EXECUTIVE SUMMARY

Energy Reduction Using Epoxy Coatings for Sealing Leaking Compressed Air Systems

ESTCP Project EW-201517

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1.0 INTRODUCTION

From March 2016 to September 2017, the Environmental Security Technology Certification Program (ESTCP) funded the Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC) to demonstrate an in-situ pipe rehabilitation epoxy coating technology that seals pipeline distribution system leaks in compressed air systems. Air distribution pipeline leaks are commonplace at intermediate and depot level maintenance facilities, and if resolved can improve system operational performance and reduce lifecycle energy costs. The application of epoxy coating on compressed air distribution systems is a new use of an existing technology that was originally developed for corrosion control on carriers’ copper-nickel wastewater pipelines, and can facilitate more efficient air management of Department of Defense (DoD) compressed air systems.

Leak management of compressed air systems at DoD maintenance facilities is often neglected due to mission-essential operational and funding requirements taking priority. One symptom of a leaky system is continuous compressor cycling (i.e., on and off) under light- or no-load conditions, and degraded downstream pressure and airflow. The cost of compressed air leaks can be significant due to: 1) facilities procuring larger (or additional) air compressors to compensate for leaks; 2) compressors having shortened service life due to extended load up time to make up for the lost air and increased maintenance cycles; and 3) leaks degrading mission capability. Some pipeline distribution system leaks are difficult and expensive to repair, particularly those in inaccessible locations where piping runs beneath slabs, roadways, through walls, or if located in areas that first require abatement of hazardous material. It is under these circumstances that the application of the epoxy coating technology is thought to be most appropriate and cost effective.

In February 2016 NAVFAC EXWC constructed a bench scale testbed to assess the technology’s ability to seal simulated pinhole, threaded fitting, and soldered fitting leaks. Favorable results from the bench scale tests prompted the decision to proceed with a full-scale demonstration of the technology.

In September of 2017 NAVFAC EXWC and Nu Flow Inc. collaborated to demonstrate the epoxy coating technology on two recently abandoned underground pipelines located at the Naval Base Ventura County Construction Equipment Department (NBVC CED). The underground steel pipelines consisted of approximately 140 feet of 1½-inch diameter pipe, and 420 feet of 4-inch diameter pipe. The compressed air distribution pipelines were likely installed in 1952 and are fairly representative (i.e., 60+ years) of other DoD compressed air systems. The full-scale demonstration provided a low-risk opportunity to evaluate the epoxy coating sealing performance under actual field conditions without significantly risking NBVC CED equipment or operations.
2.0 OBJECTIVES

The project objectives were to reduce energy losses associated with the operation of compressed air systems, validate the epoxy coating’s ability to seal leaks common to compressed air distribution pipelines, and increase the system service life of existing compressed air systems via a robust epoxy coating that prevents future corrosion.
3.0 TECHNOLOGY DESCRIPTION

Unlike conventional pipe repair and replacement options that may require significant demolition and downtime, the epoxy coating technology can be managed to minimize the duration of operational disruption (≤ 72 hours) where the technology is to be applied. The application of the epoxy coating technology involves the following steps:

1. System analysis to identify the current leaks and confirm system layout;
2. Repair of major leaks and removal of sensitive equipment as appropriate;
3. Drying of the system with dried compressed air;
4. Rust and scale removal with an abrasive garnet sprayed through the system;
5. System cleaning by blowing dry compressed air through pipelines;
6. Distribution of epoxy using compressed air flow to form an epoxy pipe coating;
7. Curing of the epoxy with warm compressed air;
8. System testing to ensure that the system is functioning as intended.

Figure 1 illustrates steps 4), 6) and 7) of the application process. Figure 2 shows images of the pre and post epoxy coating application process at NBVC CED.

Figure 1. Depiction of the Epoxy Coating Process (Courtesy of Nu Flow)

Figure 2. Uncoated Pipe and Epoxy Coated Pipe at NBVC CED, Port Hueneme, CA
4.0 PERFORMANCE ASSESSMENT

Performance objectives with specific success criteria metrics were established to determine the success of the full-scale demonstration and validate the epoxy coating technology with a primary focus on sealing leaks. The two primary performance objectives were: 1) static pressure tests requiring > 90% reduction in pressure loss over a baseline measurement with minimal negative side effects (i.e., <20% reduction of internal pipe cross section area due to epoxy pooling); and 2) a coating installation efficiency of less than 72 hours to avoid operational disruption.

The demonstration performance objectives yielded the following results:

- **Coating installation efficiency:** success criteria not achieved. The total combined duration for the epoxy coating application process from mobilization to demobilization for the 1½-inch and 4-inch diameter pipes was greater than 72 hours. However, it should be noted that excessive time was taken attempting to epoxy coat the 1½-inch pipeline that was later determined to have two holes greater than ½-inch in diameter. The performance objective would have been met had each pipe segment been independently evaluated.

- **Pressure variation (pre- and post-coating):** success criteria not achieved. The results of the pressure variation tests were mixed. The > 90% reduction in air loss was not achieved on the 1½-inch diameter pipe due to major leaks that worsened during the coating application process. The 90% reduction in air loss was achieved on the 4-inch diameter pipe. However, it should be noted that baseline static pressure tests on the 4-inch diameter pipeline showed that the pipeline was not appreciably leaking. The decision to proceed with epoxy coating of the 4-inch diameter pipeline was made in an attempt to further evaluate the pros and cons of the epoxy application process in a full-scale application.

- **Coating thickness and uniformity:** success criteria not achieved. The 4-inch diameter pipeline met the thickness and uniformity criteria. The 1½-inch pipeline did not meet the thickness and uniformity criteria due to substantial corrosion in the pipe. Camera inspection of the 4-inch diameter pipeline showed negligible pooling within the pipe.
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5.0 COST ASSESSMENT

The team developed cost models to assess return on investment (ROI) of the technology to three alternative scenarios. NBVC CED was chosen as the economic case study because it is a fairly representative site having buried steel pipelines (over 60 years old) with leak issues similar to those found at many other DoD installations. The cost models include the following: local utility rates, cost to repair a major leak, cost to conduct underground pipeline camera inspections, and cost to apply the epoxy coating to an underground compressed air pipeline. The models were prepared in Microsoft Excel and are generic so they can be used at other DoD activities with similar issues.

The three scenarios evaluated are:

- **Scenario 1**: Represents military activities that simply add more compressors to ensure adequate air supply is available to end users in lieu of fixing leaky compressed air system pipelines.
- **Scenario 2**: Represents military activities that do nothing to address leaky compressed air systems pipelines, operate at high leakage rate, and are just marginally able to provide adequate air supply to end users.
- **Scenario 3**: Represents military activities comparing the cost of installing new pipelines through traditional methods to address substantially leaking underground compressed air distribution pipelines thought to be beyond repair. The model uses the 2012 pipeline construction report – $200,000 per inch-mile for estimating new pipeline cost (e.g., the cost to install a mile of 1-inch diameter pipe would be $200,000).

Facility pipeline characteristics including length, diameter, layout (the number of branches), accessibility, and overall condition are all important factors that impact the technology’s ROI. For NBVC CED, the cost of the epoxy application was $38,000, which was approximately $45 per foot. However, according to Nu Flow, epoxy application costs can vary dramatically at other sites ranging from $35 - $200 per foot based on the complexity and size of a given compressed air system. Hence, it is recommended that Nu Flow or other epoxy contractors be contacted to provide an estimate on application cost for accuracy of the models. The common costs for each of the three models at NBVC CED included the epoxy application expense of $38,000, conventional repair of one large pipeline breach at $5,000, the site preparation cost at $3,500 for pipe condition assessment, and an estimated compressor replacement cost of $72,000 for a 125 horsepower rotary screw air compressor.

**Scenario 1**: The ROI for the epoxy application at NBVC CED was calculated at 2 years. The major cost benefits of the epoxy technology were: 1) annual energy savings from operating with one air compressor instead of two; 2) the annual energy savings from reduced air leakage; and 3) deferred capital cost of buying a new compressor by operating with minimal air leaks (i.e., extended service life).

**Scenario 2**: The ROI for the epoxy application at NBVC CED was calculated at 12 years. The major cost benefits are derived by: 1) the annual energy saving from reduced air leakage; and 2) the tangible benefit of improved compressor efficiency and improved service life (i.e., efficient duty cycle, reduced compressor maintenance and reduced workload). Scenario 2 conservatively assumes a five-year reduction in compressor service life (i.e., from 25 to 20 years).
**Scenario 3:** The ROI for scenario 3 was calculated at 17 years. This scenario represents the cost of installing a new pipeline and looks at a timeframe of 25 years, which is the estimated service life of utilities. Assuming the annual energy savings and the ability to operate with one compressor as equitable, the cost benefit is derived from the difference in capital cost. When normalizing the cost of epoxy application and the cost of installing a new pipeline over 25 years, the cost avoidance would be $2,179 per year by using the epoxy coating.
6.0 IMPLEMENTATION ISSUES

The full-scale demonstration at NBVC CED showed there is inherent risk associated with applying the epoxy coating on pipelines where pipe condition cannot be accurately assessed. Nu Flow recommends fixing major leaks and replacing pipe sections with less than 60% wall thickness prior to applying the coating. However, ascertaining pipe wall thickness in the field proved problematic. The team discovered technology shortfalls with visual pipeline camera inspection to identify pipeline condition, as the camera head was not able to navigate through most of the pipe network due to physical constraints. Where the pipeline camera was able to navigate, two large breaches (subsequently found during the application process) were not readily seen and possibly masked by extensive tuberculation (corrosion). It was also determined that conventional wall thickness technology using ultrasonic or X-ray practices would have similar issues, and more importantly be cost prohibitive. Preliminary estimates to measure wall thickness throughout the underground compressed air pipeline at NBVC CED with ultrasonic technology was estimated at over $40,000 and would have taken longer than a week to perform.

Isolating pipe segments by closing valves and conducting static pressure and pressure drop tests may be the most pragmatic approach to assessing relative pipe conditions. A pipe segment which cannot be brought up to pressure likely has too large of a leak to be filled by epoxy. A pipeline that does come up to pressure but then drops to zero within 10 minutes (after isolation by closing valves) may also have a leak too large to be filled with epoxy. Additionally, the operations of existing pipeline valves should be inspected to assure a proper seal prior to conducting pressure tests. New leak free valves were required at NBVC CED to allow for a more accurate assessment of the pipeline condition. The 1½-inch diameter pipeline was not a good candidate for a successful epoxy application, as the pipe was unable to maintain 100 psi during baseline tests and had significant pressure drop. The epoxy coating procedure was nevertheless conducted on the below-grade pipeline to better understand if the soil immediately surrounding the leaking pipeline was dense enough to act as a backing in conjunction with a larger application of epoxy.

Follow-up forensic study of the 1½-inch diameter line at the rupture point showed large voids in the soil (approximately 1 cubic foot) that were lined with epoxy. In addition, large vanes of epoxy were found following the path of air to the surface. The 1½-inch diameter pipeline repair and accompanying forensic study showed that the pipe breaches were on the top of the pipe, the outer protective coating was damaged, and that corrosion primarily thinned out the walls where the coating was removed. Pipe wall thickness was intact outside of the corroded areas.

The epoxy application on the 4-inch diameter pipeline was successful with minimal pressure loss.

The CED demonstration results revealed that pipe conditions vary considerably, and when significant tuberculation is encountered, it may likely point to multiple and significant breaches, which result in a high risk for pressure test failure. Pipelines with minimal leakage, as seen with the 4-inch diameter pipe, are a lower risk.

The team recommends that the epoxy coating technology be used primarily as a preventative maintenance measure to extend the service life of existing pipelines that do not already have significant indicators of corrosion. As previously stated, static pressure and pressure drop tests may be the most pragmatic approach to assessing relative pipe conditions.
Future research efforts in below-ground compressed air pipeline repair should focus on low cost methods to identify accurate air leak locations, pipe breaches, and the associated void spaces created by underground leaks where conventional repair, in-pipe restoration techniques or excavation may be required.

6.1 LESSONS LEARNED

The following lessons were learned from the demonstration:

- The added time and costs associated with identifying pipeline location, validating pipe wall integrity, static pressure tests, and fixing substantial leaks must be addressed prior to the application of the epoxy coating technology.
- Camera inspection prior to epoxy application may not adequately identify small breaches or holes within the pipe system. In addition, introducing a camera into an uncoated underground pipeline has challenges such as inability to pass through short sweep 90° elbows, pushing the camera through multiple 90° elbows and moving the camera in small diameter pipes. Manipulating long camera cord lengths necessary to traverse long distances also presents challenges.
- Leakage through existing compressed air system valves complicates the leak detection process. Valves should be inspected and exercised regularly, and repairs made if they do not provide a leak-free seal.
- Road or pavement construction repairs conducted near existing underground compressed air pipelines should take special care not to damage existing pipelines (e.g., outer wrap or coating) or other utilities, as small ruptures can contribute to accelerated corrosion. If contact is made with the outer wrap or coating of any existing pipeline or utility, repairs should be conducted prior to the soil compaction and re-pavement.