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Catalyst Report

Catalytic methane synthesis upgrades heavy hydrocarbons
Myriad Maverick basin prospects test San Antonio independent
Abrasive cutting offers one option
Rigid-PU coating addresses chronic corrosion on Chinese gas line

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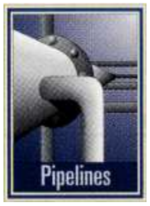


An advanced 100% solids structural and rigid polyurethane coating was employed in rehabilitating the Dagang-Cangzhou gas pipeline in northeastern China. Outlined here are the challenges and requirements for such a system and the performance testing results achieved during this project on both laboratory and field prepared samples.

Rigid-PU coating addresses chronic corrosion on northern Chinese gas pipeline

Corrosion extent

Corrosion is the primary factor affecting the longevity and reliability of pipelines throughout the world. In the US, there are more than 328,000 miles of natural gas transmission and gathering pipelines, 74,000 miles of crude transmission and gathering pipelines, and 82,000 miles of hazardous liquid transmission pipelines. Estimates of the corrosion-related cost to the US gas and liquid transmission pipeline industry range from $5.4 to $8.6 billion/year. Corrosion-related costs of operation and maintenance make up 80% of this cost.[1]

A recent survey of major US pipeline companies found that the primary cause of loss of corrosion protection was coating deterioration (30%) and inadequate cathodic-protection current (20%).[2] With 30% of the operational pipeline corrosion problems attributed to coating deterioration, a large portion of the corrosion control budget covers monitoring, identifying, and repairing coating anomalies.

Since 1999, China has built about 12,500 miles of long-distance transmission pipelines and 155,500 miles of gathering pipelines; most of the coatings on these buried pipelines have aged so severely that the lines are exposed to corrosive underground environments.[3]

The desire to extend a pipeline's operating life and reduce its life cycle costs has led to the emergence of coating rehabilitation as a means of pipeline corrosion control.

The need to be able to apply coatings at all environmental temperatures, particularly in cold winters, has challenged pipeline rehabilitation. Applying coatings in the field in cold weather raises issues of coating properties, surface preparation, and inspection. This challenge puts various requirements on a pipeline rehabilitation coating system in terms of coating formulating properties including environmental and safety issues, surface preparation, field-application properties, performance and overall cost.

Over the years, many field-applied coating systems have been developed for pipeline rehabilitation in China. These systems include field-applied single or dual-layer fusion-bonded epoxies, liquid-applied coal-tar or non-coal tar epoxies (either solvent-based or 100% solids), elas-tomeric polyurethanes, cold-applied or hot-applied tapes, cement materials, and wax and composite systems. None of these coatings provides a good solution for all temperature field applications.

As a result, the Chinese oil and gas pipeline industry for some time has searched for a coating system that can provide not only high performance for oil and gas field pipeline rehabilitation but also can be applied during winter in Northern China.

One of the main pipelines that supply natural gas to northeastern Chinese cities is the 62 mile, 21-in. OD Da-Gang-CangZhou line installed in 1973 and originally protected by a petroleum-asphalt enamel coating. Since then the pipeline has experienced severe corrosion problems, which were not resolved even after numerous localized rehabilitation applications.

In 2001, operator PetroChina Da-gang Oilfield Natural Gas Co. decided to refurbish the pipeline completely. A 100% solids, rigid and structural aromatic PU coating was selected for a river crossing and some underground and aboveground portions.

In November 2001, PetroChina Da-gang Oilfield formed a special technical

CHALLENGES, REQUIREMENTS FOR COATING SYSTEMS IN PIPELINE REHABILITATION Table 1

Area of challenges	Requirements
Formulating, handling, and safety properties	
• Is the coating resin curable at the field ambient temperature? • Is an accelerator needed? • Is heating needed for the coating material? • Will the coating become either too viscous when it is cold in the winter or too thin when hot in the summer? • Any potential health and safety issue due to less than ideal environmental temperatures?	• Cold-temperature naturally cured coating systems are more desirable than those that require heat. • Fewer coating components are better. • Viscosity of the coating shall be proper for easy application. • For rehabilitation of piping, less than 80 ft, airless spray can be effective. For longer lengths, liquid systems application using 1:1 plural component spray equipment is desirable • 100% solids and solventless systems are desirable.
Surface preparation	
• Is heating or cooling needed for the substrate by the coating? • How sensitive is the prepared substrate surface and coating to ambient temperature and moisture? • Will it be possible to control the pipe surface temperature?	It is ideal to have a rehabilitation coating that can be applied as fast as possible onto the substrate regardless of its temperature under the environmental and climate conditions.
Field application properties	
• How easy is the application of the coating at cold or hot temperatures? • Any special equipment requirements due to the ambient temperature? • Is the coating formulated for easy application? • Any potential problem on spray pressure, coating material temperature, and substrate temperature? • For how long does the coating need to be dry to touch, to handle, inspection, backfill, and to service? • What is the maximum coating thickness to hang on the pipe per single coat application at the ambient temperature? • How many coats are required? What is the minimum and maximum recoat or topcoat window between coats? • What are and how easy can the field inspection tests be done a the ambient temperatures? Would the time for inspection cause delaying the project? • How easy can repairing be done? • Would the coating application meet the tough schedule due to climate changes?	• Easy application is important. Proven systems are best. • Plural component coatings with a mixing ratio other than 1:1 will be more likely to cause mismetering problems (often called "off-ratio") during application. The greater the ratio, the higher the possibility it will occur. It is recommended to select those systems in which both components have the same or very close values of medium-ranged viscosities. Too high viscosity values of these coatings may cause application and equipment problems in handling. • A fast-cure single coat system is the ultimate goal to meet the work schedule requirements and to minimize costs.
Performance properties	
• Are any performance properties affected by exposure to hot ambient temperatures during field application (such as adhesion, resistance to penetration of the back-fill material, etc.)? • Are any performance properties affected by exposure to cold ambient temperatures during field application (such as brittleness, impact resistance, etc.)?	A rehabilitation coating system shall perform at all environmental conditions that can be encountered during the field application.

committee officially to appraise the rehabilitation project based on both testing and field performance. Details of the committee's findings, although publicly available, form the basis of this article.

Design, selection

For years, the pipeline industry has required an effective rehabilitation coating system with excellent application and performance properties and the ability to withstand corrosive environments. To meet these requirements, a pipe rehabilitation coating system must be able to meet the challenges of environmental and safety regulations, economics, field application conditions, effectiveness, and high performance.

Engineers must strike a balance between these five areas. The ideal pipeline rehabilitation coating system must be environmentally friendly, worker-safe, durable, and able to expose little or no metal or substrate surface to the environment. It must also resist environmental, mechanical, and chemical damage during application, handling, burial, or insulation. It should be capable of being applied efficiently and effectively under restricted environmental and work conditions in the field. Finally, it should come at a reasonable cost.

As a result of these requirements, design and selection of a pipeline rehabilitation coating system should be based on careful considerations of the following parameters:

• Handling, safety characteristics. These characteristics include mixing ratio, solids content, volatile organic compounds, flammability, application methods, as well as whether the coating contains any hazardous ingredients such as coal tar, amines, solvents or VOCs, and isocyanate monomers.

• Field application, repair attributes. These attributes determine the construction contractor's ability to achieve the proper results for pipeline rehabilitation.

The quality of field application is limited by the number of coats, curing temperature, and cure time required by the coating materials.

The coating system should also be able to be applied under a wide variety of specific field and environmental conditions such as humidity, wind, rain, ambient temperatures, dewpoint, space limitation, location, etc.

If the pipeline is in service during the rehabilitation, any heating or cooling necessary for good coating application is severely limited because product flow temperature will overpower any localized attempt at heating or cooling. Because ambient conditions are difficult to control, rehabilitation coating should be ready to apply and handle as soon as possible.

Surface-preparation requirements. Surface preparation is essential to the ability of the coating to bond to the pipe substrate and the existing coating. This bonding is important to eliminate environmental fluid migration between the substrate and the pipe coating. It also ensures permanence and the ability to withstand handling, burial, or insulation without losing effectiveness.

Surface preparation often becomes a bottleneck for pipeline rehabilitation. Abrasive blasting to an often recommended SSPC-SP10 (NACE 2) near-white or SSPC-SP5 (NACE No.l) white-metal surface can be slow.

It is also important to ensure the compatibility of the field-applied coating with the plant-applied mainline

PRODUCT HANDLING, SAFETY CHARACTERISTICS

Table 2

	Coal-tar epoxy	100% solids epoxy	Elasto-meric poly-urethane	Rigid and aro-matic poly-urethane	Fusion-bonded epoxy
Product type	Coal-tar, polyamide cured epoxy	Polyamine cured epoxy	Coal tar or pure aromatic polyurethane	Aromatic polyurethane	Epoxy powder coating
Primer	No primer required	Self-priming or use others	No primer required	No primer required	No primer required
Solids content	74%	100%	100%	100%	100%
Mix ratio	4:1	2:1	4.5:1	1:1	1:1
VOC	1.9 ppg	0	0	0	0
Contain amines	No	Yes	No	No	No
Contains coal tar	Yes	No	Yes/No	No	No
Contains flammable solvents	Yes	No	No	No	No
Application methods	Brush, roller, conventional spray	Brush and conventional spray	Plural component spray	Plural component spray	Electrostatic spray, fluidized bed heat cured
Shelf life	24 months	18 months	12 months	6 months	6 months

coating. Surface preparation often requires special procedures at transitions between the existing coating and the rehabilitation coating such as feathering the abrasive blasting edge for several inches into the existing coating to improve adhesion.

The extent of surface preparation for the transitions depends on how compatible the rehabilitation coating is with the existing coating. The choice of a type of blasting machinery to use for surface preparation during a pipeline rehabilitation project is related to the total length of the pipeline, production daily rate, and whether the pipeline can be taken out of service and cut into long sections.

• Physical performance require ments. Performance of a pipeline reha bilitation coating depends on such fac tors as the adhesion to the pipe sub strate and the existing coating, abra sion, impact, and penetration resistance (hardness), chemical and corrosion re sistance, dielectric strength and cathodic disbondment resistance, flexibility or bendability, stability at low or elevated temperature service conditions, and water absorption or water vapor per meability. Details of the requirements of these performance properties can be found elsewhere.[4]

• Case histories. Many coating man ufacturers are in a rush to develop and launch new pipe rehabilitation coating systems. An example is 100% solids polyurea coating. While the industry should appreciate the variable choices of rehabilitation coatings and coating suppliers, it is very important to select those coating technologies, products, and coating suppliers that are backed by solid case histories for both performance and technical support.

Cost analysis. The true cost of any rehabilitation coating system is not the "cost per bucket" or even the initial applied cost ($/sq feet or $/sq m).The true coating cost = materials cost + application cost + maintenance cost + "hidden" cost. This true cost should cover the initial costs of the coating material and its field-application, handling and burial, throughout the entire operation period.

Dealing with costs cannot avoid maintenance costs and hidden costs. To reduce the total life cycle cost of a pipeline, it is also desirable to reduce the rehabilitation and repair to a one-time event or to reduce the mainte-

FIELD APPLICATION REPAIR CHARACTERISTICS

Table 3

	Coal-tar epoxy	100% solids epoxy	Elasto-meric poly-urethane	Rigid and aro-matic poly-urethane	Fusion-bonded epoxy
Application methods	rush, roller, conventional spray	Brush and conventional spray	Plural component spray	Plural component spray	Electrostatic spray, fluidized bed heat cured
Recommended dry-film thickness	16 mils or more	25 mils or more	40-80 mils	25 mils or more	16 mils (12 mils minimum)
Surface preparation	SSPC-SP10	SSPC-SP10	SSPC-SP10	SSPC-SP10	SSPC-SP10
Blast profile	2.0-3.0 mils	2.0 mils +	2.0-3.0 mils	2.5 mils +	2.0 mils +
Ambient temperature	50 -110 F.	>41 F.	50 -140 F.	-40 -150 F.	NA
Substrate surface temperature	50 -110 F. & 5 F. above dewpoint	>41 F. & 5 F. above dewpoint	50 -140 F. & 5 F. above dewpoint	-40 -150 F. & 5 F. above dewpoint	425 -488 F.
Materials temperature	50 -90 F. both A & B	150 F. (A) 120 F. (B) (spray grade)	120 -140 F. both A & B	32 -150 F. both A & B	NA
Airless spray pump	Single (30:1 ratio)	2:1 plural (25:1 ratio)	4:1 plural (70:1 ratio)	1:1 plural (30:1 ratio)	NA
Spray pressure	2,100-2,500 psi	About 2,200 psi	4,260 psi	1,800-2,500 psi	NA
DFT per coat	Up to 24 mils	Up to 45 mils	Unlimited @ multiple passes	Unlimited @ multiple passes	25 mils maximum
No. of coats required	1-2	1	1	1	1
Dry to touch	4 hr @75 F.	1 hr 45 min @75 F.	<10 min @75 F.	1-10 min @75 F.	Up to 90 sec. @450 F.
Dry to handle	12-24 hr @75 F.	3 hr @75 F.	6-8 hr @75 F.	5-60 min. @75 F.	Upon completion of coating
Holiday	24-48 hr @75 F.	3 hr @75 F.	2 hr @75 F.	5-60 min. @75 F.	Upon completion of coating
Backfilling	24-48 hr @75 F.	3 hr @75 F.	6-8 hr @75 F.	30-180 mm. @75 F.	After holiday testing
Ultimate cure	7 days @75 F.	7 days @75 F.	7 days @75 F.	7 days @75 F.	NA
Recoat time	6 hr (min) 24 hr (max) @75 F.	Within 3 hr @75 F.	2-6 hr @75 F.	0.5-1.5 hr @75 F.	No recoat
Repair material	Brush grade	Brush grade or patch compound	Self or brush grade	Self or brush grade	Patch component or liquid epoxy

nance cost of the rehabilitation coating.

Maintenance costs of a field-applied rehabilitation coating project are related to the performance of the coating.

High-performance coatings, although normally having higher initial material costs, often provide the advantage of lower maintenance costs.

An example of "hidden" costs is the one due to project delay; hence the high production rate of a field-applied coating is important. The ability to bring the pipeline back into service almost immediately can mean significant economic and other benefits.

The challenge of field-applying coatings for pipeline rehabilitation at all environmental temperatures, particularly in cold winters, implies additional requirements on the rehabilitation coating systems in terms of coating formulating properties including handling and safety characteristics, surface preparation, field-application flexibility and properties, performance and cost.

Table 1 outlines these requirements.

COMPATIBILITY TESTS*

Table 5

Cathodic disbondment type of surface preparation	Adhesion (ASTM D4541)	Resistance (CSA245,20M, -1.5 v, 80 C. 72 hr)
Brush blast & air blown off, old FBE	3,300 psi cohesive failure of polyurethane	3.2-mm radius (FBE base), no disbonding between PU &FBE
Brush blast & air blown off, old three-layer PE	3,200 psi cohesive failure of polyurethane	2.9-mm radius (three-layer PE base), no disbonding between PU & FBE

*For 100% solids structural and rigid PU with FBE and polyethylene.

Rigid PU technology

From the very first years that polyurethanes were introduced to the pipeline market, most engineers recognized the capability of the versatile PU chemistry to meet the challenges outlined above to establish a good field-applied coating technology for pipeline rehabilitation. While there are many types of PU coatings available and already utilized in various conditions, today's PU coatings for pipeline applications refer only to the materials that are 100% solids and defined by ASTM Dl6 as Type V, two-package, liquid, polyiso-cyanate, polyol cured, urethane.[5]

This coatings technology has received attention from the pipeline industry for many reasons.

First, 100% solids polyurethanes have excellent handling and safety attributes. They are safer and more environmentally friendly than traditional anti-corrosion coatings. They contain no solvents, VOCs, styrene, amine, tar, or other carcinogens. They are generally not affected by scrutiny from the US Environmental Protection Agency, Occupational Safety and Health Administration and the Department of Transportation scrutiny over the health and safety hazards associated with other polymer systems.

Secondly, because of the rapid curing speed of these coatings, the coated pipe section and joints can be holiday tested and buried within hours.

Thirdly, many 100% solids polyurethanes have a cold-temperature-curing ability, making it possible to apply the coating at ambient temperatures as low as -40 C. and retain their performance characteristics, which is impossible for other types of coatings.

Finally, no heat is required during application to ensure the polyurethanes will cure, and the coatings can be applied to almost any thickness on any diameter or length of pipe.

PERFORMANCE OF REHAB COATING UNDER LAB CONDITIONS

Table 4

	Coal-tar epoxy	100% solids epoxy	Elastomeric polyurethane	Rigid and aromatic polyurethane	Fusion-bonded epoxy
Average coating film thickness	20 mils	27 mils	53 mils	30 mils	18 mils
Adhesion to steel ASTM D4541	750 psi	1,850 psi	1,000 psi	2000 psi	1,650 psi
Abrasion resistance ASTM D4060, CS17, 1 kg, 1000 cycles	160 mg loss	135 mg loss	40 mg loss	80 mg loss	120 mg loss 35 mg loss (ceramic version)
	160 mg loss	135 mg loss	40 mg loss	80 mg loss	
Flexibility ASTM D522	Failed at 180° 1 -in. mandrel	Failed at 180° 1-in. mandrel	Pass at 180° over 1-in. mandrel	Pass at 180° over 1-in. mandrel	Failed at 180° 1-in. mandrel
Elongation ASTM D638	3.2%	2.8%	59%	4.8%	4.8%
Cathodic disbondment CSA245.20M (-3.5 v, 48 hr)	17.5 mm radius	6.0 mm radius	10.0 mm radius	4.0 mm radius	8.0 mm radius
Dielectric strength ASTM G149	5.1 kv @20 mils 255 v/mil	7.1 kv @27 mils 263 v/mil	31.0 kv @53 mils 585 v/mil	22.4 kv @40 mils 568 v/mil	20.7 kv @18 mils 1,150 v/mil
Hardness ASTM D2240	65 Shore D	82 Shore D	68 Shore D @75 F.	72 Shore D @75 F.	85 Shore D @75 F.
Impact resistance ASTM G14	28 in.-lb	29 in.-lb	76 in.-lb	50 in.-lb	160 in.-lb
Penetration resistance ASTM G17	13%	NIL	6.6%	5.0%	NIL
Stability (wet) ASTM D870	-30 -120 F.	-30 -120 F.	-30 -1 50 F.	-40 -150 F.	-100 -230 F.
Water absorption ASTM D570	1.2%	2.0%	2.0%	1.4%	0.83%
Water vapor permeability ASTM D1653	12 g/sq m /24hr	3.8 g/sq m /24hr	37 g/sq m /24hr	12 g/sq m /24hr	7.5 g/sq m /24hr
Volume resistivity ASTM D257	$3.5x10^{14}$ ohm. cm	$8.6x10^{14}$ ohm. cm	$2.6x10^{14}$ ohm. cm	$5.8x10^{15}$ ohm. cm	$1.3x10^{15}$ ohm. cm
Salt spray ASTM B117, 2,000 hr	<3/8 in. undercutting	<3/8 in. undercutting	Pass	Pass	Pass
Chemical resistance CSA245.20M (10% HCl, 10% NaOH, 5% NaCl)	Pass	Pass	Pass	Pass	Pass

LABORATORY PERFORMANCE PROPERTIES*

Table 6

Properties	Mix-and-apply aliphatic polyurethane*
Application temperature	0-50° C. (32-120° F.)
Initial setting time @ 20° C./70° F.	1 hr
Curing time before handling @ 20° C./70° F.	4 hr
solids content by volume	72%
Adhesion direct-to-steel (ASTM D4541)	1,000 psi
Hardness (ASTM D2240)	50 Shore D
Impact resistance (ASTM G14)	80 in.-16
Abrasion resistance (ASTM D4060, Taber CS17 wheels, 1 kg 1,000 cycles)	60 mg loss
Initial gloss 60° & gloss retention (ASTM G154, 5,000 hr QUV 313B)	86 (initial) 92 (retention)
Chemical resistance after 96 hr immersion exposure	No color change, slightly softened in 10% H_2SO_4 & 25% NaOH

*1:4 plural component, 70% solids, rigid, aliphatic PU coating for aboveground pipeline rehabilitation.

Most field-applied PU coatings used for pipeline rehabilitation applications, however, have been traditionally based on 100% solids elastomeric PU chemistry, with or without coal tar or petroleum tar.

The major advantages of 100% solids elastomeric PU coatings are their flexibility and elongation properties, impact resistance, and abrasion resistance. The major disadvantages are that they are relatively low in alkali and solvent-resistance, low in adhesion to substrate or existing plant-applied pipeline coatings, low in Cathodic disbondment resistance, low in dielectric strength, low in high-temperature resistance, but high in moisture and water absorption and permeability.

In addition to these performance issues, many elastomeric PU coatings used in pipeline rehabilitation often come with a high mixing ratio (4.5:1, for example) as well as unbalanced high viscosity of the components.

These formulating weaknesses make the coatings difficult to apply and many coating film defects are associated with application error.

The past 10 years have seen a movement in North America towards development and use of high-performance 100% solids rigid (or structural) PU coatings for corrosion protection of all three pipe substrates: steel, ductile iron, and concrete.

Differing from the linear polymeric structures of a 100% solids elastomeric PU or polyurea system, a 100% solids rigid PU forms a three-dimensional, cross-linked structure, thus providing the coating film with superior resistance to chemicals, water penetration, Cathodic disbondment, and temperature extremes.

The finished product is structural in nature because it forms a strong polymeric solid film, similar in feel and appearance to the casing on a laptop computer, and has structural rigidity.

In North America, 100% solids rigid PU coatings were first developed in the early 1970s specifically for underground storage tanks. In 1975, Underwriters Laboratories of Canada issued the first listing for cathodically protected steel tanks with a rigid PU coating system. In 1981, the same technology was approved for use in the STI-P3 tank by the Steel Tank Institute.

By the late 1980s, 100% solids rigid or structural PU technology had almost completely replaced coal-tar epoxy and other coatings technologies in the North American underground storage tank industry. By January of 1998, STI reported that more than 250,000 STI-P3 underground steel fuel storage tanks had been registered and installed in the US.

In addition, STI of Canada estimated that 100,000 steel tanks had been installed in Canada. In total, these tanks involved approximately 200 million sq ft of steel and more than 80% of the area was coated with 100% solids rigid PU coatings. The technology's performance has been nearly flawless, according to a 1993 report by a US-based risk-management consulting firm.[6]

A tank can be viewed as a pipe with two closed ends. If such an underground tank could be installed to eliminate corrosion, why not coat an underground pipe with that very same coatings technology?

This idea has resulted in the use of the 100% solids rigid coatings in pipelines. In water and wastewater transmission pipeline applications, the 100% solids structural PU coatings have been demonstrated to be by far the most successful protective coating systems used for both exterior and interior applications.[7]

AWWA C222 describes the material and application requirements of 100% solids rigid PU coatings for the interior and exterior of steel water pipe, fit-

FIELD TEST RESULTS AT COLD TEMPERATURES*

Table 7

Application and test date	Dec. 26, 2004
Testing location	Hong-Yuan salt field, No. 3 Section
Ambient temperature	Cloudy, application temperature: -15° C.
Field inspection	
Surface preparation	Sa 2.5, angular profile: 40-60 m
Coating dry-to-touch time	1.5 min
Coating appearance	Smooth, glossy
DFT thickness	average 900-1,000 m based on 12 points
Adhesion testing (X cut)	Excellent, no disbondment difficult to cut
Holiday testing	Passed 12 kv holiday testing

*Of the 100% solids rigid, aromatic PU coating.

FIELD TEST RESULTS IN SUMMER*

Table 8

Application and test date	Apr. 11, 2001
Testing location	Cang-Lang river crossing
Ambient temperature	Sunny, application temperature: 30° C.
Field inspection	
Surface preparation	Sa 2.5, angular profile: 40-60 m
Coating dry-to-touch time	40 sec
Coating appearance	Smooth, glossy
DFT thickness	average 900-1,000 m based on 24 points
Adhesion testing (X cut)	Excellent, no disbondment difficult to cut
Holiday testing	Passed 10-kv holiday testing

*Of the 100% solids rigid, aromatic PU coating.

tings, and special sections.[8] Currently, NACE Task Group (TG) 281, administered by NACE Specific Technology Group 03, is developing a NACE standard recommended practice for the use of PU coatings for field repair, rehabilitation, and girth weld joints on pipelines. This standard applies to underground steel pipelines in the oil and gas gathering, distribution, and transmission industries.

Partnership

Since 1998, PetroChina Tianjin Dagang Oilfield and Madison Chemical Industries Inc., Canada, have joined to develop advanced pipeline rehabilitation coatings for the Chinese oil and gas pipeline industry, based on the 100% solids rigid and structural PU chemistry.

One of the projects is to develop and utilize a sprayable, aromatic 100% solids rigid and structural PU coating for the Chinese oil and gas pipeline industry to resolve its long-term search for a coating system that can not only provide high performance for field oil and gas pipeline rehabilitation but also be applied during winter in Northern China.

The sprayable, aromatic PU resin version involves various formulations that have a 1:1 mixing ratio with balanced viscosities between the two reactive components: Part A-polyisocyanate rich component and Part B polyol rich component.

Relatively lower viscosity (70-1,000 cps at 70 F.) of both the components can be obtained by a skilled formulator. This enables easier metering of the components, requiring less in-line heating and offering better atomization for spray. Special setting times are often made in order to meet the manual spray application needs in-field as well as the need for faster back to service times.

The plural component material is transferred from the containers to a plural component airless pump, heated as it moves through the in-line heaters, and then applied with a plural component spray gun or, for slower setting formulations, through a whip hose and then the gun. The gun and hoses are held by the sprayer and the coating is applied to the required thickness in a one coat multi-pass operation.

Depending on its setting-time design and pipe-surface temperature, the coating material can set up over the ditch within minutes. The pipeline can be holiday tested and brought back into service within hours.

Table 2 highlights the product handling and safety characteristics of the 100% solids rigid sprayable, aromatic PU resin version, together with some other typical liquid-applied field coatings that are used today in the market for pipeline rehabilitation. Examples of these typical coatings include a coal-tar epoxy, a 100% solids epoxy and a 100% solids elastomeric, aromatic PU, and an FBE coating.

As to the field rehabilitation application, both 100% solids elastomeric PU and 100% solids rigid PU have their own limitations.

First, the economics of applying the spray-applied coating must be favorable to substantiate the cost of transporting and operating a plural-component spray system to the site. Secondly, since the polyurethanes are a liquid spray system, precautions must be taken in heavily traveled and built up areas to ensure that buildings are not hit by overspray or people are not exposed to any health risk. This, of course, is true for all the spray-applied coatings systems including liquid epoxies.

Finally, again due to the use of a plural-component spray system, the spray application process can be very sophisticated, and therefore the coating personnel must be experienced and trained to ensure that the proper procedures are being followed at all times.

Table 3 outlines the field application and repair attributes of the 100% solids, rigid, aromatic PU technology, compared with other rehabilitation coating systems.

Performance properties of the advanced 100% solids rigid sprayable, rigid, aromatic PU resin version were determined in-house and through independent laboratories on samples prepared under laboratory conditions.[9~12] Tests were conducted on pipe samples on which the coatings had been applied over surfaces prepared according to manufacturers' specifications.

Test results of these performance properties were obtained and compiled with the results of tests performed by independent laboratories on other coatings systems. Table 4 lists the typical testing results of these performance properties.

The test results shown in Table 4 suggest that the 100% solids rigid, aromatic PU coatings outperform liquid-applied epoxies and the 100% solids elastomeric PU, with properties compa-

PERFORMANCE DURING THE DAGANG-CANGZHOU REHABILITATION PROJECT* Table. 9

Properties	Results	Testing standard
Appearance	Smooth, glossy, no visual defects	Visual examination
Curing time, surface dry	40 sec	ASTM D1640-95
Curing time, complete dry	4 min	ASTM D1640-95
Cathodic disbondment (48 hr)	4.0 mm	CAN/CSA245.20M 98
Adhesion	Rating 1	CAN/CSA245.20M 98
Hardness	Shore D 65	GB/T 1720-89
Abrasion (1 kg/1,000 cycles)	60-mg weight loss	ASTM D4060-95
Bendability	Pass with 13 mm diameter mandrel	ASTM D522-93
Water permeability	4.08 mg/sq cm; 24 hr	ASTM E96-95
Chemical resistance	No effect after exposure to 10% HCl, 10% NaOH, and 5% NaCl, at room temperature for 30 days	CAN/CSA245.20M 98
Impact resistance	10 J.	ASTM D2794-93
Salt spray testing	No effect after 1,000 hr exposure	ASTM B117-97
Cycling (30 times)	Passed	-40 to 70 C.
Heat resistance	No effect after 500 hr at 100°C.	GB/T 1735-89
Dielectric strength	22.5 mv/m	ASTM D149-95
Volume resistivity	$5.8 \times 10^{13}\ \Omega.m$	ASTM D257-93
QUV UV resistance on the high solids aliphatic polyurethane coating	Rating 1 after 500 hr of UV exposure	ASTM G53-95

*For the PU coating system on field samples.

rable to those of the typical FBE system

Additional tests evaluated the compatibility of the 100% solids rigid, aromatic PU system with various pipe samples coated with the plant-applied mainline FBE or polyethylene. Two sets of samples were produced.

The testing set of samples was made by spraying the 100% solids rigid, aromatic PU coating onto a 2 month-old FBE and three-layer PU-coated pipe section. A brush blast was employed. Adhesion tests (ASTM D4541) and cathodic-disbondment tests (CSA245.20M, -1.5 v, 80   C, 72 hr) were then conducted on the multi-coated samples, with results shown in Table 5.

For aboveground application, high solids or 100% solids, aliphatic PU coatings technologies were also developed in order to provide UV stability. An example is a 1:4 plural component, mix-and-apply, 70 % solids, fast chemically-cure, UV and color stable, direct-to-metal, aliphatic PU

The mix-and-apply PU is applied with a single component spray gun. Because it involves premixing two ingredients before application, the per-coat film build is higher. The pot life of the PU is about 2 hr, and the coating has an initial cure time of about 1 hr

A 1:1 plural component, 100% solids, aliphatic PU has also been developed and is under field testing for pipeline rehabilitation applications. Table 6 outlines some properties of the 1:4 plural component, mix-and-apply, high solids, direct-to-metal, aliphatic PU

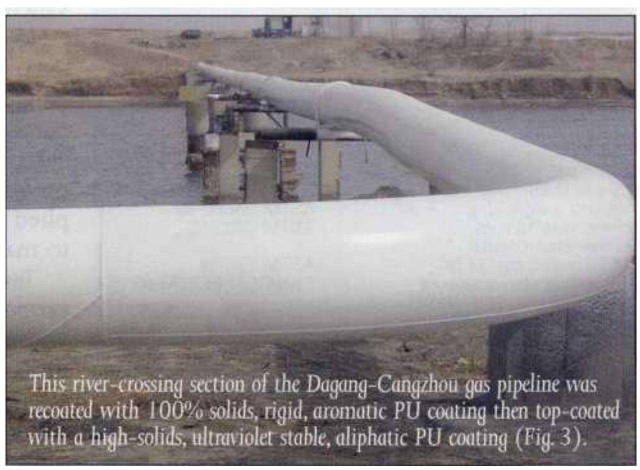
Dagang-Cangzhou rehab

One of the main pipelines that supply natural gas to northeastern Chinese cities is the 62-mile, 21-in. OD Dagang-Cangzhou gas pipeline, installed in 1973 and originally protected by a petroleum asphalt enamel coating.

Since installation, the pipeline has faced severe corrosion problems, despite numerous rehabilitation efforts. In 2001, PetroChina Dagang Oilfield Natural Gas Co. decided to refurbish the entire pipeline. A 100% solids, rigid and structural aromatic PU coating technology was selected for a river crossing and some underground and aboveground portions.

Coated and uncoated pipe are compared after 5 min of polyurethane coating application at −15° C. (9° F; Fig. 1).

The 100% solids, rigid, aromatic polyurethane coating is applied for a river crossing atop an iced river (Fig. 2).



This river-crossing section of the Dagang-Cangzhou gas pipeline was recoated with 100% solids, rigid, aromatic PU coating then top-coated with a high-solids, ultraviolet stable, aliphatic PU coating (Fig. 3).

For the river crossing and aboveground pipe segments, a thin film (3-5 mils, or 75-125 (μ) of a 1:4 mixing ratio, high solids, aliphatic PU, was applied over the 100% solids aromatic PU coating for protection against UV light. The total application coating film thickness ranged from 35 to 40 mils (850 to 1,000 (μ).

Application of the Madison's PU coating took place between November 2001 and May 2002, with field application temperature ranging from 5癒. to 86   F. (-15   °C to 30   °C). Extensive tests on lab and field samples were then conducted. In November 2001, PetroChina Dagang Oilfield formed a special technical committee and officially appraised the rehabilitation project based on both testing results and field performance (Figs. 1, 2, and 3).

Before the coating application, the pipe section to be coated was surface cleaned to remove contaminations such as oil and dirt and then abrasive blasted with medium grade coal slag abrasives to a near-white metal blasting (SSPC-SP 10 / Sa 2.5) with a surface profile of 40-60 (μ). Coating application was done within 4 hr of blasting.

The field inspection included two elements: in situ adhesion and holiday inspection and field sample preparation for third-party lab testing. At -15°C, the field-applied coating cured in about 5 min. Adhesion and holiday testing occurred within 60 min of the coating application and revealed that at that time the coating breakdown testing voltage already reached 12 kv (more than 342 v/mil).The field-coated samples were packed and sealed on site then sent immediately to the Pipeline Coating Testing Centre of the Research Institute of Engineering Technology of China National Petroleum Corp.

Tables 7 and 8 show typical field inspection results of the rehabilitation using the PU coatings at cold and hot ambient temperatures.

Table 9 shows results of testing on the field samples.

Results of both field inspection and lab evaluation showed that the properties of the 100% solids rigid PU coating outperformed all liquid-applied epoxy systems used in China and exceeded or matched the performance of fusion bonded epoxy coating. ♦

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