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HIGH TEMPERATURE INSULATED COATING AND CONSTRUCTION METHODOLOGY FOR THE MACKAY RIVER PIPELINE

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ABSTRACT

Continued development of the oilsands in the Fort McMurray area of Alberta lead to a need for the MacKay River Pipeline. This heavy oil pipeline provides long-term, cost-effective transportation for production from the MacKay River area. The pipeline is designed to transport bitumen with little or no dilution (dry bitumen). In order to operate without diluent, the bitumen must be heated. Heat must be retained using a continuous layer of insulation, which ensures that viscosity remains low. The high operating temperature and the environment, through which the pipeline passes, were major challenges encountered during the design and construction phases. This paper focuses on the design, selection criteria, and testing of the coating system and discusses the important aspects of construction.

INTRODUCTION

The MacKay River Pipeline is a 323.9 mm O.D. (NPS 12) insulated bitumen pipeline designed to move dry bitumen from the Petro-Canada MacKay River Production Facility to the Enbridge Athabasca Terminal, a distance of approximately 35 km (22 miles). At the Athabasca terminal the bitumen will be blended and transported on the Athabasca Pipeline to Hardisty, Alberta. The design capacity of the MacKay River pipeline system is 7,000 m^3/day (44,000 bpd).

Environmental and operating conditions of the pipeline posed substantial challenges for selecting a coating system. An operating temperature of 120°C (248°F) with the possibility of short excursions up to 130°C (266°F) and a design life of 30 years substantially limited the range of feasible coating materials. From an operational standpoint, it was necessary to design the coating system so sufficient heat would be retained to enable the pipeline to be shutdown for two days and restarted while pumping an unblended product. The right-of-way, composed of segments of clay and wet (muskeg) terrain, imposed further design constraints upon the coating system. Coating material testing began in October 2000. Pipe coating began in July 2001. Construction began in September 2001 and was completed by mid October 2001. Pipeline operation is expected to begin by late October 2002 once production begins.

COATING SELECTION

Operational requirements and the environment were key factors influencing the final design of the coating system. Thermal insulation was necessary to meet the heat retention requirement in order to maintain the pumpability of dry bitumen even after a two-day shutdown. Because polyurethane foam has relatively low mechanical strength, an external jacket was essential. The outer jacket had to be robust and water-resistant to withstand the demands placed on it by the environment, composed of clay soil, muskeg, and directional drill sections. The possibility of a failure of the shop-applied coating or the field-applied joint coating drove the requirement that the anti-corrosion barrier be suited to immersion service at elevated temperatures. All factors considered, an insulated three-layer coating system was selected.

Historically, there have been similar insulated three-layer coating systems in service around the world used to transport fuel oils, sulphur, and sour gas. In Europe, district heating systems using an insulated three-layer coating system are not uncommon. Insulated coating systems are available for on-shore and sub-sea pipeline applications. The operating temperatures of most insulated pipelines in North America are below 110°C (230°F).

There were relatively few options for the anti-corrosion layer, given that it must be able to withstand immersion conditions up to 130°C (266°F). Three-layer polyolefin coating systems, one of the most robust coatings available for immersion service, consist of fusion bond epoxy (FBE) primer, adhesive, and extruded polyolefin (Coating System B of CSA Z245.21-98). Typically, these systems are limited to operating temperatures below 85°C (185°F) for polyethylene (PE) and 110°C (230°F) for polypropylene (PP), though some PP systems are rated considerably higher. PE tapes have been used for insulated pipelines operating up to 95°C (203°F). Common high temperature FBE coatings are designed for use as a primer coat in multi-layer coating systems and are rated for high operating temperatures in dry conditions only. A stand-alone, high temperature FBE coating, which had just become commercially available, was utilized as the anti-corrosion layer of choice for the MacKay River Pipeline.

A spray-applied polyurethane foam based on a European District Heating approved product was selected as the insulation for the MacKay River Pipeline. This foam has a well-documented service history at high temperatures similar to project requirements. The foam system used on the European District Heating systems is mold injected. Foam insulation is normally spray-applied in North America; thus some modification of the foam was necessary to speed up the curing process. The foam thickness and thermal conductivity were selected to meet the operational requirement for an unblended shutdown window of two days. This insulation thickness corresponded to an outer jacket temperature of 60°C (140°F).

Extruded PE is a relatively low cost material, which has excellent properties including water resistance, toughness, impact resistance, and strength. As a result, extruded PE has become an industry standard for protecting foam insulation. Outer jackets are composed of extruded PE, with the option of a PE tape innerwrap between the foam insulation and extruded PE. The PE tape tends to improve the impact and handling resistance of the outer jacket. The PE tape is joined to the extruded PE outer jacket with an adhesive layer or by way of heat fusion. A range of PE types are available for extrusion from low density PE to high density PE (HDPE). HDPE has the highest tensile strength and hardness of all extruded PE coatings. HDPE is the material of choice except for winter construction where the temperature may dip below –30°C (-22°F) at which point the impact resistance and elongation at break decrease significantly. At ambient temperatures of –40°C (-40°F) HDPE may crack when subjected to moderate impacts or pipe movement. Low or medium density PE is recommended for winter construction. [1] Since the MacKay River Pipeline was scheduled for late summer/ early fall construction an outer jacket consisting of a PE tape innerwrap heat fused to extruded HDPE was chosen.

Shop-applied Coating:

Based on a review of existing insulated three-layer coating systems and consultation with a third-party consultant, a base coating system was proposed for the shop- and field-applied application. Qualification and quality assurance tests were defined for each of the three layers as well as the overall, composite system. Specific coating materials were then selected in cooperation with two coating applicators. The following system was proposed:

1. Anti-corrosion coating: 350 µm (14 mil) nom. FBE
2. Insulation: 50 mm (2 in.) min. polyurethane foam
3. Outer jacket: 2.5 mm (100 mil) min.
   (directional drill: 3.8 mm (150 mil))

Figures 1 and 2 below illustrate the shop-applied coating.

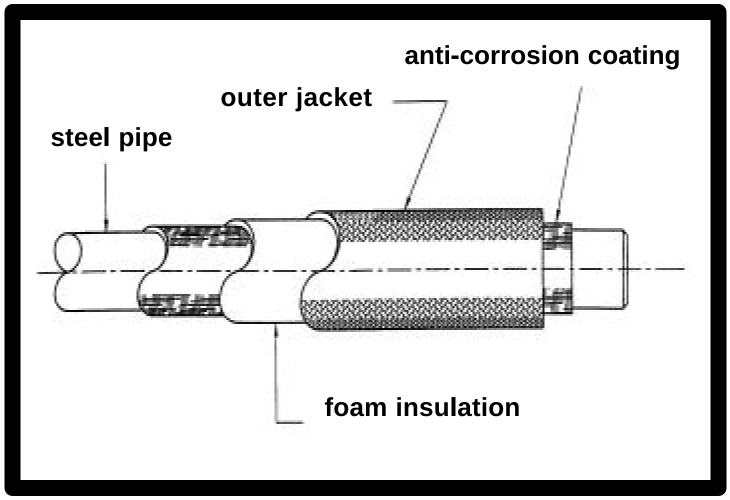

Figure 1: Shop-applied Coating

Figure 2: Shop-applied Coating

Shop-applied Coating Qualification:

Once coating materials were selected the two applicators prepared and tested lab panels. The qualification tests and corresponding acceptance criteria for the various coating layers are provided in Tables 1 to 3.

Table 1: Anti-Corrosion Coating Qualification Tests

Qualification Test Standard	Test Method	Acceptance Criteria
Cathodic Disbondment CSA Z245.20	1.5V, 23ºC, 28 day 1.5V, 95ºC, 28 day 1.5V, 95ºC, 56 day	< 10 mm < 18 mm < 25 mm
Adhesion CSA Z245.20	95ºC, 24 hr. 95ºC, 28 day	rating 1-2 rating 2
Thermal Oxidative Aging bent 2.5º/ p.d. then oven aged	120ºC, aged 28 day 120ºC, aged 56 day	no cracks no cracks
Impact Resistance CSA Z245.20	-30ºC, 1.5J	no holidays
Flexibility modified CSA Z245.20 -30ºC, 2.0º/ p.d.	new 120ºC, aged 28 day 120ºC, aged 56 day	no cracks no cracks no cracks
Thermal Char. CSA Z245.20	Tg determination	> 130ºC

Table 2: Thermal Insulation Qualification Tests

Qualification Test Standard	Test Method	Acceptance Criteria
Core Density EN 253	new	50 - 70 kg/m^3
Compressive Strength ASTM D1621 oven aged	new 120ºC, aged 28 day 120ºC, aged 56 day	350 - 475 kPa < 10% increase < 10% increase
Thermal Conductivity **(K Factor)** ASTM C518 oven aged	new 120ºC, aged 28 day 120ºC, aged 56 day	< 0.027 W/m^{o}C < 0.027 W/m^{o}C < 0.027 W/m^{o}C
Closed Cell Content ASTM D2856 oven aged	new 120ºC, aged 28 day 120ºC, aged 56 day	> 90% > 90% > 90%
Water Absorption EN 253	90 min. boiling water	< 2% wt. gain
Thermal Characteritics TGA: 250^{o}C, 1^{o}C/min.	Tg determination TGA analysis	> 140ºC > 85% wt. retention

Note:

- minimum compressive strength of foam to exceed full load to be transferred from the pipe to the soil;
- minimum thermal conductivity shall ensure that the outer jacket temperature does not exceed 60^{o}C (140^{o}F)

Table 3: Outer Jacket Qualification Tests

Layer 1: PE tape

Layer 2: Adhesive (optional - may be substituted with heat fusing)

Layer 3: Jacket (extruded PE)

Qualification Test Standard	Test Method	Acceptance Criteria
Adhesive Layer ASTM E28	ring and ball softening	> 80ºC
Tensile Strength ASTM D638	23ºC	> 17.0 MPa
Elongation at Break ASTM D638	23ºC -30ºC	> 500% > 50%
Flexibility CSA Z245.21	-30ºC	no cracking
Adhesion (Tape to Foam) CSA Z245.21	peel strength at 23ºC	> foam strength
Adhesion (Tape to Jacket) CSA Z245.21	peel strength at 23ºC	> 19.6 N

Both coating systems proposed by each applicator were qualified on lab panels according to the requirements originally set out with select modifications. Test pipe was then coated by the two applicators during plant trials. Ring samples were taken from the production pipe and the qualification tests listed in Tables 1 to 3, inclusive were performed on each ring sample. In addition, the tests shown in Table 4 were performed on the composite coating system.

Table 4: Composite Coating Qualification Tests

Qualification Test Standard	Test Method	Acceptance Criteria
Impact Strength CSA Z245.21	23ºC -30ºC	3.0 J/ mm coating 3.0 J/ mm coating
Shear Resistance EN 253 (full scale test)	new 130ºC, aged 28 day 130ºC, aged 56 day	> 0.12 MPa > 0.12 MPa > 0.12 MPa
Flexibility (full scale field trial)	bend at -20ºC, 1.5^o/ p.d.	foam: crack < 5 mm deep outer jacket: no cracks
Cracked Insulation Fit for Service Test **-** fluid temp.: 120^{o}C - air temp.: 23^{o}C	temp. diff. between location with 3 mm wide crack and intact location	< 5ºC increase

The FBE was qualified based on modified CSA Z245.20-98 cathodic disbondment and adhesion tests at temperatures up to 95^{o}C (203^{o}F), not at the design temperatures of 130^{o}C (266^{o}F). The only way to perform the 130^{o}C (266^{o}F) tests would be in a pressurized container (autoclave) and the results would be difficult to interpret since there is little experience with this type of test and realism of the test could be questionable. In the case of an outer jacket failure, any moisture will be, in theory, driven out of the insulation covering the FBE at temperatures above 100^{o}C (212^{o}F), validating the 95^{o}C (203^{o}F) tests. A glass transition temperature in excess of 130^{o}C (266^{o}F) indicated that the coating is suited to operation under intended service temperatures.

Full-scale bend tests to up to of 1.5° per pipe diameter length, the maximum allowed by CSA Z662-99, were performed on production pipe coated by both applicators at temperatures below -25°C (-13°F). Examination of the field bent pipe revealed that the outer jacket was free of cracking, the foam insulation had not been crushed, the PE tape to extruded PE layer was intact, and the foam insulation remained bonded to the FBE. The foam experienced cracking during the bending of pipe coated by both applicators. Later fit-for-service testing was performed to check to see whether insulation cracks significantly increased the surface temperature. Results revealed only a modest temperature increase of less than 5°C (9°F) at the surface with a 3 mm wide cracking extending to the pipe surface when the pipe was heated to 115°C (239°F). Despite these results it was decided not to perform field bending of insulated pipe. Pipe to be bent in the field was delivered coated with FBE only. It was then bent, coated with foam by sequential foam injection, and then coated with a spray-applied polyurea coating.

Field Joint Coating:

Liquid epoxy (novalac epoxy resin) and FBE powder were considered for the anti-corrosion layer on field joints. The liquid epoxy had a number of advantages over the FBE powder including a lower preheat temperature, a simpler application procedure, and a lower cost.

Polyurethane foam insulation at the field joints may be installed by foam injection method or by use of pre-cut half shells. Half-shells require considerable time and manpower to cut the foam shells to fit each joint and there are gaps in the insulation layer. Besides increased sleeve temperature during operation, gaps allow a direct path for water to reach the anti-corrosion layer in the case of a field joint failure. The injection method is a process whereby polyurethane foam is injected into a mold mounted over the girth weld. Following injection, the foam subsequently expands to completely fill the void. This method was selected, because the foam bonds to the shop-applied foam forming a complete seal and the foam formulation is similar to the shop-applied version with comparable thermal conductivity and compressive strength.

A variety of heat shrink sleeves were considered for application over the field injected polyurethane foam. Initially, leak testable (casing) sleeves used in European District Heating systems, a proven technology, were assessed. A double-layer sleeve and conventional (wrap-around), single-layer sleeves were also considered. Each type of sleeve from various manufacturers was demonstrated and the final decision was to use a single-layer sleeve. The material costs, installation times, and complexity were considerably higher for double-layer and leak testable sleeves. The single-layer sleeve performance was considered adequate, though increased attention to training and inspection was important during installation.

The final field joint coating system was composed of the following:

1. Anti-corrosion coating: 500 µm (20 mil) min. liquid epoxy
2. Insulation: 50 mm (2 in.) min. polyurethane foam injected into molds
3. Outer jacket: heat shrink sleeve (directional drill: edge protector sleeve required on leading edge)

Field Joint Coating Qualification:

The manufacturer applied liquid epoxy to lab panels and an approved third-party lab performed the tests shown in Table 5.

Table 5: Liquid Epoxy Qualification Tests

Qualification Test Standard	**Test Method**	**Acceptance Criteria**
Cathodic Disbondment	1.5V, 95ºC, 7 day	< 18 mm
CSA Z245.20	1.5V, 95ºC, 14 day	< 18 mm
	1.5V, 95ºC, 28 day	< 18 mm
	1.5V, 95ºC, 56 day	< 25 mm
Adhesion	95ºC, 24 hr.	rating 1-2
CSA Z245.20	95ºC, 7 day	rating 1-2
	95ºC, 14 day	rating 1-2
	95ºC, 28 day	rating 1-2
Impact Resistance CSA Z245.20	-30ºC, 1.5J	no holidays
Flexibility	new	no cracks
modified CSA Z245.20	120ºC, aged 28 day	no cracks
25ºC, 2.5º/ p.d.	120ºC, aged 56 day	no cracks

The liquid epoxy met all acceptance criteria shown in Table 5 except the 2.5° flexibility requirements. Since field joint coatings are not bent in the field, lower levels of flexibility than the shop-applied coating are acceptable.

The formulation of the field-injected polyurethane foam was similar to the shop-/ spray-applied version, except that there was less catalyst, slowing the cure process. The foam could be poured into the mold and it flowed to the bottom of the mold before expanding to fill the cavity. Spray-applied foams are quicker reacting in order to prevent the foam from running off the pipe. The field-injected insulation underwent qualification testing in the manufacturer's lab as per the shop-applied foam qualification test requirements.

The heat shrink sleeves were assessed based on the following criteria:

- ease of installation;
- time of installation;
- effects of preheat on shop-applied coating;
- visual assessment of sleeve (noting adhesive flow at edges and lack of air entrapment);
- peel testing at overlap to PE and to polyurethane foam.

Acceptable modes of failure included a cohesive failure over the PE and the adhesive bond to foam exceeding foam strength.

COATING PROCESS

The FBE was applied in accordance with the requirements of CSA Z245.20-98. Immediately prior to FBE coating application, the pipe surface was abrasive blasted to SSPC-SP10/ NACE No. 2, near-white metal blast cleaning, treated with a phosphoric acid wash, rinsed, dried, and heated with a combination of induction coils and a propane-fired oven. Following FBE application it was quenched and inspected for holidays. Holidays (coating damage or defects) were repaired with the approved field joint liquid epoxy. The pipe was then temporarily stockpiled in the yard. Prior to application of the foam insulation and the outer jacket, the FBE was again holiday tested for any discontinuities. Pipes with defects were set aside and repaired. Pipe free of holidays was cleaned of any foreign matter that would be deleterious to the adhesion of the foam to the FBE. The pipe was preheated with an induction coil and then the coating flame oxidized to ensure adhesion of foam to FBE. The polyurethane foam insulation was sprayed onto the pipe. As the foam cured, it was wrapped with PE tape, and then PE was extruded over the tape. The bond between the PE tape and extruded PE was achieved by heat fusion. The pipe was quenched and the foam cutback area was holiday inspected and repaired as necessary.

A number of quality assurance (QA) tests were performed throughout production. The QA tests performed on each layer are described in Table 6.

PIPE STORAGE AND HANDLING

The pipe was coated in two steps. First, the pipe was coated with FBE then stockpiled. Subsequently the pipe was coated with insulation and an outer jacket. In order to minimize the number of FBE repairs, numerous precautionary measures were undertaken in handling the pipe. Once the pipe was completely coated, pipe ends were covered with plastic bags to protect the exposed insulation from the elements and to maintain internal cleanliness of the pipe. Pipe was then transported to the stockpile using a loader with wide, padded forks to avoid damage to the coating (i.e. crushing). The pipe was stacked four tiers high on sawdust filled bags.

The pipe was transported from the applicator's facility to the site by trucks. A crane was used to load pipe onto truck trailers, which were stacked no more than four tiers high. Short joints were placed on the top two tiers. During transport the front end of each load was tarped to ensure that the end bags survived the journey.

Table 6: Quality Assurance Tests

Coating Layer	Qualification Test Standard	Test Method	Acceptance Criteria	Frequency
Anti-Corrosion Coating	**Thickness** CSA Z245.20		> 300 microns	3/ pipe length
	Cathodic Disbondment CSA Z245.20	1.5V, 95ºC, 48 hr	< 14 mm	once/ 12 hr. production
	Adhesion CSA Z245.20	95ºC, 24 hr.	rating 1-2	
	Flexibility CSA Z245.20 -30ºC, 2.0º/ p.d.	new	no cracks	
Thermal Insulation	**Thickness** CSA Z245.20	manufacturer's spec.	50 - 60.3 mm	3/ pipe length
	Core Density EN 253	new	50 - 70 kg/m3	once/ 4 hr. production
	Compressive Strength ASTM D1621	new	350 - 475 kPa	once/ 4 hr. production
Outer Jacket	**Thickness** Layer 1: PE Tape Layer 2: Adhesive (Optional) Layer 3: PE Jacket (Standard Pipe) Layer 3: PE Jacket (Directional Drill Pipe) Combined Total (Standard Pipe) Combined Total (Directional Drill Pipe)	manufacturer's spec.	0.5 - 1.0 mm - 1.5 - 2.0 mm 2.8 - 3.3 mm 2.54 mm min. 3.80 mm min.	2/ pipe length
	Adhesive Layer ASTM E28	ring and ball softening	> 80ºC	once/ adhesive batch
	Tensile Strength ASTM D638	23ºC	> 17.0 Mpa	once/ 12 hr. production
	Elongation at Break ASTM D638	23ºC	> 500%	once/ 12 hr. production

CONSTRUCTION

The field application of a three-layer coating system is quite involved. To ensure that field joint coating proceeds smoothly, it is important that the prospective contractors understand the entire scope of work, the properties of all coating materials, and overall job complexity during the bid stage. Once the contract has been awarded, a pre-job meeting, where the contractor demonstrates the field joint application on a number of girth welds, is also recommended. The pre-job meeting makes certain that all installation details have been worked out improving the chances of a successful job from the perspective of both the contractor and the owner. Field training, provided by the manufacturers of each coating layer, is indispensable.

Pipeline construction on the MacKay River Pipeline began in mid September and was nearly completed by mid October 2001. Field training was provided at the beginning of construction. Each worker involved in the field coating process was trained and certified by the coating manufacturers. Only workers with certification were allowed to apply the field joint coating.

The steps in the field joint coating process consist of:

- preheating the girth weld to remove moisture with an induction heater or propane method;
- abrasive blasting the girth weld area to SSPC-SP10/ NACE No. 2, near-white metal blast cleaning, and check surface profile;
- preheating of the girth weld using an induction coil to an appropriate preheat temperature;
- applying liquid epoxy and allowing to cure;
- holiday detection and repair as necessary;
- foam injection and allowing to cure;
- abrading the PE overlap;
- preheating the PE overlap with propane torches;
- applying shrink sleeve according to manufacturer's instructions.

Welders were required to use pads to protect the FBE from damage caused by weld spatter as this can be problematic to repair especially if damage is adjacent to the polyurethane foam. Welders were encouraged to protect the polyurethane foam during preheating and welding to avoid igniting the polyurethane foam.

The width of heating device used to preheat the girth weld area should be considered when determining the length of the polyurethane foam cutback. If the exposed girth weld area is shorter than the width of standard heating equipment, specially designed heating devices may have to be constructed or an alternate heating system used. Induction coils and catalytic heaters offer a number of advantages over a propane torch. Benefits include elimination of damage (charring) to the polyurethane foam and FBE, prevention of contamination of the substrate prior to liquid epoxy application, reduction of flash rusting; and ensuring that the pipe preheat temperature is evenly distributed around the pipe circumference.

On the MacKay River Pipeline project, the foam cutback was specified as 175 mm (7 in.) nominal, which did not provide enough space for standard induction coils or catalytic heaters. As such, the following procedure was used for field-coating application: preheat the girth weld with propane torches; abrasive blast to SSPC-SP10/ NACE No. 2, near-white metal blast cleaning; reheat the girth weld with propane torches due to rapid cooling of the steel; brush blast the girth weld to remove contaminants and flash rusting caused by reheating; brush off the girth weld; and apply the liquid epoxy. This procedure was less than ideal since the abrasive blasting and coating operation were never more than one joint apart. In order to achieve reasonable liquid epoxy cure times it was important that the steel be hot, but not so high as to damage the coating or cause vaporization of harmful vapours. Pipe adjacent to the girth weld acted as massive heat sinks cooling the girth weld area and leading to extended epoxy cure times. In order to improve the process, entire welded sections of pipe were preheated by blowing hot air in one end.

The injection of foam into the molds proved relatively trouble free. Once the liquid epoxy had cured and was holiday free, steel molds were mounted over the girth weld. If moisture was present on the girth weld, it was wiped dry as isocyanate in foam reacts with water. The polyurethane foam was injected into the mold by timing or counting the number of pump strokes. The steel molds were treated with a silicone-based release agent. The amount of release agent used was minimized as any residue adversely affects adhesion of the shrink sleeve to the PE overlap and polyurethane foam.

Once the foam insulation had cooled the mold was removed and the insulation was inspected for defects prior to heat shrink sleeve installation. The PE overlap was abraded to improve sleeve adhesion and to remove all traces of foam adhering to the PE. The PE overlap area was preheated to the minimum preheat temperature recommended by the sleeve manufacturer. Heating of the polyurethane foam was minimized to avoid damaging and reduce off gassing of the polyurethane foam. Adequate and even preheating of the PE overlap area was critical to ensure that the hot-melt adhesive used on the sleeve was activated. The sleeve was installed with a minimum overlap of 75 mm (3 in.). Sufficient rolling during the sleeve application was required to ensure all entrapped gases were removed.

Drill sections over 500m (1640 ft) in length were required to cross major waterways and several roads. Edge protectors were applied to the leading edge of all shrink sleeves to lower the risk of sleeve damage. The diameter of the drill bore was oversized to lessen the possibility of damage. All directional drills were deemed successful as the coating on the lead joints pulled beyond the exit was in good condition and resistance-to-ground measurements taken at each crossing revealed high resistance.

Valves and fabricated bends were coated in the shop with the liquid epoxy approved for girth welds by plural-component spray application. Above ground portions of the valves were painted with an epoxy phenolic paint. These items were coated in the field with polyurethane foam using a sequential injection molding process and were subsequently coated with a spray-applied polyurea coating.

Repairs to the outer jacket and heat shrink sleeves were dependent upon the size of the defect. The PE outer jacket was abraded prior to applying the repair material. Repairs under 50 mm x 50 mm (2 in. x 2 in.) were repaired using a PE repair patches, ensuring an minimum overlap of 75 mm (3 in.). Heat shrink sleeves were used to repair any larger defects. Prior to lowering the pipe in the ditch the outer jacket was carefully inspected for damage and repaired as required.

CATHODIC PROTECTION

Mainline and station piping will be protected with cathodic protection (CP) using impressed current upon completion. Studies have shown that the PE outer jacket and insulation may limit the effectiveness of CP systems. PE is known to shield CP under certain conditions not to mention a large ohmic drop is experienced across polyurethane foam insulation. The CP system will provide protection in damaged areas where the CP current is not shielded. Where the CP current is shielded, the anti-corrosion layer is designed to protect the pipeline.

Qualified CP inspectors were selected to evaluate coating condition at directional drill sites, install CP test facilities, and collect information for the CP system final design and installation. Their inspection duties included the following:

- collection of soil resistivity data and a description of the topography in the area;
- installation of CP test stations including a final pipe-to-soil check after backfill;
- recording the resistance-to-ground of pipe sections where directional drilling and/or slip-bore techniques were used to install pipe under roadways and rivers;
- completion of preliminary current requirement testing at possible impressed current (rectifier, groundbed) sites for use in final design;
- assessment of the effects of high voltage alternating current (HVAC) interference.

The final CP design will cover the cathodic protection system size and location, HVAC testing and mitigation, foreign crossing testing and mitigation, equipment installation, a static and energized survey, and a final report.

OPERATION

A comprehensive integrity management plan is in place to ensure that safe operation and integrity of the pipeline is maintained from start up to deactivation of the line. The plan includes monthly CP system maintenance inspection and annual survey. The pipeline will be internally inspected within 10 years of installation. Based on operation, the coating integrity, and the internal inspection results an appropriate internal inspection interval will be established and continually adjusted throughout the life of the pipeline.

CONCLUSION

An innovative coating system was developed to meet the demanding requirements for transport of dry bitumen. The coating system was developed in close cooperation with consultants, coating applicators, material manufacturers, and suppliers. The material selection process took into consideration: the pipeline operational requirements; operating temperatures up to 130°C (266°F); environmental conditions composed in part of muskeg; coating application process in shop and field; reparability; and material costs. An assessment of existing material testing procedures was performed and a number of standard qualification tests were modified to qualify coating materials. A robust, cost-effective coating system was selected. While historical performance information is not yet available, it is expected that long-term monitoring will validate the design and application of the insulated three-layer coating system used on the MacKay River Pipeline.

ACKNOWLEDGMENTS

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