ABSTRACT

This dissertation contains three chapters and each chapter is a stand-alone manuscript, with the first chapter already having been published. This dissertation focused on cured-in-place-pipe (CIPP) technology, which is being used to repair sewer pipes across the globe. The CIPP process involves the manufacture of a new fiber-reinforced composite plastic pipe inside an existing damaged pipe. By 2022, the global CIPP market will exceed $2.5 billion, and will constitute 40% of the U.S. pipe rehabilitation market. In recent years, concerns about the type, magnitude, and toxicity of chemical air emissions associated with CIPP installations have markedly increased. CIPP installations in Asia, Europe, Oceania, and North America have been associated with indoor and ambient air contamination incidents, afflicted schools, daycare centers, homes, and offices and prompted building evacuations. This research program was designed to better understand chemical release into the air during CIPP composite manufacture and the human health risks. Principles and techniques from the environmental engineering, air quality, material science, and risk analysis were applied.

Chapter 1 involved the characterization of chemical emissions for steam-cured CIPP installations in Indiana (IN, sanitary sewer) and California (CA, storm sewer). It was discovered that a complex multiphase mixture of organic vapor, water vapor, and particulate (condensable vapor and partially cured resin) was emitted. Chemicals captured included a variety of hazardous air pollutants, carcinogens, endocrine disrupting compounds, and other chemicals with little toxicity data. The materials captured in California during 4 CIPP installations, when normalized against styrene concentration, exhibited different toxicity towards mouse cells. This toxicity indicated that non-styrene compounds were probably responsible for toxicity. Testing revealed significant and previously unreported worker and public safety chemical risks existed with CIPP installations.

Chapter 2 describes experiments conducted to determine which CIPP manufacturing conditions (i.e. curing pressure, temperature, time and ventilation) influenced chemical air emissions during and after composite manufacture. During thermal manufacture, approximately 8.87 wt% volatile organic compounds (VOC) was released into the air at standard pressure. For the CIPP styrene-based resin examined, chemical volatilization during manufacture was influenced by pressure, but temperature and heating time did not influence the composition of

chemical residual inside the new composite. All cured composites, regardless of temperature or heating time, contained approximately 3 wt% VOC. No statistical difference was found for: (1) VOC loading across cured composites and (2) styrene emission into the air across cured composites despite different curing temperature and heating times. Styrene was the most abundant compound in the composite and in air. High styrene air concentration signals inhibited the author's ability to determine if other non-styrene compounds were emitted into the air. Short-term ventilation (2 hr) reduced styrene air concentration to near zero in 10 min, but styrene levels rebounded when ventilation was halted. Due to the high styrene loading in the cured composite, it is expected that ventilation will only temporarily reduce VOC air levels in pipes, manholes, and other affected spaces.

Chapter 3 includes inhalation health risk assessment due to chemical emission from CIPPs during manufacture and use. This study utilized publicly available worksite data for ultraviolet (UV)- light and steam-CIPP installations, applied Monte Carlo simulations, and data-gaps were identified. Health risks associated with post-cured chemical emission from lab scale manufactured CIPPs were also evaluated. In CIPP resins and post-cured CIPPs (31) chemicals have been quantified among which many are unique volatile organic chemicals VOCs, but only 8 air testing studies were found. At a steam-CIPP worksite, VOCs were found in a condensed multiphase mixture discharged into air (5), 4 VOCs were detected in the vapor phase, while only styrene vapor phase results could be used for risk assessment. Worksite styrene levels (1,825 ppm_v, 1070 ppm_v, 140 ppm_v) have been reported indicating a health risk can exist. Monte Carlo simulation over literature data revealed that for the single UV CIPP and single steam-CIPP study negligible styrene HQs were found, while unacceptable styrene LECRs% > 10^{-4} (i.e. 37-38%) were obtained. Monte Carlo simulation on laboratory data showed that post-cured emissions from the composite cured longer increased unacceptable styrene LECR (from 17.86% to 21.12%) and HQ (0.95% to 8.04%). Whereas for the composite cured at greater temperature styrene LECR and HQ caused by post-cured emissions reduced to 0.89%. and 0, respectively. Ventilation also diminished the acceptable LECR% in all composites but did not reduce the carcinogenic health risk to an acceptable level.