change in the measuring tube, which corresponds to a styrene concentration of <10 ppm.

The following boundary conditions were observed during the sewer renovation:

- Temperature: 8 °C
- Weather: clear, dry
- Wind: weak, variable from southwest to west

Results

The results of the measurements taken during the curing are presented in the following Tables B1 and B2.

Table B1. Road: In der Mark

distance period	5 m	10 m	15 m	20 m
5 min	< 10 ppm	**10 ppm**	< 10 ppm	< 10 ppm
10 min	< 10 ppm	< 10 ppm	< 10 ppm	< 10 ppm
15 min	< 10 ppm	< 10 ppm	< 10 ppm	< 10 ppm
20 min	< 10 ppm	< 10 ppm	< 10 ppm	< 10 ppm

Table B2. Road: Lakestraße

distance period	5 m	10 m	15 m	20 m
5 min	N/A	N/A	< 10 ppm	< 10 ppm
10 min	**20 ppm**	< 10 ppm	**11 ppm**	**10 ppm**
15 min	< 10 ppm	< 10 ppm	< 10 ppm	< 10 ppm
20 min	**10 ppm**	< 10 ppm	< 10 ppm	< 10 ppm

The highest measured concentration of styrene in air was 20 ppm (85 mg/m³) located at a distance of 5 m from the emission source. It was measured 10 Minutes after starting the curing process. This value was above the permissible mass concentration (according to TA Luft *) of 11.63 ppm. According to TA Luft (Number 5.2.5 Total Carbon, dated 24 July 2002), the emissions contained in the exhaust gas must not exceed the mass flow of 0.50 kg/h or the mass concentration of 50 mg/m³ (11.63 ppm). Overall, the average of all measured values, at around 2 ppm, is classified as low.

Germany has an air pollution control regulation titled “Technical Instructions on Air Quality Control” (“Technische Anleitung zur Reinhaltung der Luft”) and commonly referred to as the “TA Luft.”

Conclusions and Recommendations for Future Research

In this specific case, the release of styrene was compared to the German air pollution control regulation titled “Technical Instructions on Air Quality Control” (“Technische Anleitung zur Reinhaltung der Luft”). The allowed release of 50 mg/m³ according to this Technical Instruction is lower than the occupational exposure limit of 86 mg/m³.

Overall, the average of all measured values, at around 2 ppm, is classified as low. This study found no evidence to suggest that the release of styrene vapors from CIPP installation will have an impact to the health of the public. There was only one single measured value in a distance of 5 m to the emission source that was above the requirements of the German Air Pollution Control Regulation but lower than the Occupational Exposure Limit.

Part B: Reviewer’s Critique

Test Methods, Equipment, and Instrumentations Used

- The measurements of the styrene concentration were taken at a distance from emission source of 5m, 10m, 15m and 20m in the wind direction.

- The measurements were carried out every 5 minutes, between the curb and the middle of the road at a height of approx. 1.5 m above the road surface.

- Equipment and Instrumentation: Measuring tube from DRÄGER in the DRÄGER Accuro pump.

Data and Analysis

QA/QC

- Weather conditions during sampling were noted qualitatively (e.g. clear, dry).

- Temperature was measured and wind direction was noted.

- The used original Dräger measuring tube were best before 2013 (Study from 2011).

Does the data sample collected represent the whole population?

Only one steam-cured site was selected and analyzed at one single day. This study does not represent the whole population in terms of various diameters, lengths, curing method, etc.

Reporting and detection limits

The used Dräger Accuro pump with the measuring tubes for styrene has a detection limit of 10 ppm.

Did the document include employee sampling data from NASSCO companies?

No

CIPP materials used (including resin systems)

Polyester

Reference Review

Do references support conclusions?

The only other field study referenced was from Wessex Water, which found similar levels of styrene from steam cured installation technique.

There the installation company found maximum styrene levels recorded (site 1) at the road and in a garden of 24 ppm and 34 ppm (here: 20 ppm).

Peer review documentation of literature or study findings

Peer review of literature

Not Applicable.

Peer review of findings

Not Applicable.

Statistical Analysis Presented

What types of models have been used?

No statistical analysis was stated in this study.

Were the models used representative, calibrated and validated?

No statistical analysis was stated in this study.

Verification of CIPP Product Definition

Not Available

List of Compounds of Interest

Styrene

Discussion of Employee/Public Safety and Health Standards and Regulations Including OSHA, ACGIH, NIOSH, and Other Regulatory Limits

In this specific case, the release of styrene was compared to the German air pollution control regulation titled “Technical Instructions on Air Quality Control” (“Technische Anleitung zur Reinhaltung der Luft”). The allowed release of 50 mg/m³ according to this Technical Instruction is lower than the occupational exposure limit of 86 mg/m³.

Overall, the average of all measured values, at around 2 ppm, is classified as low. This study found no evidence to suggest that the release of styrene vapors from CIPP installation will have an impact to the health of the public. There was only one single measured value (20 ppm) in a distance of 5 m to the emission source that was above the requirements of the German Air Pollution Control Regulation but lower than the Occupational Exposure Limit.

Review of the Data with Respect to Environmental Impacts, Toxicology and Employee Chemical Exposure

In this specific case, the release of styrene was compared to the German air pollution control regulation titled “Technical Instructions on Air Quality Control” (“Technische Anleitung zur Reinhaltung der Luft”). The allowed release of 50 mg/m³ according to this Technical Instruction is lower than the occupational exposure limit of 86 mg/m³.

Overall, the average of all measured values, at around 2 ppm, is classified as low. This study found no evidence to suggest that the release of styrene vapors from CIPP installation will have an impact to the health of the public. There was only one single measured value (20 ppm) in a distance of 5 m to the emission source that was above the requirements of the German Air Pollution Control Regulation but lower than the Occupational Exposure Limit.

Chemical Exposure Limits at Different Locations Relative to Steam Exhaust Discharge Source

In this specific case, the release of styrene was compared to the German air pollution control regulation titled “Technical Instructions on Air Quality Control” (“Technische Anleitung zur Reinhaltung der Luft”). The allowed release of 50 mg/m³ according to this Technical Instruction is lower than the occupational exposure limit of 86 mg/m³.

Determination of Actual Short-Term and Long-Term Health Issues Identified From Odor Complaints As Verified By Professional Medical Personnel

No customer complaints regarding styrene levels were recorded in the study.

Verification of Test Methods

Verification of test method in the field

Not Available

Verification of test method in the lab

Not Available

Part C: Overall Review

(Applicability, Originality, Completeness, Limitations, etc. – in own words)

Strengths of the Study

The study measured the release of styrene into the air (at the street) at one steam-cured site using sorbent tubes (Dräger Accuro) and compared to the German air pollution control regulation titled “Technical Instructions on Air Quality Control” (“Technische Anleitung zur Reinhaltung der Luft”).

Weaknesses of the Study

Only one steam-cured site was assessed at one single day.

Paper No. B4

Technical Information on Measures in the Leaflet about Sewer Renovation Using Lining Techniques

Citation: Dusseldorp, A.; and Schols, E. (2006). “Rioolrenovatie met kousmethoden-Achtergronden bij het informatieblad “RIVM rapport 609021038/2006, Bilthoven, RIVM-Rijksinstituut voor Volksgezondheid en Milieu.

Part A: Literature Information

Abstract

During installation of a sewer, liner styrene may be released into the environment. Styrene, with its low odor threshold, has led to complaints from residents during some of the lining projects, which was a reason for the VROM Inspectorate to prepare a leaflet in close cooperation with representatives of municipalities and sewer renovation companies. The basic principle for the Inspectorate was that this kind of construction work falls under regular tasks and must therefore not lead to any unnecessary nuisance for civilians. Application of these measures will prevent exposure of the population exceeding exposure risks stipulated for these types of construction works.

Introduction

In March 2006 the Inspectorate of the Dutch Ministry of Housing, Spatial Planning and the Environment (VROM) published a leaflet in Dutch on ‘sewer renovation with cured-in-place pipe lining techniques’, to provide local authorities with information on sewer renovation using these techniques. This report gives background information on the measures and the derivation of the recommended exposure limits described in this leaflet, together with details of some background studies.

Objectives

To investigate and demonstrate readings from realized CIPP sewer relining within The Netherlands.

Methodology

Data from studies before measuring project: The fire department in Wageningen undertook some measurements in housing which was connected with a sewer that was rehabilitated using the CIPP-relining method (literature, which describes this, is from 2004, and so is from that year or before). The measurements were undertaken roughly one hour after a first complaint was received about a strong odor. In most houses, no styrene was found. In one house, a concentration of around 10-15 ppm was recorded. In manholes, concentrations of 0-300 ppm were recorded (Van Vliet, 2004). In 2005, there were indicative measurements taken in Apeldoorn. Within the sewers, styrene concentrations of around tens to hundreds of ppms were recorded. In “dead spaces” under manhole-covers, a maximum concentration of 1,400 ppm was recorded. The styrene concentration decreased rapidly after uncovering the manhole. On the street level, the styrene concentration fluctuated. Next to the manhole, the concentration was tens of ppms and at a distance of a few meters of the manhole; the concentration was a few ppms (Van Putten et al., 2005).

Extra measurements: To develop measures to prevent styrene vapor intrusion into housing, the need was established to obtain more insight into concentrations of vapor in and around a sewer that is being relined and how these concentrations develop over time during the process. This was needed to substantiate recommendations concerning:

1. When can the lateral sewers be opened again.

2. When can the main sewer be opened again (at which point air spreads throughout the whole sewer system)

Results

This data was obtained from measurements in Sevenum, Cuijk and Barendrecht (Table B3) in 2005 -2006.

Table B3. Overview Measurement Data, Location and Project Type

Date	Location	Data Project	Measurements
28-11-2005	Cuijk-Vianen	Liner with DN 300 and a length of 76 m. cured at 28-11-2005.	During curing: Up to 20 cm around the manhole At 1 m above the manhole opening (breathing height) During cooling: Concentration of blown air out of vent.
22-12-2005	Barendrecht	Liner with egg 300/450 and a length of 143 m. Cured on 21-12-2006	Air in housing after complaints inhabitant. In the manhole (during opening of the liner) At 1 m above the manhole opening (breathing height) Concentration of blown air out of vent.
10-01-2006	Sevenum	Liner with DN 350 and a length of 51 m. Cured at 10-01-2006.	During curing: At 10 and 30 cm away from the manhole During cooling: Concentration of blown air out of vent During cooling and releasing water: Concentration in sewer pipe below current After project: Concentration in the sewer pipe near the manhole.
13-01-2006	Sevenum	See above	Few days after the relining project was completed, in the sewer pipe.

Results from extra measurements: Using the measurements described above, the following overall picture concerning the development of styrene concentration was determined:

During curing process: the concentration around a manhole (up to 20 cm) was higher - a dozen ppms. At the height of 1 m above street level, a maximum of 10-ppm styrene was measured. After the curing process, the concentrations at around 1 m from a manhole were a few ppms.

During cooling: In the air that the vent sucks out of the sewer, the concentrations were around 35 ppm in Cuijk and 85 ppm in Sevenum. This peak was maintained for about fifteen minutes.

After cooling: After cutting the CIPP-liner and letting the first water run out, a styrene peak was measured. After release of the water, the peak was around 300 ppm.

During drilling of the lateral connections: It was measured a concentration of 20 ppm in the sewer in the direction of flow. A peak (around 50 ppm) was measured, possibly caused by turning of the vent during work in the manhole.

After completion: In the manhole, where the vent caused pressure reduction, after sealing all the other manholes, the concentration was about 40 ppm (about 4 hours after curing), at Sevenum. In Barendrecht they measured up to 100 ppm the day after the curing process (at the manhole). Three days after curing no styrene was measured in the sewer air near the manhole.
The results of extra measurements are listed in Table B4.

Table B4. Results of Extra Measurements

Period in Process	Measurements	Location	Time after Start of Curing
Curing	20-35 ppm 4-14 ppm 5-10 ppm	Directly next to manhole (Cuijk) Directly next to manhole (Sevenum) Breathing height (1 m) above manhole (Cuijk)	0-30 min
After curing and before cooling	0-6 ppm (some short spikes)	Breathing height (1 m) above manhole (Cuijk)	30 -60 min
Cooling process water (for this a hole in the liner must be cut)	10-35 ppm 10-85 ppm 0-30 ppm	Air out of vent (Cuijk) Air out of vent (Sevenum) Air in first manhole below current (Sevenum)	60-90 min
After cooling	Few ppm	Air out of vent (Cuijk/Sevenum)	90 min
Draining the water	0-300 ppm (short spike)	Air in first manhole below current	120-150 min
Opening holes for lateral connections	1-7 ppm 9 ppm	Living room after complaint Sub terrain house after complaint	0-12 hours
During cutting of holes for lateral connections (with negative pressure)	10-50 ppm (short spike) 50-100 ppm 20 ppm Few ppm	Air in first manhole below current (Sevenum) Air in manhole (Barendrencht)[1] Air out of vent (Barendrencht)[2] Distance to manhole: 50 cm downwind and 50 cm against the wind	150-180 min 12 hours 12 hours 12 hours
Relining done	40-50 ppm	Air in manhole (Sevenum)	Around 4 hours.
Relining done	0 ppm	Air in manhole	Around 3 days

[1] The concentrations in Barendrecht were higher. This is partly explained due to the absence of another manhole in the near vicinity to attract fresh air through the sewer pipe. A negative pressure was still maintained, but the styrene will not disperse as quickly.

[2] The vent was only able to stand halfway on the manhole and therefore fresh air was also blown the vent.

Conclusions and Recommendations for Future Research

The study concludes that the data obtained are not sufficient to find out how long the installation company should wait - to prevent styrene vapor intrusion into housing - until the sewer or the lateral can be opened again. This study recommends that during the installation of the CIPP there should be a negative pressure in the sewer for at least 24 hours after curing the liner to prevent the release of styrene. Additional there should be a good ventilation of the sewer.

Part B: Reviewer’s Critique

Test Methods, Equipment, and Instrumentations Used

This data was obtained from measurements in Sevenum, Cuijk and Barendrecht in The Netherland 2005-2006.

During different stages of the installation process, the concentration of styrene in the air around a manhole was measured at a height of 1 m above street level. Additional the styrene content in the air that the vent sucks out of the sewer was measured as well. Furthermore, the styrene content in different manholes and after complaints in a living room and in a sub terrain house was measured.

The measuring was in some cases continued after cooling and cutting the CIPP-liner, letting the first water run out, during drilling of the lateral connections and after completion until three days after curing.

The used equipment and instrumentation are not specified.

Data and Analysis

QA/QC

Not Specified.

Does the data sample collected represent the whole population?

As there is no information about the curing method available. The study does not represent the whole population, in terms of pipe diameters, lengths, etc.

Reporting and detection limits

No reporting limit or detection limit was specified in this report.

Did the document include employee sampling data from NASSCO companies?

No

CIPP materials used (including resin systems)

Polyester

Reference Review

Do references support conclusions?

The measured values above a manhole in this study show higher styrene peaks in comparison with other field studies like “City of Ruhr Area”.

Other field studies do not report on measurement of styrene content at a vent that sucks the air out of the sewer.

Peer review documentation of literature or study findings

Peer review of literature

Not Applicable.

Peer review of findings

Not Applicable.

Statistical Analysis Presented

What types of models have been used?

No statistical analysis was stated in this study.

Were the models used representative, calibrated and validated?

No statistical analysis was stated in this study.

Verification of CIPP Product Definition

List of Compounds of Interest

Not Available.

Discussion of Employee/Public Safety and Health Standards and Regulations Including OSHA, ACGIH, NIOSH, and Other Regulatory Limits

In the Netherland, a maximum workplace concentration (MAC) is used. The MAC-value for styrene is 25 ppm (107 mg/m^3).

During curing process: the concentration around a manhole (up to 20 cm) was higher - a dozen ppms. At the height of 1 m above street level, a maximum of 10-ppm styrene was measured. After the curing process, the concentrations at around 1 m from a manhole were a few ppms.

During cooling: In the air that the vent sucks out of the sewer, the concentrations were around 35 ppm in Cuijk and 85 ppm in Sevenum. This peak was maintained for about fifteen minutes.

After cooling: After cutting the CIPP-liner and letting the first water run out, a styrene peak was measured. After release of the water, the peak was around 300 ppm.

During drilling of the lateral connections: It was measured a concentration of 20 ppm in the sewer in the direction of flow. A peak (around 50 ppm) was measured, possibly caused by turning of the vent during work in the manhole.

After completion: In the manhole, where the vent caused pressure reduction, after sealing all the other manholes, the concentration was about 40 ppm (about 4 hours after curing), at Sevenum. In Barendrecht, they measured up to 100 ppm the day after the curing process (at the manhole). Three days after curing no styrene was measured in the sewer air near the manhole.

Review of the Data with Respect to Environmental Impacts, Toxicology and Employee Chemical Exposure

In the Netherland, a maximum workplace concentration (MAC) is used. The MAC-value for styrene is 25 ppm (107 mg/m³).

During curing process: the concentration around a manhole (up to 20 cm) was higher - a dozen ppms. At the height of 1 m above street level, a maximum of 10-ppm styrene was measured. After the curing process, the concentrations at around 1 m from a manhole were a few ppms.

During cooling: In the air that the vent sucks out of the sewer, the concentrations were around 35 ppm in Cuijk and 85 ppm in Sevenum. This peak was maintained for about fifteen minutes.

After cooling: After cutting the CIPP-liner and letting the first water run out, a styrene peak was measured. After release of the water, the peak was around 300 ppm.

During drilling of the lateral connections: It was measured a concentration of 20 ppm in the sewer in the direction of flow. A peak (around 50 ppm) was measured, possibly caused by turning of the vent during work in the manhole.

After completion: In the manhole, where the vent caused pressure reduction, after sealing all the other manholes, the concentration was about 40 ppm (about 4 hours after curing), at Sevenum. In Barendrecht, they measured up to 100 ppm the day after the curing process (at the manhole). Three days after curing no styrene was measured in the sewer air near the manhole.

Chemical Exposure Limits at Different Locations Relative to Steam Exhaust Discharge Source

In the Netherland, a maximum workplace concentration (MAC) is used. The MAC-value for styrene is 25 ppm (107 mg/m³).

Determination of Actual Short-Term and Long-Term Health Issues Identified From Odor Complaints As Verified By Professional Medical Personnel

The study reports that styrene has led to complaints from residents during some of the lining projects, which was a reason for the VROM Inspectorate to prepare a leaflet in close cooperation with representatives of municipalities and sewer renovation companies. However, no health issues identified from odor complaints as verified by professional medical personnel are reported.

Verification of Test methods

Verification of test method in the field

Not Available

Verification of test method in the lab

Not Available.

Part C: Overall Review

(Applicability, Originality, Completeness, Limitations, etc. – in own words)

Strengths of the Study

CIPP installations in three different cities were analyzed.

During different stages of the installation process, the concentration of styrene in the air around a manhole was measured at a height of 1 m above street level. Additionally the styrene content in the air that the vent sucks out of the sewer was measured as well. Furthermore, the styrene content in different manholes and after complaints in a living room and in a sub terrain house was measured.

The measuring was in some cases continued after cooling and cutting the CIPP-liner, letting the first water run out, during drilling of the lateral connections and after completion until three days after curing.

Weaknesses of the Study

- No information about the curing method are available.

- The used equipment and instrumentation are not specified.

Paper No. B5

Health Risks Associated With Airborne Styrene Release from CIPP Sites

Part A: Literature Information

Abstract

Styrene is an important component of the polyester resins used in the CIPP process. Concerns have been raised about the possible release of styrene vapors during the installation process and the impact this may have upon members of the public near these sites. Styrene vapors are known to have some health impacts, as studies have demonstrated that airborne styrene can cause irritation to the throat, eyes and nose at concentrations of approximately 100 ppm. Styrene vapors are detectible at 0.1 ppm, well below the level at which it becomes hazardous to health. The UK recommended OELs are 430 mg/m^3 (8 hour TWA) or 1080 mg/m^3 (15 minute STEL).

During the CIPP installation process members of the public can be exposed to styrene vapors as they pass the construction site or if, their residence or place or work is close to the site. Wessex Water commissioned Airtech ECS Ltd., to undertake independent air monitoring at two CIPP installation sites. Onsite Central Ltd., also carried out spot monitoring at the two selected sites and at an additional two sites. The sites covered a range of curing techniques, as well as a range of liner lengths and site conditions. The Airtech ECS Ltd., monitoring assessed the styrene volumes released from the sites in terms of the 8-hour TWA and the 15-minute STEL. For Case Study 1 (steam cure) the highest value found was 14 mg/m^3 (8-hour TWA) at the guardrail of the termination manhole, which is significantly lower than the TWA OEL. For the Case Study 2 (water cure), negligible levels of styrene were recorded (<0.25 mg/m^3 TWA) by Airtech ECS Ltd., Onsite Central monitoring revealed that relatively high levels of styrene occurred within the termination and inversion manholes but that this quickly dissipated, as readings taken 1 m from the manholes returned 0 ppm. Low levels of styrene were also detected at a surface water gully and at a cellar grid, indicating that styrene can travel through lateral connections.

Overall, the results of styrene monitoring at four sites found that levels escaping the work site were significantly below the recommended OELs, with no expected impact upon the health of members of the public. Reported levels within the site were only considered high within the termination and inversion manhole chambers, where periods of work extended is unlikely. It is recommended the risk of concentrated styrene vapors at these locations is communicated to workers and that good practice methods are followed to limit exposure.

Introduction

Health & Safety Executives (HSE) asked that Wessex Water present their existing procedure for management of airborne release of styrene monomer during the cross polymerization of thermoset resin liners for sewer renovation. As part of this, a scheme was raised to carry out detailed surveys at a number of Wessex Water CIPP sites. This report details the CIPP process and styrene health considerations, as well as the results of surveys carried out at four case study sites (one steam cure and three water cure).

Objectives

To investigate and demonstrate measured readings from planned CIPP sewer relining within Wessex Water Services Limited (WWSL) region.

Methodology

AirTech ECS Ltd., was employed by Wessex Water as a specialist environmental monitoring consultant to independently verify the levels of styrene near the lining works to European eco-toxicological standards. AirTech ECS Ltd., undertook independent air sampling during the installation of CIPP at two sites, one water cure and one steam cure. The survey methodology focused on quantifying the level of exposure to members of the public outside the site boundaries.

Onsite Central Ltd., also undertook separate styrene monitoring at four sites (one steam cure and 3 water cure), including the two surveyed by AirTech ECS Ltd., The Onsite Central Ltd., survey included monitoring within the site boundary.

AirTech ECS Ltd., designed their sampling methodology to assess potential operative exposure in accordance with guidance published by the HSE including HSG173 ‘Monitoring strategies for toxic substances’. Measurements were taken in accordance with MDHS 96 “Volatile organic compounds in air” published by the Health and Safety Executive. Volatile organic compounds (VOCs) were measured by drawing known volumes of air through sorbent tubes, placed at 8 locations for the first case study (steam cure) and at four locations for the second case study (water cure). The samples were subsequently subjected to chemical desorption and gas chromatography. From the survey results, AirTech ECS Ltd., calculated the short-term exposure (15 minute STEL) scenario for passers-by and a time weighted average (8-hour TWA). These results were reported in terms of mg/m^3.

Onsite Central Ltd., is a CIPP lining contractor utilized by Wessex Water. They also carried out testing at four sites in order to assess the effect upon their employees working on site. These surveys were carried out using a handheld BW Micro5 PID monitor calibrated to styrene only and reported in terms of ppm. At the steam-cured site, spot readings taken at the termination and inversion manholes, at a distance of 1m from the manhole openings and at a number of gullies along Newbridge Road believed to be connected to the surface water sewer being lined.

The two sites selected for AirTech ECS Ltd., sampling were chosen based on availability of planned polyester lining works and on the availability of AirTech ECS Ltd. A water cure site and steam cure site were selected. Additional monitoring sites selected by Onsite Central Ltd., were chosen based on the planned program of work.

Results

Case Study 1 (Steam Cure):

The Airtech ECS Ltd., results indicate the recorded volumes of styrene were significantly lower than the OEL values of 430 mg/m^3 for the 8 hour TWA and 1,080 mg/m^3 for the 15-min STEL. The highest 8-hour TWA value recorded was 14 mg/m^3 at the guardrail of the termination manhole for segment 2. The highest recorded STEL reading of 0.87 mg/m^3 was also recorded at this location.

The Onsite Central Ltd., results found high levels of styrene within the manholes themselves (165 ppm) but the significantly lower readings taken within 1 m of the manholes (6 ppm max) indicate the styrene dissipates rapidly. If sustained for the duration of the works, the recorded level within the manholes of 165 ppm and higher would violate the OEL; however, the results indicate that these levels above 100 ppm were not sustained for longer than 2 hours. Site workers would not be within the manholes themselves during this time and therefore would not be exposed. Higher than anticipated readings were found in the gully closest to the termination manhole (24 ppm); this is believed to be a result of the liner coming out of a suspected faulty pre-liner which had split prior to passing through the termination manholes chamber.

Case Study 2 (Water Cure):

The Airtech ECS Ltd., monitoring found very low levels of styrene were present at the guardrails of the site, with the monitor recording almost 0 mg/m^3 at all four sites. The Onsite Central Ltd., monitoring found styrene was present within the manholes themselves, with the highest levels at the termination and intermediate manhole during “end-cutting.” The levels were significantly lower than those found during Case Study 1 monitoring and significantly lower than the STEL recommended level of 250 ppm.

Case Study 3 (Water Cure):

Styrene was identified within the termination and inversion manholes during the ‘end-cutting’ and ‘inversion’ stage of works. Levels were lower than the STEL or TWA values of 100 ppm and 250 ppm and were not sustained for a significant period. Workers are unlikely to be within the manholes themselves for an extended period and the readings taken at 1 m from the manholes indicate the styrene quickly dissipated.

Case Study 4 (Water Cure):

Styrene was identified within the termination and inversion manholes during the “heating” stage of works. Levels were lower than the STEL or TWA values of 100 ppm and 250 ppm and were not sustained for a significant period. Workers are unlikely to be within the manholes themselves for an extended period and the readings taken at 1 m from the manholes indicate the styrene quickly dissipated.

Low levels (7 ppm) of styrene were identified at one of the cellar grids during the "curing and cutting ends" stage. This suggests styrene is escaping through the laterals into the properties, albeit in low levels.

Conclusions and Recommendations for Future Research

This study found no evidence to suggest that the release of styrene vapors from CIPP installations will have an impact on the health of the public in the immediate vicinity of the 15 works. Working within the manhole for extended periods could put workers at risk of reversible impacts on health, such as irritation to the throat, eyes and nose. In a typical CIPP installation, the workers are not within the manhole for extended periods however, it is worthwhile ensuring CIPP installation crews are aware of the risk from styrene vapors in the confined space of the manhole.

There is merit in undertaking spot checks on airborne styrene as a means to keep contractors attentive to good practice and generate current data to provide reassurance to the public wherever necessary.

Part B: Reviewer's Critique

Test Methods, Equipment, and Instrumentations Used

AirTech ECS Ltd., was employed by Wessex Water as a specialist environmental monitoring consultant to independently verify the levels of styrene in the vicinity of the lining works to European eco-toxicological standards. AirTech ECS Ltd., undertook independent air sampling during the installation of CIPP at two sites, one water cure and one steam cure. The survey methodology focused on quantifying the level of exposure to members of the public outside the site boundaries.

Onsite Central Ltd., also undertook separate styrene monitoring at four sites (one steam cure and 3 water cure), including the two surveyed by AirTech ECS Ltd. The Onsite Central Ltd., survey included monitoring within the site boundary.

AirTech ECS Ltd., designed their sampling methodology to assess potential operative exposure in accordance with guidance published by the HSE including HSG173 "Monitoring strategies for toxic substances." Measurements were taken in accordance with MDHS 96 "Volatile organic compounds in air" published by the Health and Safety Executive. Volatile organic compounds (VOCs) were measured by drawing known volumes of air through sorbent tubes, placed at 8 locations for the first case study (steam cure) and at four locations for the second case study (water cure). The samples were subsequently subjected to chemical desorption and gas chromatography. From the survey results, AirTech ECS Ltd., calculated the short-term exposure (15 minute STEL) scenario for passers-by and a time weighted average (8-hour TWA). These results were reported in terms of mg/m^3.

Onsite Central Ltd., is a CIPP lining contractor utilized by Wessex Water. They also carried out testing at four sites in order to assess the effect upon their employees working on site. These surveys were carried out using a handheld BW Micro5 PID monitor calibrated to styrene only and reported in terms of ppm. At the steam-cure site, spot readings taken at the termination and inversion manholes, at a distance of 1 m from the manhole openings and at a number of gullies along Newbridge Road believed to be connected to the surface water sewer being lined.

The two sites selected for AirTech ECS Ltd., sampling were chosen based on availability of planned polyester lining works and on the availability of AirTech ECS Ltd. A water cure site and steam cure site were selected. Additional monitoring sites selected by Onsite Central Ltd., were chosen based on the planned program of work.

Data and Analysis

QA/QC

A calibration certificate for the PID meter was presented. Weather conditions during sampling were noted qualitatively (e.g. hot, sunny, cloudy, and dry).

Specific QA/QC for the sorbent tube analysis was not reported. The report simply states that the sampling methodology was in accordance with the Health and Safety Executive's HSG173 ‘Monitoring strategies for toxic substances’ and MDHS 96 ‘Volatile organic compounds in air.’

Does the data sample collected represent the whole population?

A water and steam cure site were each selected, along with two additional water sites based on availability of planned polyester lining works. Since only one steam cure site was selected, it does not represent the whole population, in terms of various pipe diameters, lengths, etc.

Reporting and detection limits

No reporting limit or detection limit was specified in this report.

Did the document include employee sampling data from NASSCO companies?

No

CIPP materials used (including resin systems)

Polyester

Reference Review

Do references support conclusions?

The only other field study referenced was AirZOne (2001), which similarly found low levels of styrene from water cure.

Peer review documentation of literature or study findings

<u>Peer review of literature</u>

Not applicable

<u>Peer review of findings</u>

Peer review of the findings is not reported.

Statistical Analysis Presented

What types of models have been used?

No statistical analysis was stated in this study.

Were the models used representative, calibrated and validated?

No statistical analysis was stated in this study.

Verification of CIPP Product Definition

N/A

List of Compounds of Interest

Styrene

Discussion of Employee/Public Safety and Health Standards and Regulations Including OSHA, ACGIH, NIOSH, and Other Regulatory Limits

The Airtech ECS Ltd., monitoring assessed the styrene volumes released from the sites in terms of the 8-hour TWA and the 15-minute STEL for the UK. For the Case Study 1 (steam-cure), the highest value found was 14 mg/m^3 (8-hour TWA) at the guardrail of the termination manhole, which is significantly lower than the TWA OEL. For Case Study 2 (water-cure), negligible levels of styrene were recorded (<0.25 mg/m^3 TWA). Onsite Central Ltd., monitoring revealed that relatively high levels of styrene occurred within the termination and inversion manholes but that this quickly dissipated, as readings taken 1 m from the manholes returned 0 ppm.

Review of the Data with Respect to Environmental Impacts, Toxicology and Employee Chemical Exposure

See section on public safety and health standards and regulations above.

Chemical Exposure Limits at Different Locations Relative to Steam Exhaust Discharge Source

See section on public safety and health standards and regulations above.

Determination of Actual Short-Term and Long-Term Health Issues Identified From Odor Complaints As Verified By Professional Medical Personnel

No customer complaints regarding styrene levels were recorded during the four case studies.

Verification of Test Methods

Verification of test method in the field

N/A

Verification of test method in the lab

N/A

Part C: Overall Review

(Applicability, Originality, Completeness, Limitations, etc. – in own words)

Strengths of the Study

- The study measured potential worker and community exposure at one steam-cure site throughout the liner installation and curing process, using sorbent tubes at eight locations, and compared to the UK TWA standard.

- Styrene concentrations were also measured at the steam-cure site using a portable PID, at various locations (termination manhole, 1 m away from termination manhole, and in gullies) throughout the liner installation and curing process, to assess potential worker exposure.

Weaknesses of the Study

- Only one steam-cure site was assessed (the other three were water cure).

- Sorbent tubes were not attached to workers themselves.

APPENDIX C

MS ACCESS DATABASE

1. System Requirements

Microsoft Access 2016 component of Microsoft office 2016 is required.

2. How to Access the database

2.1. Click on Google Drive link:

https://drive.google.com/file/d/1yn6F1fzNMbvRibqOX4innRwXwa67KrEw/view?usp=sharing

2.2. Click on: Download

2.3. Click on: Download Anyway

2.4. Open the Database

3. Contents of Database

3.1. Tables and Queries:

Tables and queries have been created to store the papers related to research. Users do not need the tables and queries' configuration to use the database.

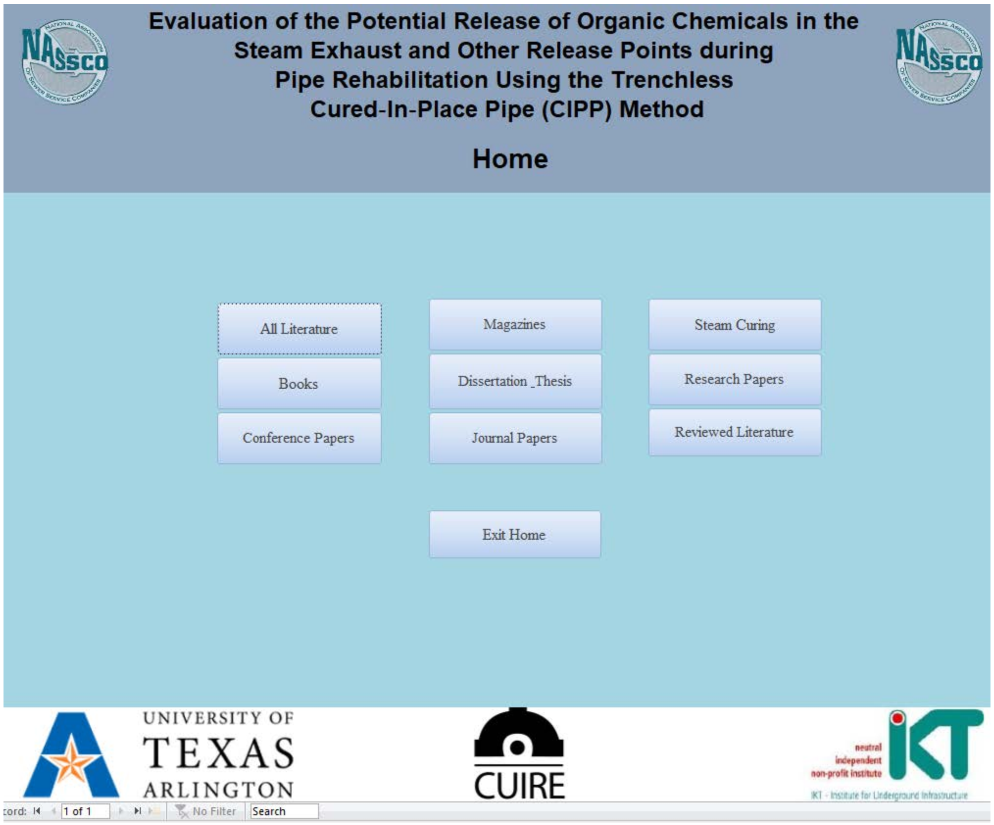
3.2. Forms:

The following Forms have been created for easy access to literature:

- All Literature
- Books
- By Authors
- By Title of Publication
- Conference Papers
- Dissertation & Thesis
- Home
- Journal Papers
- Magazines
- Phase I Literature
- Research Papers
- Steam Cure

Form: Home

Figure C1 shows Form "Home." This Form is created to make navigation through the database possible. The user needs to open this Form at the beginning to access the documents.



Evaluation of the Potential Release of Organic Chemicals in the Steam Exhaust and Other Release Points during Pipe Rehabilitation Using the Trenchless Cured-In-Place Pipe (CIPP) Method

Home

Figure C1. Form "Home" for Navigation through Database

Click on the different categories to view categorized literatures.

For example, click on **Reviewed Literature** to view all the literatures available in the database.

Figure C2 shows the Form having all the information about the reviewed publication.

This form shows following information about the reviewed literature:

Title of Publication: The Title under which the paper has been published.

Literature ID: The unique number assigned to each literature for identification purpose only for purpose of this database.

Authors: Provides the name(s) of the author(s) of the paper.

Publication Year: The year in which the paper was published.

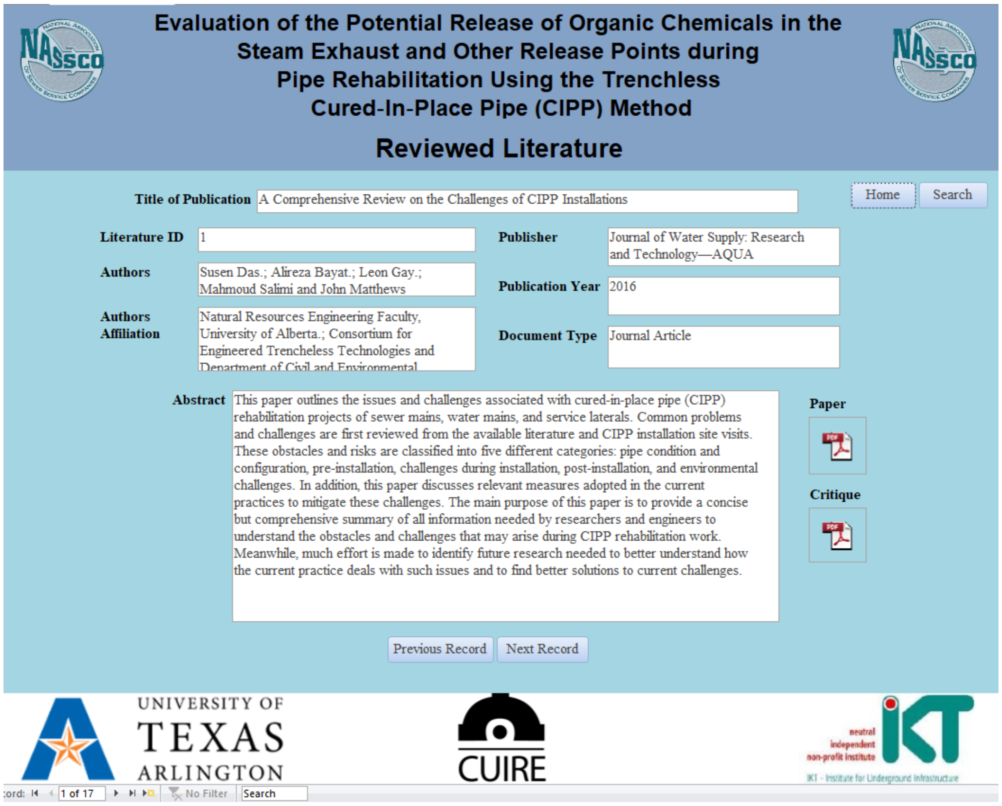
Publisher: The publisher of the paper.

Document Type: The type of publication viz., Conference Paper, Journal Paper, Books and Manuals, Standards, Magazine Articles, Newsletter Articles and Others.

Abstract: The full abstract (author abstract if available or edited abstract) of the paper.

File: The file with full text of the paper. When the user clicks on the Pdf file icon a pop is seen. Click on Open, and the user can see the document. Full text of the corresponding article is opened if the instructions are followed.

Critique: The file with critique template. When the user clicks on the Pdf file icon a pop is seen. Click on Open, and the user can see the critique document.



Evaluation of the Potential Release of Organic Chemicals in the Steam Exhaust and Other Release Points during Pipe Rehabilitation Using the Trenchless Cured-In-Place Pipe (CIPP) Method

Reviewed Literature

Title of Publication: A Comprehensive Review on the Challenges of CIPP Installations

Literature ID: 1

Authors: Susen Das.; Alireza Bayat.; Leon Gay.; Mahmoud Salimi and John Matthews

Authors Affiliation: Natural Resources Engineering Faculty, University of Alberta.; Consortium for Engineered Trenchless Technologies and Department of Civil and Environmental

Publisher: Journal of Water Supply: Research and Technology—AQUA

Publication Year: 2016

Document Type: Journal Article

Abstract: This paper outlines the issues and challenges associated with cured-in-place pipe (CIPP) rehabilitation projects of sewer mains, water mains, and service laterals. Common problems and challenges are first reviewed from the available literature and CIPP installation site visits. These obstacles and risks are classified into five different categories: pipe condition and configuration, pre-installation, challenges during installation, post-installation, and environmental challenges. In addition, this paper discusses relevant measures adopted in the current practices to mitigate these challenges. The main purpose of this paper is to provide a concise but comprehensive summary of all information needed by researchers and engineers to understand the obstacles and challenges that may arise during CIPP rehabilitation work. Meanwhile, much effort is made to identify future research needed to better understand how the current practice deals with such issues and to find better solutions to current challenges.

Figure C2. Information about Reviewed Literature

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