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PROTECTIVE LININGS FOR STEEL PIPE IN POTABLE WATER SERVICE

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ABSTRACT

This paper gives a comparative study of the performance and application parameters of various ANSI/NSF 61 approved lining systems that are presently specified and used in North America for the internal lining of municipal potable water pipelines. Direct testing and the reported results of the respective lining manufacturers are utilized.

Performance of the 100% solids rigid polyurethane lining system is excellent on all test parameters and exceeded the overall performance of all the other summarized lining alternatives.

100% solids epoxy and solvent amine based epoxy performance is similar to one another, but less than the 100% solids rigid polyurethane option. The 100% solids polyurethane and epoxy options do offer the added benefit of better safety and environmental parameters when compared to the solvent based materials.

100% solids elastomeric polyurethanes exhibit good chemical resistance and impact resistance but suffer from poor adhesion to the steel substrate and cathodic disbondment resistance as well as a higher permeability rating.

Cement-mortar lining systems are very economical but are very poor corrosion protection systems when subjected to a corrosive environment. A lack of adhesion to the substrate coupled with poor chemical, impact and abrasion resistance results in the cement-mortar system being at risk in an environment that is slightly aggressive.

Keywords: ANSI/NSF 61 Standard, 100% solids, polyurethane, potable water, pipe, pipeline, corrosion protection, protective lining

1. INTRODUCTION AND BACKGROUND

The financial losses due to a shortened service life or increased operating and maintenance expenses make the selection of a corrosion protection system very critical. Often the most cost effective measure that can be taken for corrosion control is to protect the structure with a protective coating or membrane. The coating or lining is to act as a physical barrier to prevent chemical compounds from contacting the structure and thus causing corrosion.

Most protective lining systems used today for North American steel pipes in potable water service are certified to meet the requirements of the ANSI/NSF 61 Standard. The primary lining systems that were considered in this study included: solvent-borne amine based epoxy, 100% solids epoxy, 100% solids elastomeric polyurethane, 100% solids rigid polyurethane, and cement-mortar.

Among the above systems, however, the selection of a suitable lining material can be a difficult task based on various attributes including coating properties, surface preparation requirements, application parameters, resistance to environmental attack, economics, and worker safety. Results of various performance laboratory tests on the lining systems can play a major role in the selection exercise. Laboratory testing of different lining systems and their various performance attributes form the basis in establishing correlation with field performance and long term life expectancy.[i]

Municipalities and specifying engineers are constantly researching and studying various available lining systems. In most cases, however, their study has been focused onto a very limited number of specific lining systems (often 1 or 2 only). Therefore, a systematic evaluation of all of the above different lining systems becomes important, in order to allow engineers and municipal utilities to make a reliable prediction and selection regarding specific corrosive conditions and linings.

This paper gives a comparative study of the performance and application parameters of 13 different ANSI/NSF 61 approved lining systems that are presently used for steel pipelines in potable water service. Where possible, performance results were gathered by direct testing of the comparative systems. Wherever direct testing was not possible the reported values of the respective lining manufacturer are reported. All application and product attributes are detailed as per the respective lining manufacturers' reports or industry standards.

2. EVALUATION METHODOLOGY AND TESTED SYSTEMS

The evaluation process encompassed the summarizing and testing of 13 different lining materials.

Table 1: Summarized Lining Systems by Classification

Product Type	Solvent Amine Based Epoxy	100% Solids Epoxy	100% Solids Elastomeric Polyurethane	100% Solids Rigid Polyurethane	Cement-Mortar (ANSI/AWWA C205)
Number of Systems Compiled	6	2	2	2	1

The municipal pipeline market has always required a corrosion protection system that is durable and able to withstand the corrosive environment that can be present in the municipal water pipeline. For a lining system to be classified as a suitable corrosion protection system, the lining must expose little or no metal surface to the environment while also being resistant to environmental, mechanical and chemical damage throughout its service life. Standard tests have been developed and used over many years to evaluate various coating and lining systems for their use as corrosion protection coating and lining systems. In this study, tests were conducted according to the following testing standards:

- Adhesion (ASTM D4541)
- Abrasion Resistance (ASTM D4060)
- Cathodic Disbondment (ASTM G95)
- Chemical Resistance (ASTM D714)
- Flexibility (ASTM D522)
- Impact Resistance (ASTM D2794)
- Salt Spray Resistance (ASTM B117)
- Water Absorption (ASTM D570)

The above tests are listed in alphabetic order and not in any order of importance. Many of the above tests and their results are interdependent.

Evaluation of the application parameters were conducted based upon the comparison of actual in-house and filed testing results, available technical data and recommended procedures from the respective lining manufacturers. Application parameters include handling and safety characteristics of the materials, shop application, repair application, and field joint application procedures.

3. APPLICATION PARAMETERS

3.1 Handling and Safety Characteristics

Handling characteristics of the solvent based epoxy, 100% solids epoxy, 100% solids elastomeric polyurethane, 100% solids rigid polyurethanes and the cement-mortar systems include mixing ratio, solids content, volatile organic compound (VOC) weight and application methods. These characteristics were reviewed and summarized in Table 2.

100% solids polyurethanes, in both elastomeric and rigid format, and 100% solids epoxies have gained substantial interest in recent years due to environmental regulations. By definition, the term "100% solids" indicates a lining system that does not use any solvent to dissolve, carry or thin any of the resins. Lining systems that are classified as 100% solids may still contain a small volume of solvent or VOC's that can act as a dispersing agent, a stabilizer or as a carrier of pigments, catalysts or other additives.

Table 2: Product Attributes and Safety Characteristics

Product Type	Solvent Amine Based Epoxy	100% Solids Epoxy	100% Solids Elastomeric Polyurethane	100% Solids Rigid Polyurethane	Cement-Mortar
Mixing Ratio	1:1 1:4 1:5	1:1 1:4	1:1 2:1	1:1	1 cement < 3 sand water
Average % Solids	67%	100%	100%	100%	100%
V.O.C. (lbs/gallon)	2.84	0.30	0.00	0.00	0.00
Contains Amines	Yes	Yes	No	No	No
Contains Monomeric Isocyanate	No	No	No or very minimal	No	No
Flammable	Yes	No	No	No	No
Application Method	Brush, roller, single component spray	Single (King type) or plural component spray	Plural component spray	Plural component spray	Centrifugal, mechanical, pneumatic, hand application

100% solids polyurethane lining chemistry is based on the thermoset plastic reaction between an isocyanate and a polyol. Rigid and elastomeric polyurethanes are differentiated by the types of isocyanates and polyols that are used in the resin formulation. The chemical bonds of 100% solids rigid polyurethane systems are highly cross-linked to each other to create a hard, dense protective membrane that has good chemical and corrosion resistance. 100% solids elastomeric polyurethane linings are of a more linear chemical structure with much less cross-linking that allows for the lining's stretchy and elastic nature. Elastomeric polyurethanes, therefore, tend to have good impact strength and flexibility but very poor tensile adhesion and cathodic disbondment.

Catalyzed epoxies (polyamide-cured and amine-cured) are replacing the black coal-tar epoxies that were previously used in potable water service. Polyamide-cured epoxy coatings are less toxic and have better application characteristics, wetting, adhesion and gloss retention, but generally are not as solvent and chemically resistant as amine-cured systems. Most ANSI/NSF 61 approved and commonly-used potable water epoxy systems are amine-based. In this study, the tested solvent based epoxy and 100% solids epoxy linings were all amine-cured systems.

In the past, there has been a misinformed impression in the coating industry that compared to an epoxy system, polyurethane coating and lining systems were not as safe to use as epoxies due to the toxicology of the resins (polyols and especially isocyanates). The main hazardous pre-cursor of a polyurethane is an isocyanate monomer. While there are many different types of isocyanates available in the market, most isocyanates used today in ANSI/NSF 61 approved polyurethane systems are of the MDI (Diphenylmethane Di-isocyanate) type. In these lining systems, particularly in rigid polyurethane systems, polymeric MDI and special formulating technology are also used to further reduce the level of isocyanate monomer in the finished system. As a result, the polyurethane systems are in fact safer to use compared to most epoxy systems. For example, without involving the actual formulations of these NSF 61 lining systems, Table 3 outlines the single oral LD_{50} value (lethal dose for 50% of the laboratory rats) among pure resins used in these materials.[ii] Therefore, a greater value indicates that the material is less toxic. In addition to this, polymeric MDI has recently been deregulated in North America as non-dangerous goods for transportation, while most amine resins are still classified as dangerous goods.

Table 3 Oral LD_{50} Value Comparison Between Polyurethanes and Amine-cured Epoxies

Products	LD_{50} (mg/kg)
Polyurethane	
Polymeric MDI	5,000 -10,000
Polyol	2,000 - 5,000
Amine-cured Epoxy	
Amine	500 - 4,000
Epoxy Resin	less than 2,000

Cement-mortar linings are a mix of portland cement, sand and water mixed into a mortar mixture that can have as many combinations and permutations as the individual completing the mix. Cement-mortar lined steel pipe was first used in the United States in the 1800s and has evolved over time in formulation and application methods. Today's cement-mortar lined steel pipe tends to have a smooth, dense finish that can protect the steel surface with a measure of corrosion protection. Cement-mortar mixtures can be modified with admixtures and pozzolanic materials to improve their performance and to change their application parameters. Unless otherwise specified, ASTM C150 Type I and Type II portland cements are the standard cements used.

3. 2 Application Attributes

3.2.1 Shop Application

Table 4 Shop Application Parameters and Attributes

Product Type	Solvent Amine Based Epoxy	100% Solids Amine Epoxy	100% Solids Elastomeric Polyurethane	100% Solids Rigid Polyurethane	Cement-Mortar
Surface Preparation	SSPC SP10 (NACE 2)	SSPC SP10 (NACE 2)	SSPC SP10 (NACE 2) SSPC SP5 (NACE 1)	SSPC SP10 (NACE 2)	Hand cleaning to remove corrosion products
Surface Profile	2.0 mil (50 microns)	2.0 mil (50 microns)	3.5 mil (88 microns)	2.5 mil (63 microns)	Not applicable
Recommended Lining Thickness	11 to 20 mils (280 to 500 microns)	10 to 20 mils (250 to 500 microns)	20 to 125 mils (500 to 3175 microns)	15 to 20 mils (380 to 500 microns)	188 to 500 mils (4775 to 12700 microns)
Number of Coats to Thickness	2 to 4 coats	2 to 3 coats	1 to 5 coats	1 coat	1 application
Application Temperature Range (°F)	40 to 100	40 to 100	-10 to 150	-40 to 150	35 to 100
Cure to Handle Time at 70°F	4 to 14 hours	10 hours	30 to 50 minutes	15 to 30 minutes	1 day or more
Time to Service at 70°F	5 to 7 days	1 to 4 days	2 to 3 days	2 days	1 to 7 days
Curing Procedure	Maintain Temperature	Maintain Temperature	None Required	None Required	Moist curing or accelerated curing

The cost of a lining system can often be significantly influenced by the application method. Shop costs and the time required for application can greatly increase the total applied cost of any lining system. Therefore, systems that can be applied at increased rates without stringent requirements for post cure can lower the overall total applied cost of a protective lining system.

It is the general nature of lining systems that are high in solids content, such as the 100% solids epoxy and polyurethane system and the cement-mortar, to offer the applicator a one time or reduced number of applications to produce a functional protective membrane system. The added benefit of the 100% solids polyurethanes cold cure capability and rapid cure time also reduces the total applied cost of the lining system. Cement-mortar systems are generally viewed to be easy to apply and thus require a low level of applicator skill for application.

Solvent based epoxies and other spray applied lining systems are usually limited by long cure times and elongated cure periods between coats. Limitations of the lining systems to cure in cold weather usually dictate the use of secondary heat to ensure that the lining cures properly.

Cement-mortar lining systems do offer a fast one coat application but are limited by post cure requirements involving periods of curing by moisture, heat or a combination of the two methods.

Lining systems with long cure rates may also require substantially longer periods before the pipe can be handled, inspected, or shipped. 100% solids polyurethane systems offer the benefit of fast cure and therefore a reduced timeframe before handling, inspection, and shipment.

3.2.2 Repair Procedure

A lining's ability to be quickly and efficiently repaired in the factory or field is an important attribute of any system. A long cure time or an elaborate curing process can cause inefficiencies for shop and field applications.

Table 5 Repair Methods and Attributes

Product Type	Solvent Amine Based Epoxy	100% Solids Epoxy	100% Solids Elastomeric Polyurethane	100% Solids Rigid Polyurethane	Cement-Mortar
Number of Coats to Recommended Thickness	1 to 3 coats	1 to 2 coats	1 coat	1 coat	1 application
Application Temperature Range (˚F)	40 to 100	40 to 100	0 to 150	-10 to 150	40 to 100
Cure to Handle Time at 70˚F	4 to 14 hours	10 hours	4 to 6 hours	30 to 90 minutes	1 day or more
Time to Service at 70˚F	1 to 4 days	1 to 4 days	2 days	2 days	1 to 7 days

As with the shop applied lining system, the epoxy systems, both 100% solids and solvent based systems, are characterized by long cure times, multiple coat repair methods, and an inability to cure in cold ambient temperatures.

Cement-mortar repair systems are relatively easy to use and are similar to the mortar system applied in the shop.

100% solids polyurethane lining systems, both rigid and elastomeric, offer fast drying, one coat systems that can be placed in service hours after application even at lower temperatures.

3.2.3 Field Joint Application

Similar to the shop application and repair processes, the construction contractor's ability to achieve the proper results for field joint applications is very much limited by the number of coats and cure time required by the joint materials.

Table 6: Field Joint Material and Application Attributes

Product Type	Solvent Amine Based Epoxy	100% Solids Epoxy	100% Solids Elastomeric Polyurethane	100% Solids Rigid Polyurethane	Cement-Mortar
Surface Preparation	SSPC SP10 (NACE 2)	SSPC SP10 (NACE 2)	SSPC SP10 (NACE 2) SSPC SP10 (NACE 1)	SSPC SP10 (NACE 2)	Hand cleaning to remove corrosion products
Number of Coats to Thickness	2 to 4 coats	2 to 3 coats	1 to 2 coats	1 to 2 coats	1 application
Application Temperature Range (°F)	40 to 100	40 to 100	0 to 150	-10 to 150	40 to 100
Cure to Handle Time at 70°F	4 to 14 hours	10 hours	4 - 6 hours	1 to 2 hours	1 day or more
Time to Service at 70°F	5 to 7 days	1 to 4 days	2 to 3 days	2 days	1 to 7 days

A welded joint area is normally a weak spot in the steel pipe protection system, from the point of view of both mechanical and chemical failures.[iii] If the field applied joint corrosion protection system is the same as the factory applied material, proper application of the field applied joint corrosion protection material becomes the main concern of the corrosion specialist. Some lining systems require specific surface preparation methods, post application cure procedures, or application by trained and certified applicators. If one lining system is chosen over another on the basis of higher performance, the application of a field joint corrosion protection system that does not perform as well as the factory applied material is ill-advised.

4. PERFORMANCE TESTING OF THE LINING SYSTEMS

4.1 Adhesion (ASTM D4541)

The adhesion of a protective lining system to the substrate is considered to be a good indicator of the lining's ability to resist corrosion and therefore represents longevity of the lining. Generally, the better the adhesion, the longer the lining will last.

Adhesion testing determines the 'pull-off' strength of a lining system by determining the perpendicular force that the tested material will withstand before either releasing from the steel surface or pulling apart cohesively.

Table 7 lists the average values of the adhesion of the lining systems to prepared steel samples. All results were either those reported by the lining manufacturer or the average value tested for this test report. All reported values represent results that should be found under ideal or laboratory conditions.

Table 7 Adhesion Results

Product Type	Solvent Amine Based Epoxy	100% Solids Epoxy	100% Solids Elastomeric Polyurethane	100% Solids Rigid Polyurethane	Cement-Mortar
Average Adhesion	1280 psi	925 psi	1000 psi	2000 psi	0 psi

The values clearly indicate that the 100% solids rigid polyurethanes had superior adhesion compared to the other lining systems. The cement-mortar lining system had no adhesion since the cement-mortar system does not normally bond to the steel surface, but is instead held in place by its rigidity and shape.[iv]

4.2 Impact Resistance (ASTM D2794)

The impact resistance test method represents the lining's ability to withstand damage due to a direct impact with another object. This test method is often referred to for pipeline coating performance results where impact and damage resistance is of more importance.[v] This test is also relevant for evaluation of internal lining systems due to its ability to predict good lining performance and resistance to damage.

The test method consists of a fixed weight being dropped from varying heights to produce a point impact on the lining surface. The results are measured in terms of the energy required to rupture the lining and create a holiday or discontinuities. The energy is reported in terms of inch-pounds (in-lbs) where a one (1) inch-pound result would be equivalent to dropping a one (1) pound weight a distance of one (1) inch onto the steel sample. All of the tested samples were on steel panels coated with 14-20 dry film mils with the exception of the cement-mortar samples that were tested at 500 mils of thickness. The results are shown in Table 8.

Various lining systems perform differently over time as the corrosion protection system ages. Cement-mortar lining systems tend to crack and disbond while organic lining systems tend to embrittle.

The impact resistance values in Table 8 are reported for the lining materials after they have completed their initial curing process and after forced aging. The forced aging was completing on samples of the various lining materials by placing the test samples in a 50^{o}C environment for 28 days before completing the impact test.

Table 8 Impact Resistance Results

Product Type	Solvent Amine Based Epoxy	100% Solids Epoxy	100% Solids Elastomeric Polyurethane	100% Solids Rigid Polyurethane	Cement-Mortar
Non Aged Samples - Average Impact Resistance	38 in lbs	15 in lbs	80 in lbs	50 in lbs	2 in lbs
Aged Samples - Average Impact Resistance	10 in lbs	5 in lbs	75 in lbs	50 in lbs	2 in lbs

The cement-mortar system did not change in its ability to withstand direct damage from the aged and non-aged samples. Overall the cement-mortar samples displayed a very low result with little ability to withstand damage. The failures of the cement-mortar were found to be different from the failures noted in the epoxy and polyurethane lining systems. Where an organic lining system failure is noted by the creation of a holiday or rupture in the protective membrane, the cement-mortar lining system catastrophically failed with the sample breaking into several sections.

The epoxies, both solvent based and the 100% solids version, tended to decrease in ability to withstand damage as they aged. The epoxy based materials had lower impact resistance than that of the polyurethane materials.

4.3 Abrasion Resistance (ASTM D4060)

For any pipeline internal lining application, the lining must be able to withstand the constant flow of liquid and any particulates. Normal municipal pipeline velocities are in the range of 8 to 16 feet per second (2 to 4 metres per second) but these rates can increase in some cases to over 30 feet per second. The corrosion protection lining must be capable of withstanding the constant abrasion caused by the passing water at the various velocities. Premature failure of the lining system can occur thereby exposing the steel substrate to the corrosion cycle.

In the Taber Abrasion Test (ASTM D4060), a sample was rotated under a specific weight (1 kilogram) against a grinding wheel (CS17) for a defined number of revolutions (1,000 cycles). The samples were evaluated by measuring the weight of the sample before and after the test. The resulting weight loss indicated the comparative ability of the lining to resist abrasion and wear. The lower the reported weight loss, the more abrasion resistant the lining.

Table 9 summarizes the abrasion resistance testing results. The 100% solids polyurethane linings, both rigid and elastomeric, demonstrated superior abrasion resistance. This parallels what is already known in the industry that polyurethanes offer excellent abrasion resistance.[vi] The solvent based and 100% solids epoxy lining systems offered moderate abrasion resistance.

Table 9 Abrasion Resistance Results
(ASTM D4060, I kg, CS17, 1000 cycles)

Product Type	Solvent Amine Based Epoxy	100% Solids Epoxy	100% Solids Elastomeric Polyurethane	100% Solids Rigid Polyurethane	Cement-Mortar
Average Weight Loss	122 mg loss	183 mg loss	15 mg loss	50 mg loss	1500 mg loss

The cement-mortar system samples illustrated the inherent nature of cement-based products to ‘wear away’ at an accelerated rate in environments that are subject to fast velocities.[vii] However, with cementitious linings, the abrasion resistance can vary widely depending on the type and amount of aggregate as well as the smoothness of the lining surface.[viii]

4.4 Flexibility (ASTM D522)

The ASTM D522 test method is a good indicator of a lining's ability to withstand the cracking, disbonding, or other mechanical damage of the lining that can occur from handling and bending of the steel pipe not only in the field but also in the factory.

In some cases, especially with large diameter steel pipe, the use of a factory applied cement-mortar system is not advisable due to the known damage that can occur to the lining system before installation. In many cases, if cement-mortar is required on large diameter steel pipe, the cement-mortar is applied 'in situ' after the pipeline has been installed.

Table 10 Flexibility Results (ASTM D522)

Product Type	Solvent Amine Based Epoxy	100% Solids Epoxy	100% Solids Elastomeric Polyurethane	100% Solids Rigid Polyurethane	Cement-Mortar
Average Flexibility	Failure at 180° over a 2 inch mandrill	Failure at 180° over a 2 inch mandrill	Pass at 180° over a 2 inch mandrill	Pass at 180° over a 2 inch mandrill	Failure at 180° over a 2 inch mandrill

The epoxy samples tended to be brittle and therefore not able to withstand the bending of the steel sample. This is consistent with industry knowledge that epoxy coatings, both solvent and 100% solids based epoxies, are prone to embrittlement.[ix]

The cement-mortar lining had almost no flexibility. This is also well documented in the industry and therefore accounts for the elaborate shipping requirements for steel pipeline that is lined with cement-mortar systems.

The 100% solids polyurethane lining systems, both elastomeric and rigid, possessed a natural flexibility. The lining systems can withstand large movements and bends before displaying cracking or disbondment from the steel substrate.

4.5 Cathodic Disbondment (ASTM G95)

Cathodic disbondment is one measure of the undercutting resistance of a lining system. Experience in the oil and gas pipeline industry has clearly shown that linings with better cathodic disbondment resistance have better corrosion resistance and greater longevity.[x]

The cathodic disbondment tests were conducted according to ASTM G95 at 73°F(23°C) ± 3°F(1°C) for 30 days using 3% Sodium Chloride (NaCl) and a -1.5 volt DC current. This effectively created a corrosion cell through a 0.125 inch diameter hole that is created in the corrosion protective lining. After the 30 day test period, the radial disbondment, reported in millimetres, was measured from the edge of the hole to the point at which the lining system displayed good adhesion.

Table 11 shows the summary of the results.

Table 11: Cathodic Disbondment Results
(ASTM G95, 3% NaCl, -1.5 volts, 30 day, 73°F)

Product Type	Solvent Amine Based Epoxy	100% Solids Epoxy	100% Solids Elastomeric Polyurethane	100% Solids Rigid Polyurethane	Cement-Mortar
Cathodic Disbondment	15 mm avg.	15 mm avg.	30 mm avg.	8 mm avg.	N/A*

** Note that on cement-mortar samples without an electrical current, the samples demonstrated undercutting and corrosion on the entire sample. When the current was applied the sample demonstrated complete undercutting as well.*

The lining systems with good adhesion to the steel substrate tended to have a similar resistance to cathodic disbondment. If a lining is able to adhere to the steel substrate, it will therefore also tend to resist the undercutting damage of corrosion, thereby offering a longer service life.

100% solids elastomeric polyurethane systems which had a very good abrasion and impact resistance suffered from poor adhesion and a similar poor cathodic disbondment resistance.

Rigid coating systems, such as the epoxy and 100% solids rigid polyurethane systems offered higher adhesion values, and therefore also had good resistance to cathodic disbondment. However, it should be noted that, as with tensile adhesion, the 100% solids rigid polyurethane lining system provided a substantially higher performing product than the solvent based and 100% solids epoxy systems.

4.6 Salt Spray Resistance (ASTM B117)

The salt spray test is the conventional method of measuring the undercutting resistance of a lining system. The test method allows for a scribe to be cut in the corrosion protection system before being exposed to a number of hours in a salt fog cabinet. The steel panels are then evaluated for disbondment of the lining material from the point of the scribe as well as 'under film' corrosion. Under film corrosion has historically been found with poorly adhered corrosion protection systems such as polyethylene in ductile iron pipe internals for wastewater applications[xi] and tape wrap systems for steel pipe externals[xii].

Table 12 Salt Spray Resistance
(ASTM B117, 1000 hours exposure)

Product Type	Solvent Amine Based Epoxy	100% Solids Epoxy	100% Solids Elastomeric Polyurethane	100% Solids Rigid Polyurethane	Cement-Mortar
Salt Spray Resistance	Pass 1000 hours	Pass 1000 hours	Pass 1000 hours	Pass 1000 hours	Fail*

** Note that, as with the cathodic disbondment results, the salt spray samples showed a complete failure with undercutting on the entire sample. The cathodic disbondment and salt spray tests are measurements of a lining's ability to withstand undercutting. With cement-mortar, all samples showed complete undercutting whenever a crack or hole was produced in the cement-mortar.*

The results of salt spray resistance testing are often compared to the cathodic disbondment values. Although the two (2) methods test the lining's ability to resist undercutting from the corrosion process, the cathodic disbondment test method has been found to be more consistent in its ability to predict actual lining performance.

The 100% solids rigid polyurethane linings, as with the cathodic disbondment results, indicate that the lining system is very resistant to undercutting at damaged areas or holidays. The 100% solids elastomeric polyurethane linings suffer from a poor ability to adhere to the steel substrate and to withstand undercutting at points of damage.

The solvent based and 100% solids epoxy systems exhibited a good resistance to undercutting in general but the results are, as with the cathodic disbondment results, poorer than the 100% solids rigid polyurethane lining options.

4.7 Water Absorption (ASTM D570)

Water absorption is the measure of the ability of a water borne chemical or gas to penetrate the lining through to the substrate. The ASTM D570 test method was used to test the various linings. The test samples were immersed in potable water at 50°C (122°F) for 48 hours, and the weight of the samples before and after immersion in the water was noted. The results are reported in percentage (%) of weight change in Table 13. The lower the resulting number, the better the lining is able to resist blistering and disbondment.

Table 13 Water Absorption Results (ASTM D570, 50°C, 48 hours)

Product Type	Solvent Amine Based Epoxy	100% Solids Epoxy	100% Solids Elastomeric Polyurethane	100% Solids Rigid Polyurethane	Cement-Mortar
Water Absorption (% Weight Change)	2%	2%	6%	2%	7%

With the exception of the cement-mortar lining, all of the lining systems had relatively low results. 100% solids elastomeric polyurethanes tend to have higher permeability results due to their linear molecular structure.

4.8 Chemical Resistance (ASTM D714)

The ASTM D714 test method monitors the effect of a chemical solution when the lining is applied to a metal coupon. The evaluation is completed by observing the panel for blisters and general appearance after immersion in the test solutions. While this test provides a "true-life" condition, the end result is that the lining can really only be recommended as being suitable for the length of service for which the sample was tested.

Table 14 summarizes the test results of the lining systems for up to 1,000 hours. The results indicated that all of the lining systems were quite resistant to the four common chemical solutions.

Table 14 Chemical Resistance Results (ASTM D714, 1,000 hours)

Product Type	Solvent Based Epoxy	100% Solids Epoxy	100% Solids Elastomeric Polyurethane	100% Solids Rigid Polyurethane	Cement-Mortar
Sodium Hydroxide - 20%	Pass	Pass	Pass	Pass	Pass
Sodium Chloride - 3%	Pass	Pass	Pass	Pass	Pass
Sulfuric Acid - 3%	Pass	Pass	Pass	Pass	Pass
Gasoline (Nonmethanol)	Pass	Pass	Pass	Pass	Pass

CONCLUSIONS

The choice of the best corrosion protection system is a balanced decision analysis based on the corrosive environment parameters and the economics for the project.

Cement-mortar lining of steel pipes have been widely used in North America for more than 70 years. Cement-mortar linings are inexpensive, easy to apply, and offer a relatively good corrosion protection for the steel pipe under normal environmental conditions. Soft or aggressive waters, intermittent operations, high flow velocities, and strains can all lead to the deterioration of the cement-mortar linings.[xiii] Therefore in cases of aggressive environmental conditions, cement-mortar linings should be critically evaluated.

Amine-epoxy corrosion protective systems offer good performance attributes including good chemical resistance but are limited by other performance attributes such as poor flexibility and abrasion resistance. As well, application difficulties common to epoxy systems are multiple coats, slow cure, and an inability to cure at lower temperatures.

100% solids elastomeric polyurethane technology provides good abrasion resistance and flexibility, but are limited by their poor adhesion to the steel substrate and thus their inability to resist undercutting.

The best performing corrosion protection system is the 100% solids rigid polyurethane system. The coating's high tensile adhesion, low undercutting, excellent abrasion and impact resistance offer the decision maker a high performance corrosion protection system that can be used in cases of aggressive environments, repeated hydration and dehydration, high flow velocities, and possible pipe strains.

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