Cleaning of Pressure Pipes with Novel Technology – The Importance of Long-Term Bond

Randall J. Cooper[1] and Mark A. Knight[2]

[1]Consulting Engineer, Envirologics Engineering Inc., 5-193 Manitoba Street, Bracebridge, ON, Canada P1L 1S3; email: rcooper@envirologics.ca

[2]Associate Professor, Department of Civil and Environmental Engineering, University of Waterloo, 200 University of Waterloo, Waterloo, ON, Canada N2L 3G1; email: maknight@waterloo.ca

Abstract

This paper presents an innovative patent-pending, environmentally-friendly, “waterless” method of pressure pipe cleaning using airborne abrasives. This innovative cleaning method not only removes corrosion products quickly, it leaves the pipe interior in a “ready state” for the trenchless application of spray-in-place (SIPP), cured-in-place (CIPP) and/or cement linings. SIPP liners are often referred to semi-structural while CIPP liners are referred to as structural. Unlike other methods that are intended only for cleaning pipe, this new method provides enhanced pipe surface preparation and dries the pipe for superior liner bond. This paper highlights the importance of pipe cleaning and preparation in advance of installing semi-structural or structural pressure-pipe liners. It also provides details and limitations of this novel patent-pending technology. Early and promising results from a recent trenchless water main rehabilitation project, in Cambridge Ontario, showed that coal-tar coatings on ductile/cast iron pipe can be removed effectively and efficiently and the pipe can be prepared for bonding/adhesion with a SIPP liner.

Introduction

According to Folkman (2012), the percentage of cast and ductile iron in water distribution networks can range from 50 percent in the Northern central USA to 90 percent in the south. Cast iron pipe manufactured the United Kingdom and Europe in the mid 1800’s was installed in the USA. Many of these pipes are still in use today. A large percentage of these critical water conveyance assets have been in service for over 50 years and are now approaching the ends of their service and operational life. These aging metallic pipes are often operating at reduced efficiency in terms of flow, and increased energy is required to pump the water though tuberculated pipes and/or to pump extra water to account for the water loss from breaks, fractures and/or leakage. These aging pipes also produce poor water quality (health and aesthetics impacts) and require increased disinfection products that result in poor tasting water and reduced customer confidence. All these issues have resulted in a “call to action” by the owners and operators of aging networks of distribution mains. Despite many studies that point to the need for action, relatively little has been done to date to repair, renovate or replace these aging and failing pipes. One reason for this is the cost to replace all these pipes using conventional dig-and-replace methods, as well as, the slow adoption and development of cost-effective, environmentally friendly trenchless technologies to renovate these pipes in-situ.

Early pipe lining pressure pipe lining strategies have followed existing, older AWWA standards and practices which are now being updated to account for new knowledge and promising innovative trenchless technologies. Currently, the state of the industry for trenchless pressure liner design and installation is still in its infancy as well as the need for proper cleaning and pipe preparation prior to SIPP and CIPP liner installation.

Strained municipal infrastructure budgets coupled with increased awareness and CIPP installation successes have resulted in trenchless rehabilitation becoming a more economical and acceptable alternative to the dig-and-replace option. Industry standard pressure-pipe cleaning methods for CIPP and SIPP lining currently include drag scraping, pressure flushing/flailing, or using rack-feed boring machines, each of which require high volumes of fresh water. These pipe-cleaning methods have limited success in the removal of old pipe linings such as cement and asphaltic coatings and do not remove internal metal graphitization. The removal of these materials is deemed essential if the liner needs to bond or adhere to the pipe wall. The need for better pressure pipe cleaning and preparation when SIPP and CIPP lining strategies are employed is addressed in the following sections.

State of the Art – Pressure Pipe Cleaning and Surface Preparation

Current methods for water pipe cleaning broadly include flushing air scouring, swabbing, abrasive pigging, drag scraping and rack-feed boring. Various forms of high and low pressure jetting and even chemical cleaning have also been deployed. All of these methods vary in terms of cleaning results, costs and longevity; however, it is beyond the intent or scope of this paper to describe, differentiate, or evaluate these methods. This information has already been documented in numerous publications such as the American Water Works Association (AWWA) M28 Manual and “Investigation of Pipe Cleaning Methods” (Ellison, 1993). It is important to point out that these methods each provide very different outcomes in terms of purveying “clean pipe”.

However, the vast majority of current methods for pipe cleaning date from the 19th and 20th centuries. In the past, pipe cleaning was intended to remove sediment, scale, biofilm, tubercles and the like. Current innovations in pipe cleaning technology have been sparse, at best. Even more recent modifications, such as ice pigging, still focus on “pipe cleaning”, and the desired outcomes still include: increased hydraulic capacity, lower pumping costs, better water quality through reductions in biofilm, better taste and less odour.

Pipe cleaning can be simply defined as the removal of all internal debris (tubercles, sediment) and films from the pipeline. Pipe cleaning seldom includes surface preparation as an important outcome or prerequisite for pressure-pipe lining. Limited published research documentation exists in the public domain; thus, it is argued that the importance of pipe surface preparation prior to pressure pipe rehabilitation has yet been fully or properly investigated by researchers and/or industry professionals. .

When one considers the subject of coating metallic substrates, surface preparation is well recognized and well established design consideration and is outlined, categorized and controlled by standards generated by professional bodies such as National Association of Corrosion Engineers (NACE). The standard for surface preparation that is specified depends upon the in-service conditions placed on the coating by the end user. For instance, the NACE 1 Standard (White Metal Blast cleaning) states, “When viewed without magnification, the surface shall be free of all visible oil, grease, dust, dirt, mill scale, rust, coating, oxides, corrosion products and other foreign matter”.

In contrast, in-service design of gravity-based trenchless pipe liners, surface preparation is not treated as a critical design parameter. Generally, industry standards (such as ASTM F1216) and best practices (such as NASTT Best Practices for the Design of Cured-In-Place Pipe) are generally silent on the matter of surface preparation as the liner is not design to bond to the host pipe. While pipe cleaning is a prerequisite for liner installation, surface preparation is not. Proper cleaning is only intended to enhance “closeness of fit” for the liner.

The trenchless rehabilitation of pressure pipelines is significantly more complex than the gravity pipelines as pressure liners can often subjected much greater and varying cyclic, surge and vacuum pressures (Macey, 2007). Even though pressure liners have very different design and operational conditions, they are often designed using gravity liner design (ASTM F1216) design methods.

While certain pressure-pipe rehabilitation methods such as carbon fiber repairs have taken comprehensive steps to highlight and control the criticality of proper surface preparation and moisture control for liner bonding, as well as providing liner restraint using end seals, other lining methods have excluded such measures, often because the host pipe is structurally irrelevant to design.

The importance of surface preparation for providing fifty-year design protection against post-lining movement, and leakage at service connections remains unaddressed. In the opinion of the authors, surface preparation has to be considered as an integral part of pressure-liner design for semi-structural and fully-structural designs whenever and wherever in-service design conditions so dictate.

State of the Art – Pressure Pipe Liner Design and the Relevance of Bond

To address this lack of awareness, a review of pressure pipe liner design relative to liner bonding is presented in the following sections. It is not the intent in this paper to outline all the critical requirements for pressure liner design. It is however our intent to cast doubt on the effectiveness of current cleaning best practices to prepare the pipe for liner bonding and/or adhesion.

Barrier coatings/liners for pressure pipe are relatively thin, and are designed to transfer all imposed structural loads to the host pipe. These coatings/liners provide corrosion protection for the host, better hydraulics (higher "C" factor) and improved water quality. Superior adhesion of the coating/liner is necessarily designed to prevent leakage and ensure the transfer of all imposed structural loads to the host.

Semi-structural coatings/liners are similarly designed to provide corrosion protection and better hydraulics (higher "C" factors), but also to bridge holes and gaps in the host pipe to reduce leakage, and to reduce the potential for leakage at service connections. These lining are also relatively thin, and adhesion to the host may or may not be required (AWWA M28 Manual, 2001). The design of semi-structural barrier coatings/liners includes the ultimate transfer of all imposed loads (structural and pressure) to the host pipe since the coating liner is unlikely to survive catastrophic burst. Thus, the performance of the semi-structural coating/liner is dependent on the structural integrity of the host pipe. The amount of internal load sharing can be changed by varying the thickness of the liner (ring stiffness) and adhesion of the liner to the host pressure pipe.

Fully structural liners are designed to carry all external and internal loads and pressures with no consideration of the host pipe to absorb or share any of these loads or pressures. Thus, the host pipe is irrelevant to design and is largely a placeholder or a form for the new structural liner which is considered to be a replacement pipe.

While these definitions of structural integrity form the current basis for pressure liner design, they are not inclusive of all the potential failure modes that a liner may experience over its design life.

Examples of missing potential failure modes include:

a. shear failure caused by freeze-thaw cycles or soil voids;
b. axial movement of the liner due to unbalanced thrust (pressure transients); and,
c. leakage at service connections that can flow between the liner and lined host pipe.

It is argued that an understanding of both failure tolerance and potential failure modes for pressure pipe is a key consideration when formulating a comprehensive lining program.

ASTM F1216 non mandatory design Appendix X1.1 is a popular design specification for the design of gravity and pressure liners. The authors are not aware of any published "good practices" manuals for pressure pipe lining published by leading professional bodies such as the American Water Works Association, North American Society of Trenchless Technology, Trenchless Technology Centre, and/or Centre for Advancement of Trenchless Technologies. To date, most proprietary technologies have produced their own standard practices manuals which are basically guidelines for liner installations.

It is well known that pressure pipe leakage is a not only a significant source of water loss but also a source of pressure pipe failure. It stands to reason that if lining does not address leakage over the long-term, then failures of lined pipe can also occur in the future. Thus, post-lining leakage at service connections and transitions (lined to unlined pipe) is a relevant, long-term design matter.

Figure 1 (below) shows axial forces that are applied to pressure liners (adapted from Moser, 2009).

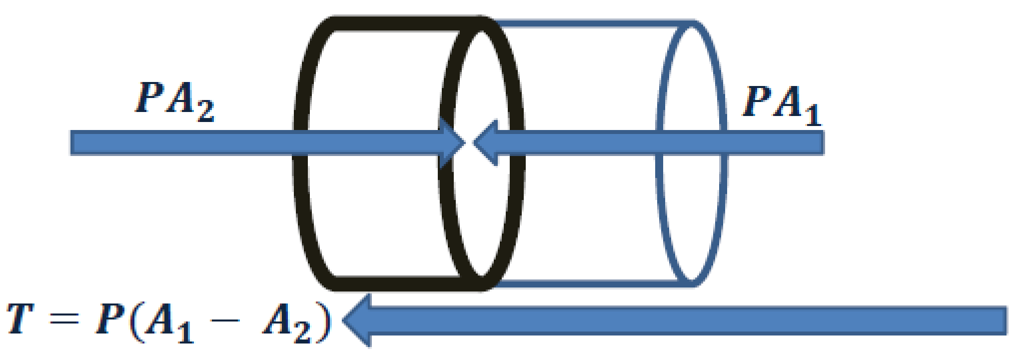

Figure 1. Axial forces on pressure liners

A pressure liner forms a cylinder inside host pipe and is subjected to thrust forces by virtue of the difference in cross sectional area between the liner and host pipe wall. The magnitude of the thrust force “T” varies directly with the values of pressure “P” and the wall thickness of the liner (difference in areas “A”). While “T” remains balanced during steady-state operational conditions when operating pressure “P” acts uniformly in all directions, this is not always the case. Surge pressures, which can be random or cyclic, frequent or infrequent, can produce pressure waves in piping systems that will result in a variation in “P” at the ends of the liners. This pressure difference will create a thrust force “T” on the liner. Although, typically, this pressure is short in duration, the pressure waves can be substantially above the operating pressure “P” and change direction (axially forward and backward) as they decay. The liner must rely on either liner bonding, adhesion, and/or a physical restraint at liner-to-host transitions to resist this thrust force.

As the pressure wave (surge, transient) travels down the pipe inside the liner, the liner and/or host pipe will expand on diameter, even slightly. As the pressure wave impacts the service connections, the surge pressure will act perpendicularly and axially on that service connection. Restraint or bonds at service connections are thus subject to cyclical pressure variations as are liner transitions. A liner must be able to resist these cyclical pressure changes over fifty year service life. Currently, this is not part of any design practice or any known testing program.

An unbalanced thrust force may also result in disbondment and leakage. While more experimentation and testing are required to quantify the extent possibilities, incidents of disbondment and liner movement are well known within the gravity liner industry.

Pressure surges can be negative (vacuum), as well as positive. While buckling resistance calculations (for negative pressure) are included in popular pressure design specifications such as ASTM F1216, liner bonding can also provide resistance to vacuum for a liner. By providing a pre-determined amount of resistance to a tensile pull, the liner bond can provide a qualified improvement in vacuum resistance.

Finally, pressure pipes and pressure liners are subject to temperature variations that are largely seasonal, but can be dramatic. Variations in water temperature can cause expansion and contraction of both the liner pipe and host pipe. Differences in the thermal coefficients of liners and the host pipe (including metallic service connections) can result in differential tensile forces that can impact the liner bond/restraint. Certain liners that rely totally on resin bond to the “cleaned” host pipe (SIPP and CIPP) may be subject to adhesion failures (and leaks) over time due to cyclical pressure and temperature changes that are normal for any pressure pipe system.

There is no current requirement for CIPP pressure liners to do anything other than clean the host pipe prior to liner installation. Some CIPP lining technologies rely simply on the long-term adhesion of their resin bond as opposed to establishing or following a tested, surface preparation standard. The outcome of cyclical pressure surges and temperature cycles over the design life of CIPP pressure liners has yet to known or tested, and it is argued that the 50-year (leak-free) durability of a resin bond on "cleaned" pressure pipe is questionable.

The only design drawback currently cited against surface preparation and good liner bonding is that good adhesion means that the liner is forever bonded ("wedded") to the pipe (Ellison, 2010) and they eternally act as one. If the host pipe cracks, then so does the liner (or it tears). The novel technology outlined below works to disprove this belief in that a differential bonding or adhesion strategy is now possible along the axial length of the pipe. While lesser bond strengths can now be achieved along the pipe length, higher bond strengths can now be targeted and achieved at service connections and end seals.

State of the Art – A Novel Approach to Pipe Cleaning and Surface Preparation

The Envirologics' System (Tomahawk™) for pipe cleaning and surface preparation uses a variety of grades and types of abrasives (predominantly stone) in a high-volume air stream to remove all internal debris including scale and corrosion in 50% of the time that competing methods require and without the use of water. In addition, this innovative cleaning technology simultaneously prepares and dries the cleaned pipe providing a superior bonding surface for coatings and liners. The system also has the ability to remove water from service connections and pipe joints and can expose leaking cracks, joints or service connections. All other pipe cleaning technologies leave the inner pipe wet, often necessitating a separate drying cycle prior to pipeline renewal operations.

The Envirologics method minimizes the chances of pipe wall and service connection damage due to the nature of impact stresses. Other cleaning methods such as high-pressure water and mechanical flails (rack-feed boring and hydraulic chain flails) can damage service connections, crack fragile pipe, and do not adequately clean pipe joints.

The patent-pending Envirologics System uses targeted deflectors to concentrate the abrasives wherever additional cleaning or higher bond strength is required or desired. This allows for the removal of bumps and protrusions which can otherwise cause excessive localized stress concentrations on the liner, which in turn can cause result in liner failure. It can also remove stubborn coatings such as cement, coal tar and bitumen, and allow the system to be used effectively through challenging pipe bends.

Finally, this innovative system includes an airborne camera that allows the user to observe the cleaning/preparation process, and vacuum joints and service connections, thereby serving as an inspection tool for both cracks and pipeline leaks.

Current pipe cleaning technologies (including mechanical scrapers, high-pressure water jetting, and power boring tools) have limitations and problems such as the incomplete removal of stubborn corrosion products, potential damage to the pipe walls and joint seals, the need for high volumes of fresh water, and longer cycle times for set-up, completion and return-to-service. These processes all rely on water flushing to remove corrosion products from the pipe thereby requiring and contaminating large volumes of fresh water. This water must then be collected, settled, filtered and treated prior to being fit for re-use by customers. The Envirologics system is a dry process, requiring no water and produces a dry waste that can either be left in the excavation, or collected filtered and isolated for low-volume disposal. The system is also adaptable for varying pipe types and varying coatings including asbestos cement pipe and bitumen coatings.

To utilize this novel cleaning method, the pipeline first has to be isolated and taken out of service. The pipeline is isolated using system valves and excavations that are typically made at either end of the target pipe segment. A segment of pipe is then removed in each excavation and the system is gravity drained into either excavation.

At this point, Envirologics introduces large volumes of low-pressure air into the isolated pipe segment and tests for airflow. This air volume quickly empties the pipe of sediment and loose corrosion products. Selected abrasives are then metered, using a patent-pending metering system, into the airstream providing axial bombardment of tubercles and coatings, which are rapidly removed and collected in a controlled manner at the downstream excavation. Following the initial removal cycle, the airborne camera is introduced into the airstream for pipeline inspection. This allows the operator to accurately inspect and pinpoint areas for additional or concentrated cleaning. The operator can then introduce various airborne deflectors to concentrate the action of abrasives to clear joints or bumps, remove graphitic corrosion, or differentially improve surface preparation around service connections.

Figure 2 (below) shows the Tomahawk™ pre and post cleaning and surface preparation results.

Figure 2. Pre and post pipe cleaning and surface preparation using the patent-pending Tomahawk™ System.

This pipe-cleaning and surface-preparation system significantly reduces the water and energy footprints for trenchless rehabilitation projects and can result in the cleaning and preparation of multiple pipe lengths each day in pursuit of lower costs and same-day return to service.

Table 1 (below) presents a comparison of the Tomahawk™ System with current cleaning methods.

Table 1. Comparison of the Tomahawk™ System with other pipe cleaning methods.

Cleaning Method	Needs Water	Requires Disposal	Fast/Slow	Damages Pipe & Services	Surface Preparation	Leaves Pipe	Cost/meter
Tomahawk	N	*N*	Very Fast	*N*	Excellent	Dry	$25
Vactor/Jetter	*Y*	*Y*	Fast	*Y*	Good	Wet	$30
Flushing/Swabbing	*Y*	*Y*	Slow	*N*	Poor	Wet	$10
Drag Scraping	*Y*	*Y*	Moderate	*Y*	Fair	Wet	$15
Rack-Feed Boring	Y	*Y*	Fast	*Y*	Good	Wet	$30 - $35

Case Study for Deployment of Novel Cleaning Method – Cambridge, Ontario Canada

The City of Cambridge, Ontario, Canada called a tender for the rehabilitation of 500 meters of 150 millimeter-diameter, thin-walled cast iron water main, with a preference for using spray-in-place pipe (SIPP) technology in May 2012.

While a flow-bypass system was required and established, one objective of the project was to assess the same-day return to service potential for SIPP technology for water main rehabilitation.

The project also included an allowance for the removal of four samples of sprayed pipe following the rehabilitation for assessment of the bond and consistency of coating application.

Envirologics was retained by the SIPP contractor to provide cleaning, surface preparation and drying of the 500 meters of pipe in advance of the application of approximately 3mm (liner thickness) of fast-setting polymer spray (polyurea).

Both the SIPP contractor and Envirologics retained CATT (Centre for the Advancement of Trenchless Technology) at the University of Waterloo in Waterloo, Ontario for application oversight and performance of all testing required by the contract.

Following contract award, it was discovered that the interior of the pipeline was originally coated with coal tar bitumen. The levels of corrosion on top of the coal tar were minor with no accumulation of corrosion products (tubercules). Envirologics was able to quickly connect and satisfactorily clean and dry three pipe sections in just one day. This speed allowed the spray contractor to commence spray lining immediately following the cleaning and preparation of each section. Figure 3 (below) shows before and after photographic evidence of the effectiveness of cleaning and surface preparation.

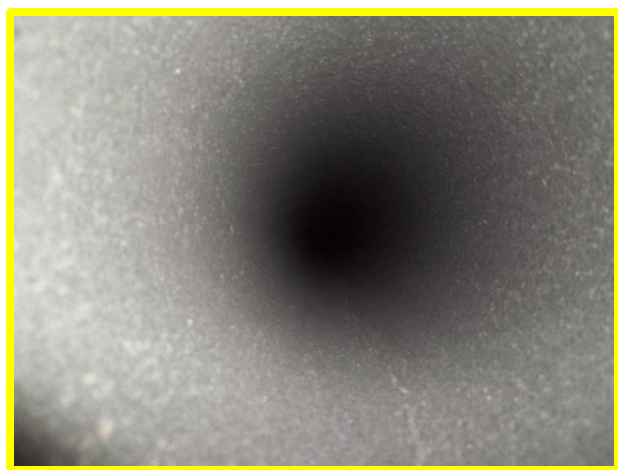

Figure 3. City of Cambridge pilot project pre and post Tomahawk™ pipe cleaning and surface preparation.

It should be noted that competing cleaning technologies cannot remove coal tar coatings either as fast or with the same superior results achieved by the Envirologics system. These types of coatings are often stubborn and remain “active” (viscous and flowing) if disturbed by mechanical abrasion and heat. In fact, it was noted that the high rate of productivity of the Envirologics machine could have accommodated two spray rigs for the SIPP contractor, thereby potentially doubling the productivity of spray applications.

Following the spray applications, field samples were excavated and removed from the finished pipe at customer-designated locations and were turned over to representatives from CATT for SIPP adhesion testing. Samples were axially cut using high-pressure water-jet technology then subjected to pull-off strength testing in accordance with ASTM D4541.

Ten adhesion tests found the SIPP to have mean adhesion pull-off values of 810psi, a minimum value of 309psi, and a maximum adhesion value of 1386psi. All tests were greater than the stipulated minimum of 250psi. Removal of the liner from the host pipe found the liner to be well-bonded to the pipe with areas strongly bonded. It should be noted that the liner was able to be removed from the host pipe, but with difficulty. Visual inspection of the clean pipe found that in some locations, not all the coal tar bitumen was removed but the majority of it was removed.

It should be noted that this pilot project did not require cleaning to remove all the coal tar and that additional cleaning could have been completed to prepare the pipe to the NACE 1 surface preparation standard.

Conclusions

Envirologics has developed an innovative, fast, environmentally-friendly, “waterless” method of pressure pipe cleaning using airborne abrasives. This patent-pending method not only removes corrosion products quickly, it leaves the pipe interior in a “ready state” for the trenchless application of either spray-in-place (SIPP) or cured-in-place (CIPP) liners. Unlike other methods that are intended purely for pipe cleaning, this new method provides surface preparation and dries the pipe for superior liner bonding. The need for long-term, leak-free performance of liners is critical over their design life, and proper bonding to the substrate through surface preparation can provide this assurance.

Many of the current lining methods (structural and non-structural) continue to use older cleaning methods that simply cannot provide the level of surface preparation and dryness required for long-term liner bonding.

The Envirologics System is capable of providing a variable bonding strategy for pipe liners (CIPP and SIPP) that will allow the liner to detach from the host pipe wall when subjected to certain failure modes. This bond strength can also be differentially increased at important service connections and transitions to afford long-term leak-tight performance. While further study and experimentation is needed to qualify a variable bonding strategy, the current disadvantages associated with strong or wedded bonding can now be addressed.

The Envirologics System has been used in the field to remove coal tar coating and produce good bond strengths on aging, thin-walled cast iron pipe. A trial in Cambridge Ontario during the summer of 2012 provided evidence of the speed and effectiveness of this method when field applied. The independent visual and bond testing provided by CATT at the University of Waterloo, Ontario proved that excellent bond strengths ranging from 300 to nearly 1400 psi were achievable in the field after the cleaning and surface preparation of tar-coated pressure pipe.

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