

Assessing the Impact of CIPP Cure Water on POTW Biological Treatment: A Comprehensive Multi-Phase Analysis

Abstract

This study presents findings from a NASSCO-funded investigation examining potential inhibitory effects of styrene-containing cure water from cured-in-place pipe (CIPP) method installations on secondary and advanced biological wastewater treatment processes at Publicly-Owned Treatment Works (POTW) in the United States. A systematic three-phase methodology was employed: 1) a literature review; 2) a survey of wastewater treatment professionals; and 3) laboratory-scale respirometry testing from representative biomass samples from three POTW (HRSD – Virginia Beach, Virginia; Charlotte Water - Charlotte, North Carolina; and Metro Water Services - Nashville, Tennessee). The biomasses were evaluated using Organization for Economic Cooperation and Development (OECD) Method 209 protocols, supplemented with extended testing for organic removal and nitrification assessment.

The literature review identified no prior peer-reviewed research addressing CIPP cure water or condensate impacts on POTW, revealing a significant knowledge gap despite decades of CIPP installations. Survey responses from 33 wastewater professionals (from over 28,000 contacted) reported no documented treatment disruptions attributable to CIPP discharges. Laboratory testing established a No Observed Effect Concentration (NOEC) of 2.3 mg/L for styrene, with supplemental analyses suggesting higher tolerance thresholds for organic removal. The half-maximal inhibitory concentration (EC50) exceeded 105 mg/L across all tested biomass samples, indicating a substantial safety margin between typical exposure levels and inhibitory concentrations.

These results provide the first empirical thresholds for styrene exposure in activated sludge systems, demonstrating that standard CIPP cure water or condensate discharges present minimal risk to biological treatment efficacy under typical operating conditions with consideration for dilution and volatilization of styrene in the water column. The established NOEC value, combined with inherent dilution factors and biodegradation capabilities of POTW, supports continued CIPP utilization while providing scientifically based criteria for evaluating risk strategies for CIPP installations near or at POTW.

Keywords: CIPP, styrene, wastewater treatment, respirometry, NOEC, EC50, OECD, biological inhibition, activated sludge

Introduction

Cured-in-Place Pipe (CIPP) technology has emerged as a trenchless rehabilitation method for gravity wastewater collection systems throughout the United States over the past five decades. Technology's widespread adoption stems from its operational efficiency, cost-effectiveness, and minimal disruption to surrounding environments compared to traditional excavation-based repair methods. The CIPP process utilizes existing damaged pipes as host structures, into which flexible tubes saturated with liquid thermoset resin are inserted and subsequently inflated. Polymerization of the resin occurs through various curing methods including hot water, steam, or ultraviolet light or other light-cured methods to create a new pipe within the existing host pipe for fully deteriorated designs or partially deteriorated designs.

CIPP installations employ either styrene-based or non-styrene resins, with styrene-based systems historically predominating due to their favorable mechanical properties, cost, and curing characteristics. However, the potential environmental and operational impacts of styrene-containing cure water or condensates discharged to POTW have generated industry concern, particularly regarding potential inhibition of biological treatment processes.

NASSCO has systematically addressed knowledge gaps through a multi-phase research program. Initial phases focused on quantifying and characterizing organic chemical emissions, including both gaseous and aqueous releases during CIPP installation, and developing mitigation strategies for potential adverse impacts on human health and environmental receptors. Phase 1 reviewed published studies to baseline the knowledge base around styrene emissions and exposure pathways. Phase 2 investigations evaluated air emissions from steam-cured polyester resin CIPP installations, identifying styrene as the primary compound of concern at concentrations potentially exceeding health-based thresholds under certain exposure scenarios. Phase 3 examined styrene emissions from various CIPP coating materials under refrigerated storage conditions, establishing that ventilation protocols can effectively reduce styrene concentrations below regulatory exposure limits, enabling safe worker entry with appropriate personal protective equipment. These studies collectively advanced understanding of styrene fate and transport in occupational settings; however, a critical knowledge gap remained regarding the fate and effects of styrene-containing cure water or condensate discharged to POTW.

Despite decades of widespread CIPP implementation representing millions of linear feet of installations annually, the peer-reviewed literature lacks systematic evaluation of CIPP cure water compatibility with POTW biological treatment processes. The present study addresses critical uncertainty in CIPP discharge impact on POTW deployment through a three-phase investigation of styrene impacts on activated sludge systems, providing the first scientifically rigorous assessment of CIPP cure water effects on POTW operations.

The research methodology comprised three sequential components: (1) a systematic literature review to identify and evaluate existing studies examining CIPP cure water styrene impacts on wastewater treatment facilities; (2) development and deployment of a structured questionnaire to capture industry perspectives, operational experiences, and documented incidents related to CIPP cure water discharge among POTW operators, engineers, and regulatory professionals; and (3) laboratory-scale respirometry testing to quantify styrene inhibition thresholds using activated

sludge biomass samples from three different geographically diverse POTW operating under different process configurations and influent characteristics.

1. Literature Review

The NASSCO Phase 4 study started with a literature review, which included searching multiple resources such as Purdue Library and several databases such as Google Scholar, ASCE, SciSpace, Scopus, open access information from web pages of national agencies in the U.S. and Europe, local Department of Transportation (DOT) agencies' public reports, and electronic science magazines to gather information. The available literature publications were collected, reviewed, and categorized. Follow-up phone calls were made with some respondents. More than 200 publications were identified and reviewed based on the review results. The list of published research that is relevant to CIPP water curing impact on wastewater treatment plants was shortlisted to a total of 26 relevant publications. The list of research publications was further shortlisted to six relevant literature publications related to water quality impact due to CIPP cure water discharge. Existing studies do not adequately capture the impact of CIPP water curing on POTW. No study discussed the topic of POTW treatability impact because of the CIPP process.

2. Questionnaire

A questionnaire was prepared with input from research team members to determine current perceptions and potential concerns regarding styrene used in the CIPP process, particularly as it pertains to cure water making its way to wastewater treatment plants. The questionnaire was intended to solicit information from POTW professionals, including operators, owners, and asset managers. The questionnaire was distributed to personal contacts of the authors, reaching 97 recipients. The participants included people from multiple cities in the United States, Brazil, Canada, Colombia, Germany, and Singapore. The questionnaire was then sent to the BAMI-I database, which included 27,029 recipients from the US, Australia, Brazil, Europe, Finland, Germany, Hong Kong, Japan, New Zealand, Pakistan, Singapore, South America, and South Korea. The total number of respondents was 28. The questionnaire was subsequently distributed to 1,000 supervisor managers through the Treatment Plant Operator (TPO) Magazine for wastewater and water operators, engineers, and lab technicians covering municipal and industrial treatment plants. The number of responses increased to 33 respondents. The low response rate and the comments received from industry professionals through direct emails, personal interviews, and questionnaire results indicate no direct impact of CIPP cure water discharge on wastewater treatment plants.

3. Biological Testing of CIPP Impact on POTW

To investigate concerns related to CIPP impact on POTW, bench-scale biological testing was conducted using biomass samples from three representative and well-operated wastewater treatment plants: HRSD in Virginia Beach, Virginia; Charlotte Water in Charlotte, North Carolina; and Metro Water Services in Nashville, Tennessee. Testing followed OECD Method 209-A, which measures Oxygen Uptake Rate (OUR) to evaluate biological inhibition. However, OECD 209 does not distinguish between inhibition caused by Chemical Oxygen Demand (COD) oxidation versus nitrification. Therefore, supplemental testing was conducted to separately assess COD removal and nitrification performance, offering greater clarity and specificity on the mechanisms of inhibition. The OECD method reveals whether inhibition occurs, but not its cause; hence, additional testing beyond OECD was essential for more definitive conclusions. Method 209 served

as the foundation for respirometry testing depicted in Figure 1, enhanced through continuous oxygen uptake monitoring using Return Activated Sludge (RAS) respirometers equipped with test bottles submerged in a water bath and connected via oxygen tubing. These modifications enabled precise tracking of biomass respiration dynamics and provided additional insight into the fate of organics, nutrients, and residual styrene beyond standard Method 209 requirements.

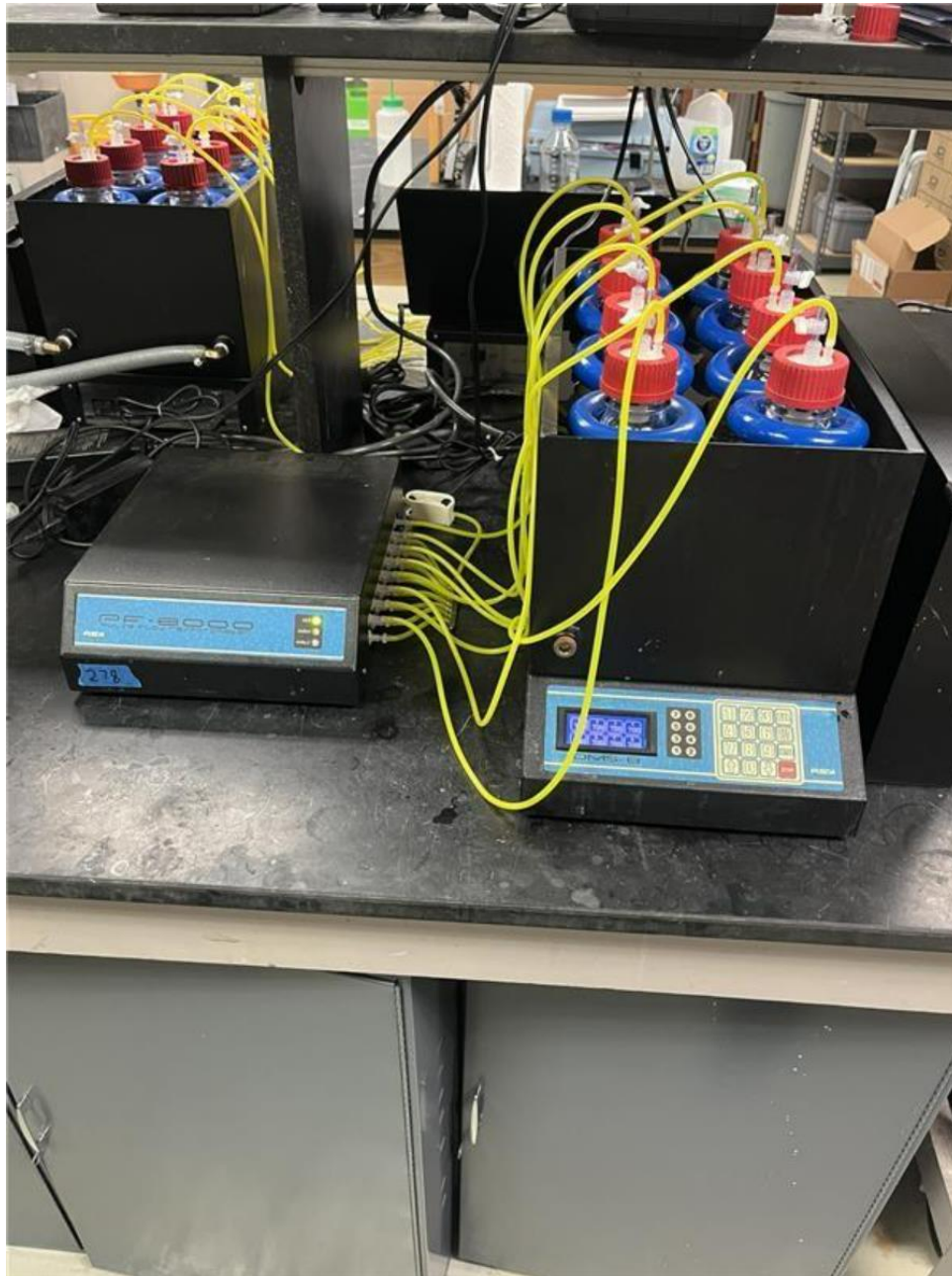


Figure 1. Respirometry testing based on Method 209

The primary takeaway from this study is the determination of the No Observed Effect Concentration (NOEC) for styrene, found to be 2.3 mg/L based on OECD 209-A. Supplemental tests showed some evidence that the NOEC could be slightly higher; however, 2.3 mg/L is recommended as a conservative benchmark for operational safety. Notably, both the OECD and

supplemental data indicate that the effective concentration causing 50% inhibition (EC50) is greater than 105 mg/L, indicating a wide margin between NOEC and EC50. This broad range enables the use of NOEC as a protective threshold without requiring additional safety factors, providing risk evaluation information for wastewater treatment plant operators to determine their system's potential resiliency to styrene.

Prior to testing, expectations were that the NOEC would be higher than 2.3 mg/L. However, real-world treatment plants benefit from substantial dilution effects. When styrenated cure water is introduced into a system, such as being released over 30 minutes into an aeration basin with a 6-hour retention time, the resulting 12-fold dilution reduces the concentration to which biomass is exposed. Even in a more extreme case, where styrenated water is discharged over 5 seconds, the dilution achieved before reaching the biological treatment phase would be much greater, meaning the active biomass may only be exposed to a fraction of the original concentration. These findings bolster confidence in the conservative NOEC value and demonstrate the inherent resiliency of treatment systems.

The respirometric testing measured cumulative oxygen uptake at 10-minute intervals to calculate Oxygen Uptake Rate (OUR) and Specific Oxygen Uptake Demand (SOUR) values, which were plotted over time to create SOUR curves for visual evaluation of the three biomasses tested. For impact assessment, SOUR values from 0.5 to 6 hours were averaged (33 data points per replicate), excluding the initial 30 minutes due to typical oxygen uptake spikes and limiting the evaluation period to when control bottles reached endogenous respiration ($\text{SOUR} < 8 \text{ mg/g/hr}$), thereby maximizing sensitivity to detect differences in SOUR between styrene test concentrations.

In Test 5, the duration was extended beyond the typical 18 hours to better evaluate styrene degradation and potential recovery of nitrification. This decision was driven by the persistent styrene odor observed in earlier tests and emerging evidence that nitrification was being inhibited. Since styrene is biodegradable, it was expected that a longer test would allow biomass more time to adapt and consume the compound. During the extended 30–60 hour period, new peaks in oxygen uptake above endogenous respiration were observed, as shown in the shaded region of Figure 2, indicating renewed biological activity likely linked to styrene breakdown. The absence of styrene odor at the test's conclusion further confirmed its consumption. These findings suggest that biomass required 30–50 hours to acclimate to styrene before effectively degrading it. In the extended test, select bottles were analyzed for $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$, and $\text{NO}_3\text{-N}$ to assess nitrification recovery. Results showed no significant change in nitrate levels from start to end, indicating persistent nitrification inhibition over the 60-hour period despite styrene degradation. This suggests recovery may take more than two days once inhibition occurs. No styrene dose showed a no-observable effect, confirming the NOEC is below 2.3 mg/L, while the highest dose (105 mg/L) did not produce an EC50 in any biomass.

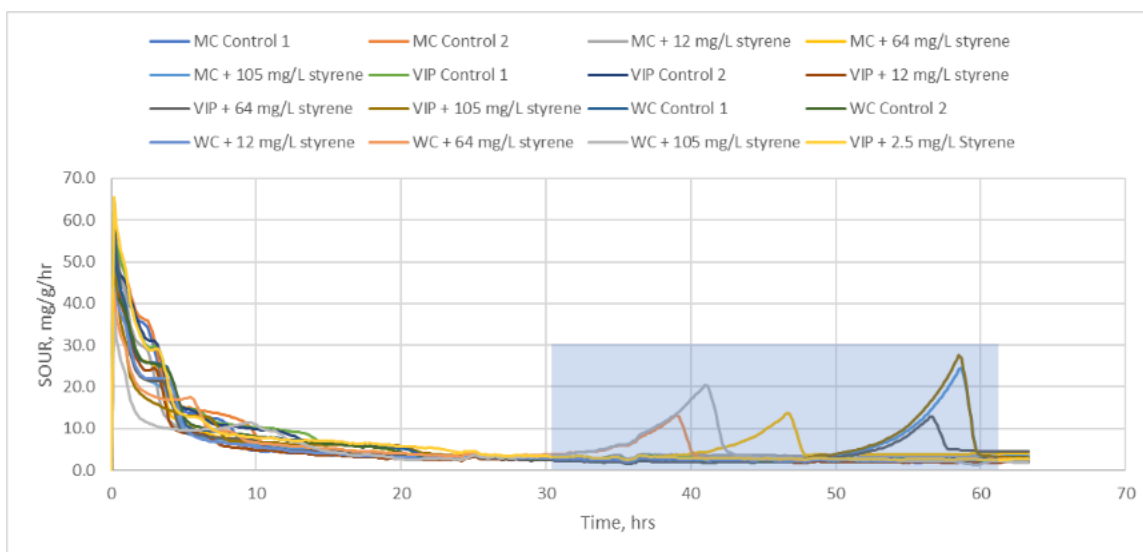


Figure 2. Test 5 SOUR data curves.

Furthermore, operational strategies can further mitigate styrene impacts. For instance, adjusting recycled flows such as Return Activated Sludge (RAS) introduces additional dilution. A 50% RAS return rate could raise the effective NOEC to approximately 3.5 mg/L, enhancing system robustness against styrene spikes. Even if a rare, high-concentration release occurred due to catastrophic resin failure, the combination of volatilization, aerobic degradation, and volumetric dilution would significantly limit risk to biomass functionality. Indeed, styrene removal exceeding 60% was observed across all test conditions, independent of air stripping. Therefore, biomass recovery is anticipated even following temporary overexposure events.

Under typical operating conditions, POTW may encounter styrene concentrations in the microgram-per-liter range, particularly following dilution by return flows, influent blending, and distribution throughout system volumes. The recommendation to maintain influent concentrations below 2.3 mg/L therefore provides a substantial safety margin. Moreover, the aeration basin, representing the most vulnerable exposure point, experiences significant mixing and dilution before peak concentrations reach active biomass, with the 2.3 mg/L threshold serving as a conservative upper limit. The dual testing approach, incorporating both OECD Method 209-A and supplemental evaluations, provides robust technical justification for the established NOEC value and validates its application as a regulatory and design criterion.

Conclusions

This investigation represents the first systematic evaluation of styrene-containing CIPP cure water impacts on POTW biological treatment processes. The comprehensive literature review identified no peer-reviewed publications directly addressing this critical knowledge gap, despite five decades of CIPP technology deployment. The industry survey, while limited by a low response rate (0.12% of contacted professionals), revealed no documented cases of treatment disruption attributable to CIPP cure water discharge among responding facilities.

Laboratory respirometry testing established a No Observed Effect Concentration (NOEC) of 2.3 mg/L for styrene in activated sludge systems, with an EC50 exceeding 105 mg/L. This substantial

margin between inhibition threshold and half-maximal effect concentration, combined with inherent system dilution factors and observed biodegradation rates exceeding 60%, indicates minimal risk to POTW operations under typical discharge scenarios. The extended respirometry trials demonstrated complete styrene mineralization within 30-50 hours, although nitrification recovery required periods exceeding 60 hours following inhibitory exposure.

Recommendations

Based on these findings, the following recommendations are advanced for industry implementation:

1. **Risk Assessment Framework Development:** An addendum to NASSCO's "Safe Use and Handling of Styrene-based Resins in CIPP Specification Guideline" (April 2023) should incorporate a quantitative risk assessment tool for evaluating site-specific discharge scenarios. The model should integrate variables including pipe dimensions, resin mass calculations, hydraulic retention times, dilution factors, and distance to receiving POTW to predict effluent styrene concentrations relative to the established NOEC threshold.
2. **Establishment of Industry-Wide Database:** A centralized repository for styrene concentration data from CIPP cure water should be developed through collaborative efforts between regulatory agencies, municipalities, and industry stakeholders. Standardized sampling protocols and quality assurance procedures should be implemented to ensure data comparability across installations and geographic regions.
3. **Advanced Treatability Studies:** Future investigations should employ continuous-flow or sequencing batch reactor configurations to more accurately simulate full-scale hydraulic and kinetic conditions. Emphasis should be placed on long-term acclimation effects, nitrification recovery kinetics, and competitive inhibition dynamics at environmentally relevant styrene concentrations (0.1-2.3 mg/L).

The established NOEC of 2.3 mg/L represents a conservative operational threshold that, when combined with typical dilution factors and biodegradation kinetics, provides adequate protection for POTW biological processes. These findings support the continued use of styrene-based CIPP technology within appropriate operational constraints while identifying specific areas requiring additional investigation to optimize discharge management strategies.

References

1. “A Database of Chemical Toxicity Environmental Bacteria and Its Use in Interspecies Comparisons and Correlation: D.J.W. Blum and R.E. Speece , Research Journal Water Pollution Control Federation, Volume 63, Pages 198-2007, 1991.
2. A Technical Review of VTRC’s Research Report: Understanding the Environmental Implications of Cured-in-Place Pipe Rehabilitation Technology, Ed Campbell, 2010.
3. CTC & Associates, LLC, 2012. *Preliminary Investigation: Environmental Effects of Cured In Place Pipe Repairs*. Caltrans Division of Research and Investigation, Sacramento, CA.
4. Currier B., 2017. *Water Quality of Flow Through Cured-In-Place Pipe (CIPP)* Caltrans Division of Research and Investigation, Sacramento, CA.
5. Das, S., Bayat, A., Gay, L., Salimi, M., & Matthews, J. (2016). A comprehensive review on the challenges of cured-in-place pipe (CIPP) installations. *Aqua (London)*, 65(8), 583-596. <https://doi.org/10.2166/aqua.2016.119>
6. Davis, L., & Ness, A. (1999). Using quantitative risk assessment to develop a cost effective spill prevention program. *Process safety progress*, 18(4), 211-213. <https://doi.org/10.1002/prs.680180408>
7. Donaldson, B. M. Environmental Implications of Cured-in-Place Pipe Rehabilitation Technology. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2123*, Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 172–179.
8. Donaldson, B. M., & Whelton, A. J. (2013). Impact of Stormwater Pipe Lining Materials on Water Quality: Field Study and Resulting Specifications. *Transportation research record*, 2362(1), 49-56. <https://doi.org/10.3141/2362-07>
9. Donaldson, B. M., and Baker, P.E., 2008, Understanding the Environmental Implications of Cured-In Place Pipe Rehabilitation Technology, Virginia Transportation Research Council, Final Report vrRC 08-RIG.
10. Handbook of Environmental Data on Organic Chemicals by Karel Verschueren (3rd Edition, 1996).
11. Howell, J. M., Matthews, E., Matthews, J., Alam, S., Bednar, A., Laber, C., & Eklund, S. (2022). Styrene Emissions in Steam-Cured CIPP: A Review and Comparison of Multiple Studies. *Journal of pipeline systems*, 13(1). [https://doi.org/10.1061/\(ASCE\)PS.1949-1204.0000620](https://doi.org/10.1061/(ASCE)PS.1949-1204.0000620)
12. Kaushal, V., & Najafi, M. (2020). Comparative Assessment of Environmental Impacts from Open-Cut Pipeline Replacement and Trenchless Cured-in-Place Pipe Renewal Method for Sanitary Sewers. *Infrastructures (Basel)*, 5(6), 48. <https://doi.org/10.3390/infrastructures5060048>

13. Knight, M. A., Ioannidis, M. A., Salim, F., Górecki, T., & Pivin, D. (2023). Health Risks Assessment from Cured-in-Place Pipe Lining Fugitive Styrene Emissions in Laterals. *Journal of pipeline systems*, 14(1). [https://doi.org/10.1061/\(ASCE\)PS.1949-1204.0000690](https://doi.org/10.1061/(ASCE)PS.1949-1204.0000690)
14. Kobos, L., Teimouri Sendesi, S. M., Whelton, A. J., Boor, B. E., Howarter, J. A., & Shannahan, J. (2019). In vitro toxicity assessment of emitted materials collected during the manufacture of water pipe plastic linings. *Inhalation toxicology*, 31(4), 131-146. <https://doi.org/10.1080/08958378.2019.1621966>
15. Kyungyeon, R., Seyedeh Mahboobeh Teimouri, S., John, A. H., Chad, T. J., Bridget, M. D., & Andrew, J. W. (2018). Critical Review: Surface Water and Stormwater Quality Impacts of Cured-In-Place Pipe Repairs: JOURNAL AWWA. *Journal - American Water Works Association*, 110, 15-32. <https://doi.org/10.1002/awwa.1042>
16. Lee R. K. Risk Associated with CIPP Lining of Stormwater Pipes and the Release of Styrene. *Proceedings of the North American Society of Trenchless Technology (NASTT) No Dig. Conference NASTT Dallas TX USA 27 April-2 May 2008*.
17. 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*.
18. Loss, A., Toniolo, S., Mazzi, A., Manzardo, A., & Scipioni, A. (2018). LCA comparison of traditional open cut and pipe bursting systems for relining water pipelines. *Resources, conservation and recycling*, 128, 458-469. <https://doi.org/10.1016/j.resconrec.2016.08.001>
19. Matthews, E., Kraft, J., Hossain, G., Bednar, A., Laber, C., Alam, S., Eklund, S. (2022). Air Quality Dispersion Modelling to Evaluate CIPP Installation Styrene Emissions. *International journal of environmental research and public health*, 19(21), 13800. <https://doi.org/10.3390/ijerph192113800>
20. Najafi, M., et al. (2018). "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." Report to NASSCO.
21. Noh, Y., Odimayomi, T., Teimouri Sendesi, S. M., Youngblood, J. P., & Whelton, A. J. (2022). Environmental and human health risks of plastic composites can be reduced by optimizing manufacturing conditions. *Journal of cleaner production*, 356, 131803. <https://doi.org/10.1016/j.jclepro.2022.131803>
22. Noh, Yoorae. (2022). "Hazardous chemical air and exposure risks during plastic CIPP manufacture and cure." Ph.D. diss., Purdue University.
23. Nuruddin, M., DeCocker, K., Sendesi, S. M. T., Whelton, A. J., Youngblood, J. P., and Howarter, J. A. (2020). "Influence of aggressive environmental aging on mechanical and thermo-mechanical properties of Ultra Violet (UV) Cured in Place Pipe liners." *J. Compos.*

Mater., 54(23), 3365-3379. [Influence of aggressive environmental aging on mechanical and thermo-mechanical properties of Ultra Violet \(UV\) Cured in Place Pipe liners \(sagepub.com\)](#)

24. Nuruddin, M., P. Mendis, G., Ra, K., Sendesi, S. M. T., Futch, T., Goodsell, J., . . . Howarter, J. A. (2019). Evaluation of the physical, chemical, mechanical, and thermal properties of steam-cured PET/polyester cured-in-place pipe. *Journal of composite materials*, 53(19), 2687-2699. <https://doi.org/10.1177/0021998319839132>
25. OECD (2010), *Test No. 209: Activated Sludge, Respiration Inhibition Test (Carbon and Ammonium Oxidation)*, OECD Guidelines for the Testing of Chemicals, Section 2, OECD Publishing, Paris, <https://doi.org/10.1787/9789264070080-en>
26. Publication, *Journal of Water Pollution Control Federation*, M.R. Hockenbury and C.P.L. Grady, Volume 49, page 768, 1977.
27. Ra, K., Teimouri Sendesi, S. M., Howarter, J. A., Jafvert, C. T., Donaldson, B. M., & Whelton, A. J. (2018). Critical Review: Surface Water and Stormwater Quality Impacts of Cured-In-Place Pipe Repairs. *Journal - American Water Works Association*, 110(5), 15-32. <https://doi.org/10.1002/awwa.1042>
28. Review of Styrene Water Quality Goals and Recommended Next Steps for CIPP Projects, Brown and Caldwell, March 2012.
29. Tabor, M., Newman, D., Whelton, A. (2014). "Stormwater Chemical Contamination Caused by Cured-in-Place Pipe (CIPP) Infrastructure Rehabilitation Activities." *Environmental Science & Technology*, 2014.
30. Taneez, M., Österlund, H., Lundy, L., & Viklander, M. (2023). Impacts of stormwater pipe materials and pipe repairs on stormwater quality: a review. *Environmental science and pollution research international*, 30(56), 118065-118077. <https://doi.org/10.1007/s11356-023-30508-6>
31. Teimouri Sendesi, S. M., Ra, K., Conkling, E. N., Boor, B. E., Nuruddin, M., Howarter, J. A., Whelton, A. J. (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. <https://doi.org/10.1021/acs.estlett.7b00237>
32. Whelton, A. J., et al. (2017). "Cured-in-place pipe: The role of engineers in worker and public safety." *PE Mag., Natl. Soc. Prof. Eng.*
33. Whelton, A. J., Ra, K., Teimouri Sendesi, S. M., Nuruddin, M., Li, X., Howarter, J. A., Youngblood, J. P., Jafvert, C. T., and Zyakyina, N. N. (2019). "Contaminant release from

storm water culvert rehabilitation technologies: Understanding implications to the environment and long-term material integrity.” U.S. Fed. Highw. Admin. Transp. Pooled Fund (TPF)-5(339). [Online]. Available: <https://doi.org/10.5703/1288284317089>.