REHABILITATION OF PIPELINE COATINGS CAN REDUCE COST AND RISK

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The economic life of a coating ends when the cost of maintaining the existing corrosion-protection system (e.g., upgrading or adding additional cathodic-protection systems, localized coating repair, etc.) exceeds the cost of rehabilitation. 1, 2

Some companies use current-density calculations to determine the point where a pipeline performs as a bare pipeline rather than a coated pipeline. When a pipeline is constructed and coated with an appropriate pipeline coating for the environment, it generally takes less than 10 micro-amps (µA) of cathodic protection current per square meter of pipe surface to protect the system from external corrosion. 1 This nominal amount of cathodic protection current provides protection to small holidays or faults located in the coating that expose the pipeline steel to the environment.

As the pipeline ages and the coating deteriorates, the current-density demand goes up. For large diameter pipelines – 660 mm to 1070 mm (NPS 26 to NPS 42) – one company uses a current density of 3500 µA/m² as the benchmark for rehabilitation consideration. For smaller diameter pipelines, it allows higher current density demand prior to consideration for rehabilitation. 3

Economic justification is a major consideration for rehabilitation, but all pipeline operators typically have risk engineering guidelines for operating a safe, reliable, and efficient pipeline system. Regulatory considerations, loss of product throughput at critical times, loss of revenue stream due to leaks and failures have to be factored in to the decision to rehabilitate a pipeline coating.

Postponing or avoiding rehabilitation of the corrosion-protection system increases the risk of pipeline failure. The result of failure is contamination or leakage of the pipeline contents.

1 One micro-amp is one millionth of an ampere of current flow, or written in numeric format is 0.000001 amp.
COATING FAILURE – ACTION CHOICES

Once external-coating failure has been determined (through bell-hole examination, intelligent pigging, Pearson, current density calculations, or DC voltage gradient surveys, etc.), appropriate corrective action must be taken. There are four alternatives:

- Reduce operating pressure
- Abandon line
- Replace line
- Rehabilitate (replace) coating

A fifth alternative is to sell the pipeline; then the new owner can make one of the four decisions. Reducing the operating pressure is a stopgap measure designed to extend the life of a failing pipeline. Abandonment assumes there are alternatives due to excess capacity or a line loop that can absorb the transportation requirements.

Table 1. The relative cost of pipe replacement compared to rehabilitation depends on pipe size.

<table>
<thead>
<tr>
<th>Pipe size</th>
<th>Rehabilitation: Percent of Replacement Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>860 mm (34”)</td>
<td>30%</td>
</tr>
<tr>
<td>710 mm (28”)</td>
<td>35%</td>
</tr>
<tr>
<td>460 mm (18”)</td>
<td>60%</td>
</tr>
</tbody>
</table>

Table 1 provides a general estimate of relative cost between replacement and refurbishment.

REHABILITATION-COATING REQUIREMENTS

It is worthwhile to note the most-desirable properties for refurbishment coatings. A survey of thirty-nine pipeline-operating companies provides a list of rehabilitation-coating performance properties.

The most frequently mentioned properties were:

- Ability to resist soil stress, cathodic-disbondment resistance, and high-temperature performance
- Impact resistance
- Cost
- Water absorption and water permeation
- Time to backfill

ABILITY TO RESIST SOIL STRESS, CATHODIC-DISBONDMENT RESISTANCE, AND HIGH-TEMPERATURE PERFORMANCE. Soil-stress resistance is the coating capability of avoiding damage during the wet/dry cycling of a clay soil. Cathodic-disbondment resistance is the ability of a coating to resist local delamination near a holiday when
subjected to cathodic protection. All organic coatings cathodically disbond. A well-
formulated coating minimizes the delamination. Cathodic-disbondment tests
conducted at the pipeline operating temperature do provide information on expected
performance, but they do not predict long-term performance. More often, the
cathodic-disbondment test is used as a method to compare the relative performance of
two or more coatings.

**IMPACT RESISTANCE.** Impact resistance is important to minimize installation damage.
In addition to the coating, proper or processed backfill reduces the probability of
coating damage.

**COST.** Cost of a pipeline rehabilitation project depends on many factors including
terrain contours and soil types. Rugged terrain and rocky soil significantly increases
rehabilitation costs. In the USA, typical rehabilitation cost for 620-mm (NPS 24) pipe
is in the range of US$100 to US$250 per meter length. These are generalized
numbers; there is a major difference in costs between rehabilitation in rural farmland,
and urban or city neighborhoods.

Another factor is material cost. Figure 1 shows the effect, as a percentage of total
rehabilitation costs, of the price of material ranging from US$10 to US$20 per
kilogram. Although many competitive materials are reviewed as part of the decision-
making process, material selection is normally made on performance, not cost.

![Figure 1. Coating materials are a minor part of a rehabilitation project cost.](image)

**WATER ABSORPTION AND WATER PERMEATION.** These properties are a measure of the
ability of the coating system to perform well in underwater or wet underground
environments. The ideal polymer has balanced water and oxygen permeability and
does not shield the pipe from cathodic protection.

A disbonded coating closely fitting, but not adhering to the pipeline, can allow soil
water to flow along the metal surface of the pipe. Shielding can occur because of the
presence of an insulating barrier, e.g., a high-dielectric coating, that prevents the
cathodic protection current from reaching the metal surface of the pipe.

Several factors affect the penetration of CP current under disbonded coatings:

- Type of coating
- Thickness and electrical resistivity of the coating
- Trapped water composition and conductivity
- Presence of corrosion products

Many texts and much of the literature call for coatings used with cathodic protection to have high-dielectric strength.\textsuperscript{11,12} To preclude shielding, the resistance must be high enough to minimize current flow through the coating, but low enough to allow sufficient current flow to penetrate the coating and protect the steel if disbondment or blistering occurs. Thick coatings of materials with high electrical resistivity can result in cathodic shielding.

**TIME TO BACKFILL.** Minimizing the time from application until the pipe can be reburied is important. The actual requirement depends on the needs of each project.

<table>
<thead>
<tr>
<th>Test/Property</th>
<th>FBE-Single Layer</th>
<th>Liquid Epoxy</th>
<th>Liquid Urethane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cathodic disbondment resistance – 14 days, 65°C, 1.5 V, mmr</td>
<td>4.3</td>
<td>6.5</td>
<td>9</td>
</tr>
<tr>
<td>Impact – ASTM G-14, 16 mm tup, 24°C, J</td>
<td>2.4</td>
<td>2.8</td>
<td>3.2</td>
</tr>
<tr>
<td>Material Cost per Unit Volume</td>
<td>X</td>
<td>3.1X</td>
<td>2.6X</td>
</tr>
<tr>
<td>Moisture Vapor Transmission $^{13}$ G/(mil)(in.$^{2}$)(24 hr)</td>
<td>1.8</td>
<td>1.8</td>
<td>4.3</td>
</tr>
<tr>
<td>Time to Backfill: Minutes @ 24°C</td>
<td>--</td>
<td>160</td>
<td>30</td>
</tr>
</tbody>
</table>

**Table 2. Rehabilitation coatings now have performance properties approaching those of premium-grade FBE materials.**\textsuperscript{14}

**COATING MATERIALS**

There are a number of coating materials available for use in pipeline rehabilitation, each with its own particular set of advantages and disadvantages. The most common materials include:\textsuperscript{15,16}

- Tape – cathodic shielding, low adhesion, susceptible to delamination and stress corrosion cracking (SCC), tenting at weld seam, easy to apply, sometimes less expensive\textsuperscript{17}
- Coal tar – low soil stress resistance, low operation temperature, susceptible to SCC, health and safety concerns, easy to apply
- Coal-tar epoxy/urethane – relatively lower maximum operating temperature, health and safety concerns, longer cure times and times to backfill
- Polyester – performs poorly with cathodic protection, can cure below freezing.
- Liquid urethane – fast curing, low temperature cure, good soil stress resistance, no known instances of SCC, typically less resistant to cathodic disbondment than liquid epoxy systems
- Liquid epoxy – good adhesion, good soil stress resistance, good cathodic disbondment resistance, good performance in wet conditions, longer cure time compared to urethane, slow cure below 5°C, no known instances of SCC
MATERIALS SELECTION: LIQUID EPOXY/LIQUID POLYURETHANE

With all coating systems, there are tradeoffs in application and performance characteristics. Through improvements in chemistry, rehabilitation materials for pipeline-coating replacement have properties approaching that of premium-grade, plant-applied FBE materials – see Table 2. Selection depends on balancing factors like requirements for backfill time, material cost, and performance. Typically, epoxy is the coating of choice, unless the temperature at time of application is too low or time to backfill is critical.

Bellhole Rehabilitation:
Support Pillars

Figure 2. The bell-hole method may be utilized for both short-segment rehabilitation or for longer lines. In the case of long lines, short segments of up to 45 meters are exposed and supported by pillars 10 meters in length. For long line segments, the newly coated and cured pipe is backfilled, the former support pillars removed, and the newly exposed segment of pipeline coating is rehabilitated. Photos courtesy of 3M.

REHABILITATION (RECOATING) METHODS

Irrespective of the material selected for rehabilitation of the pipeline coating, application requires the same general steps:

- Expose the pipe
- Remove the old coating
- Inspect the pipe and make needed repairs/replacement
- Prepare the surface
- Apply the new coating
- Hydrostatically test – normally, if the pipe is removed from the ditch and mechanically worked, it is hydrostatically tested prior to service
- Bury the pipe
EXPOSE THE PIPE. There are two common practices employed for rehabilitation of pipeline coating:

- Bell hole
- Out of ditch

Removal of Old Coating

Figure 3. Coating removal can be accomplished either manually or via automated equipment using techniques like high-pressure water wash. Photos courtesy of 3M.

BELLHOLE REHABILITATION

The bell-hole method may be utilized for both short-segment rehabilitation or for longer lines. In the case of long lines, short segments of up to 45 meters are exposed and supported by pillars 10 meters in length – see Figure 2. Actual dimensions of the exposed and unexposed support segments depend on pipe diameter, wall thickness, and steel strength. For long lines after coating and backfill, the former support pillars are excavated and the newly exposed pipe is cleaned and recoated.

For bellholes, the main determination of exposed length is the ability of the suspended pipe to support itself without buckling. The width and depth of the ditch must be large enough to accommodate the equipment used in each phase of the rehabilitation process – including cleaning and application.

In either case, the most expensive part of the excavation is establishing the clearance beneath the pipeline in the exposed sections—particularly if the soil is rocky. This must be factored into the cost of materials. For example, if one coating requires an under-pipe clearance of 30 cm and another coating requires only 20 cm, then construction and labor costs can outweigh material savings.
For out-of-the-ditch coating, the pipeline must be taken out of service, cut, and removed from the ground. It is placed on skids and supported above ground to accommodate the rehabilitation process.

**Blast Cleaning:**
Automatic or Manual

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**Automated**

**Manual**

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**Figure 4.** Either a manual or automatic process can blast clean the pipe surface to near-white metal. Photos courtesy of Incal Pipeline Rehabilitation, Inc. and 3M.

**REMOVE THE OLD COATING.** Coating removal can be done by hammering and scraping. See Figure 3. The effectiveness of manual removal varies from very easy for disbonded material to nearly impossible for well-bonded coating. The work crew requires suitable protection in case of asbestos-containing coating materials.

Automated systems are available to remove the old coating. One such system uses high-pressure water at 275 MPa. 18, 19 The use of water has the added benefit of assisting removal of water-soluble contaminants from the pipe surface. Cleaning rates depend on coating type and thickness, pipe size, presence of reinforcing materials, coating disbondment, and adhesion. Ambient and pipeline temperatures are important when removing thermoplastic materials like coal-tar enamel, because they become soft at higher temperatures and do not break away cleanly. Removing tape may require even more effort depending on the nature of the disbondment, type of adhesive, use of primer, and number of layers.

**INSPECT THE PIPE AND MAKE NEEDED REPAIRS/REPLACEMENT.** An important aspect of the coating-removal process is the ability to see corrosion damage to the pipe. See Figure 4 and Figure 5. Repairs or replacement of pipe segments must be done prior to coating. For out-of-service lines, sections can be replaced with new pipe. For in-service “live” pressurized lines, repair is more difficult but can be accomplished using pipe sleeves or other repair methods. 20
Figure 5. Inspection before or after blastcleaning is acceptable. However, it is more effective after cleaning. Significantly damaged areas need to be replaced or repaired prior to rehabilitation coating. Photos courtesy of Incal Pipeline Rehabilitation, Inc.

PREPARE THE SURFACE. See Figure 6 for an illustration on abrasive media and performance.

Equipment is available for either hand-operated or automatic blast cleaning. Automatic equipment can clean 760-mm (NPS 30) pipe at three meters a minute. Final checks after blasting include anchor-pattern profile and salt-contamination evaluation – see Figure 7.

APPLICATION OF TWO-PART LIQUID (MULTI-COMPONENT (MCL) SYSTEMS). Brushes, rollers, squeegees, and airless and conventional (air atomized) spray are tools for MCL coating application. If the dew point is within 3°C of the part temperature, the pipe should be warmed prior to abrasive blasting and coating application. For best mixing, the individual component temperatures should be 20°C or warmer. Higher mixing temperatures are acceptable, but result in substantially reduced pot life.

Individual components should be premixed before being combined. Normally, the hardener and the resin have different colors. After pouring them together, the combination should be mixed to a uniform color.

Plural-component-spray systems are also available that automatically proportion, mix, and apply two-component epoxy or urethane coatings. Each component is kept in a separate container. To achieve proper viscosity, heaters normally are used in the pots, the conveying hoses, or both. Two or three pumps deliver fixed volumes of the components either to a mixer manifold or the spray gun. Since the mixing occurs just prior to application, pot life is not an issue. Proportioning is critical to product...
performance – proper equipment selection, set up, and maintenance are crucial. See Figure 8 for photographs of the spray equipment and the coating process.

**Blast Media: Choice Affects Coating Performance**

CDT: 28 days, 65°C, -1.5 V, 3% NaCl electrolyte

<table>
<thead>
<tr>
<th>Media Type</th>
<th>CDT (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grit</td>
<td>5</td>
</tr>
<tr>
<td>Nickel Slag</td>
<td>10</td>
</tr>
<tr>
<td>Sand 1</td>
<td>20</td>
</tr>
<tr>
<td>Sand 2</td>
<td>25</td>
</tr>
</tbody>
</table>

Microscopic view of grit-blasted profile

**Figure 6. Performance of rehabilitation coatings depends on surface cleanliness and steel profile. Selection of the best blast media is as important for rehabilitation coatings as it is for FBE systems.** Photos courtesy of 3M.

Reference to the manufacturer’s data should be made to find the lowest allowed cure temperature. If the temperature is below the cure range of the specific coating, follow the manufacturer’s instructions for preheating the part. Without specific instructions from the coating-material manufacturer, a starting point to assure cure is to heat the part to about 65°C if the ambient temperature is between –10°C and 10°C. If it is colder, it should be preheated to about 90°C.23

For part temperature above 90°C, use care in application to prevent volatilization of coating components. This can often be overcome by applying a first coating layer at approximately 250 µm (10 mil) and allowing it to dry to touch before applying the remainder of the coating thickness.

An advantage of liquid coatings is that the thickness can be checked while they are still wet. If more build is required, it can be done immediately. High-build coatings can build to more than a millimeter before sagging. High-build capability significantly increases application efficiency if it eliminates multiple layers required to achieve the specified thickness.

Handling and cure time for parts coated with two-part systems depend greatly on the temperature. Some polyurethanes can be applied at temperatures as low as -20°C. Specially-formulated epoxy systems can be applied at 0°C. However, the coating does not attain full cure at these temperatures. Exposure to a higher temperature at a later time completes the cure process. Inspection and repair are similar to FBE custom coatings.
The requirements for thermoset coating application and cure depend on the circumstances of the individual project. See Figure 9 for examples of the application process. There are three major categories of coating projects:

- Bellhole (in the ditch)—out of service
- Bellhole (in the ditch)—in-situ (live line carrying product)
- Over the ditch

Surface Preparation

![Surface Preparation](image)

**Figure 7. After cleaning, tests include a check for salt contamination and a measurement of surface profile.** Photos courtesy of D. Sokol, Sokol Consultancy, Houston, B. Brobst, and author.

While essentially the same procedure is used for coating in the ditch or over it, special considerations must be made for a live line with material flowing. The temperature of the pipe surface is essentially that of the product inside. A complicating factor is when the pipe temperature is below the dew point of the surrounding air. Most rehabilitation coatings do not work well on wet pipe. Thermoset materials must be capable of curing under this circumstance.

Pipeline contents (especially when flowing) also create a large heatsink, which means that additional heat added to the surface of the pipe immediately dissipates. Therefore, additional heat to the pipe does not accelerate coating-system cure. Conversely, in the case of a hot line and low ambient temperature, the heat of the internal product assists the curing process.
For bellhole rehabilitation, the coating material should allow burial within a few hours after application. For longer lengths of pipe, quick burial may not be required; but the time-to-touch should be less than 4 hours. This minimizes the effects of insects that land on the liquid coating resulting in holidays. For hand application, pot life is an important factor – there must be time available to mix and apply a suitable amount of material.

Figure 8. A plural-component spray system (A) pumps the two-parts from individual containers. (B) The individual components are added to the holding tanks. They are automatically mixed at or near the spray gun, which means that pot-life is not a concern. Spray application (C) is straightforward. An advantage of liquid coatings is that thickness can be checked before cure (D). With 100% solids coating systems, additional build can be applied at the time of the original application if the thickness is low. Photos courtesy of B. Brobst.

Pot life is not a critical feature for plural-component-spray systems, because mixing takes place at or near the spray nozzle for immediate application. Therefore, application and performance characteristics become the most important factors.

Bellhole rehabilitation – congested areas

Pipeline coating rehabilitation application in congested or urban areas places greater requirements on the process, the coating material, and the application methods – see Figure 10. The permitting process can be lengthy, requiring a traffic control plan and arrangement for off-duty policemen to act as traffic flaggers. The work typically must be done on weekends to minimize traffic disruption. Before work begins, concrete or other physical barriers are placed to separate traffic from the work area.

After the excavation is opened and the pipe exposed, the pipeline and coating anomalies must be located, the coating removed (or the pipe cut for replacement), the surface cleaned, and the pipe coated. The coating must reach a level of cure that prevents damage during backfill. If the operation is not completed over the weekend,
the hole must be backfilled with stabilized sand and a heavy steel plate placed over the ditch for traffic during the weekdays. The following weekend, those steps must be reversed for completion of the project.

Figure 9. Coating application can be either manual or automated. Photos courtesy of Incal Pipeline Rehabilitation, Inc. and 3M.

Coating speed of cure is of critical importance to shorten the time before backfill and final ditch closing. In a nutshell, the process includes excavation, removal of the existing coating, pipe inspection (possibly cutting and replacing sections of the pipe), coating repair or replacement, cure, and reclosing the hole in the shortest possible time.

OVER-THE-DITCH REHABILITATION

High-speed over-the-ditch coating operations have different requirements. The key element in this case is the amount of time allowed before the coated pipe must be returned to the support cribbing. For an automated line-travel operation, this typically means the coating must be strong enough to support the pipe weight within three to five minutes of application. Preheating the sections of the pipe that rest on supports prior to coating application accelerates the cure rate and hastens set-down time.

The first step in the process is clearing dirt from the pipe. The pipe is then removed from the ditch and cradled on skids. In the example pictured in Figure 11, a knife machine then removed the coating and residual dirt. A water-blast machine then removed most of the rest of the debris, leaving only traces of primer behind. The weld-reinforcement area and possible corrosion areas were blasted by hand for inspection.

Line-travel blast equipment followed by the coating machine finished the coating phase of the project. On a good day, 2 km could be coated. A critical issue was
reducing the amount of dust in the air. This was minimized by frequent wetting of the
right-of-way. 24

**Bellhole Rehabilitation:**
**Congested Areas**

![Bellhole Rehabilitation Images]

Figure 10. In high traffic areas, rehabilitation work must be done on weekends. If it is not completed, the excavation must be closed and covered with a steel plate to accommodate weekday traffic. That means speed of cure for the repair or rehabilitation coating is of critical importance. (A) Traffic must be controlled and barriers in place before the weekend excavation starts. (B) The anomalies must be found, the pipe coating removed, the pipe inspected and repaired, the surface blast cleaned, and the coating applied. After the coating has reached sufficient cure to withstand backfilling, the hole can be closed and the roadway returned to traffic condition. Photos courtesy of J. D. Davis, Kinder Morgan, Inc.

HYDROSTATICALLY TEST. By Department of Transportation (DOT) regulations for gas pipelines, if the pipe is removed from the ditch and mechanically worked, it has to be hydrostatically testing prior to service.

BURY THE PIPE. While the coating material does not have to be fully cured at time of burial, it must have sufficient strength to withstand the normal stresses of installation. It must also possess reaction kinetics that allow completion of cure while underground.

**REHABILITATION COATING SUMMARY**

Pipeline rehabilitation is an economic and pipeline integrity decision. Rehabilitation-coating selection is a technical decision. The cost of coating materials constitute a minor part of the total cost of the rehabilitation project – in the range of four percent of the project cost.

Many coating-material alternatives are available. The corrosion engineer must use good judgment in the coating-decision process, taking into account ambient conditions during application, pipeline-operating temperature, and local soil
conditions. Each coating system has its own application characteristics and requirements that must be taken into account during the material-selection process.

**Coating Rehabilitation: Over-the-Ditch**

Figure 11. In this example of an over-the-ditch project, the initial topsoil dirt-removal step used a bulldozer followed by track hoes with contoured buckets to clear the top and sides of the pipe (A). (B) A knife machine then removed most of the dirt and old coating material. (C) A water blast machine cleaned the majority of the remaining residue. A manual blast crew then cleaned the weld-seam area and areas of suspected corrosion for possible cutouts. After inspection, an abrasive blast machine provided an anchor profile (D). The line-travel coating unit (E) immediately followed the blast machine. 24 Photos courtesy of J. D. Davis, Kinder Morgan, Inc.

2 D. P. Werner, “Selection and Use of Anti-Corrosion Coatings for External Corrosion Control of Buried Pipelines,” Fourth European and Middle Eastern Pipeline Rehabilitation Seminar, Paper No 16, Abu Dhabi, Pipeline Integrity Management, 1993

3 J. D. Davis, Kinder Morgan, Inc., email to author, January 23, 2002.


7 S. A. Taylor, personal interview, October 1997.


24 J. D. Davis, Kinder Morgan, Inc., email to author, February 13, 2002.