Abstract:
This paper will address the history and use of Polyethylene (PE) tapes as an anti-corrosion coating system and its evolution into the multiple industry segments within the Pipeline coating corrosion industry. This paper will also address other types of corrosion coatings used in the oil, gas and water industries, as well as application methods of pipe coating and pipeline construction techniques used in the Pipeline construction industry.

Overview:
The use of PE tapes has been used since 1953 to the present and has been used globally in the oil, gas, and water industries with proven success. The utilization of PE tapes to prevent corrosion of oil, gas and water steel pipe will be presented from the past to current day relative to industry standards, National Association of Corrosion Engineers (NACE) and American Water Works Association (AWWA) and application techniques. New developments in PE tapes coating systems will be discussed and their specific applications in the pipeline corrosion coating industry will be highlighted in terms of use and in-field application to demonstrate its proven performance. Alternate anti-corrosion coatings will be reviewed in terms of application methodologies and highlights of these other coatings used in pipeline construction. Additionally, a discussion of applicable standards and field performance will be addressed and used as the basis for performance of anti-corrosion pipe coatings for steel pipe. The anti-corrosion coating industry in the USA for the oil, gas and water pipeline construction market is approximately $1.6 Billion, which includes new pipe construction and reconditioning of aged pipelines; onshore and offshore; potable water pipelines, water treatment and power plant infrastructures. The global anti-corrosion market including USA is approximately $2.9 Billion.

Genesis of Polyethylene Tape Anti-Corrosion Coatings:
PE tape coating system are based upon the use of polyethylene resins as a backing film with inherent properties of low ingress of water as a liquid and water vapor; high flexibility and conformability; high dielectric strength and electrical resistance; and long term thermal and oxidative stability. The other component of the PE tape is a butyl based adhesive. The butyl based adhesive has the characteristics for excellent adhesion to a steel substrate as well as to polyethylene films, high resistance to oxygen permeability; low temperature flexibility and long term thermal , hydrolytic and oxidative stability. Combining the low water permeability and low water vapor using polyethylene resins, in combination with butyl elastomeric adhesives that have low oxygen permeability and long term adhesion and stable to heat and water, results in a long term PE anti-corrosion coating tape system.

A Polyethylene (PE) tape coating system consists of the following components:
* Corrosion Liquid Adhesive (primer) layer…to prepare the metal substrate for adhesion and as a last barrier to corrosion.
* Corrosion inner-layer consisting of a laminate of polyethylene film backing bonded to a butyl elastomeric adhesive.
* Mechanical outer-layer consisting of a laminate of polyethylene film backing bonded to a butyl elastomeric adhesive.
* Rock shield consisting of a high modulus thick polyethylene film or laminate to a butyl elastomeric adhesive. Rock shields are generally used in the case of high aggressive soils and sedimentary rocks and backfill.
Diagrams of a cross section of PE tapes are given in Figure 1.

Figure 1

2 Ply Tape

3 Ply Tape

The design and formulation of PE tape was based upon the requirements from the Department of Transportation regulations and under the guidelines of the Federal Energy Regulatory Commission (FERC). The federal codes governing anti-corrosion coatings outline the following minimum requirements of a coating.

- Coating must have sufficient adhesion to the steel substrate;
- Coating must have low water absorption and low water vapor transmission rate;
- Coating must have resistance to cathodic disbondment;
- Coating must have soil stress resistance and good shear strength;
- Coating must have high Dielectric strength and high Insulation resistance;
- Coating must be compatible with cathodic protection.

PE tape coatings were and are designed, formulated and manufactured to the above requirements. During the next 60 years the use of PE tape coating systems are used to protect oil, gas and water steel pipelines from corrosion under all types of environments, soil, terrain and pipeline construction conditions. The oldest continuously operating PE tape coated pipeline today in the USA is 60 years old.

**Polyethylene Tape coatings in the Pipeline Industry:**

PE tape coatings have been used in the pipeline industry since 1953 for use as external anti-corrosion coatings for steel pipe, fittings and specials (i.e., Tees, Valves, Bends, Manholes) for oil, gas and water transmission pipe. The use of PE tape coatings were originally used as a corrosion coating system for oil and gas pipeline industry. The first use of PE tapes were applied in the field at the Right-of-Way (ROW) in a continuous process, known as Over-the-Ditch(OTD) or Line Travel (LT) as shown in Figure 2.
Figure 2

Line Travel, Over-the-Ditch Coating Machine

Line Travel, Over-the-Ditch Coating Machine
This process involves a machine that is powered down the welded pipe, which may be as much as 20-30 miles of pipe prepared for coating, and in one continuous process cleans the pipe with rotating wire brushes; remove the dust and debris from the cleaning process; apply an anti-corrosion primer; followed by the application of the anti-corrosion inner-layer and then the application of the outer mechanical layer. The Line Travel application process was used extensively in the oil and gas industries on a global basis, for over 30 years. Some of the most important pipelines constructed in the USA in the 1960-1980 up to present day, were done using the LT/OTD application techniques with PE tapes. During this time PE tape coating systems were also used as Field Joint Coatings (FJC are coatings applied over the welded joint between two pipes) and coatings used for pipeline specials (bends, tees, man holes) for coal tar, fusion bonded epoxy, and extruded polyethylene mainline anti-corrosion coating systems (see Figures 3 & 4).

Figure 3-A Field Joint Coating “Girthweld Coating” with PE tape
Figure 3-B Field Joint Coating “Girthweld Coating” with PE tape

Figure 4 PE tape for Pipeline Specials
With the evolution of the pipeline coating industry in the mid 1980’s and the introduction of plant applied coatings (circa 1980; plant coatings is where the pipe is coated in a stationary plant and the coated pipe is transported to the job site ROW), the use of PE tape coatings evolved into plant applied coatings. The PE tape coatings for plant applied was based upon the same chemistry and design of the Line Travel coating systems. These PE tape coating systems continued to use a minimum of a 3 layer coating design; however, the design of the outer mechanical layer took on new requirements. In the case of the outer-layer, the mechanical outerwrap had to become tougher and more robust to withstand the rigors of pipe storage, transportation, handling, stringing along the ditch and pipe laying to prevent damage to the corrosion coating inner-layer and the total coating system. The design of the plant applied PE tape coating systems established a new coating system, distinct from any other PE tape coating systems, and equal in the pipeline coating industry as compared to other mainline coating systems in use. Examples of plant applied PE tape coating systems are shown in Figures 5, 6, & 7.
Figure 5 Plant Applied PE Tape Coating

Figure 6 Plant Applied PE Tape Coating
Performance of Polyethylene tape coatings:
Some of the unique and inherent properties of a PE tape coating system for use as a Line Travel, Plant applied and Field Joint coating systems are low temperature properties; long term adhesion; long term thermal and hydrolytic stability; low water vapor and oxygen permeability; low coefficient of friction; good bonding to mortar coatings due to the overlaps with PE tape coatings; and adhesion to multiple interfaces. Transporting of plant applied PE tape coating systems is identical to other plant applied coating systems. There must be established set conditions to protect the coatings from mechanical damage with the use of outer-mechanical layers, to provide sufficient handling resistance to withstand the transporting practices of moving and handling of steel pipe. All coatings are susceptible to mechanical damage and the proper use of handling methods must be employed to insure that the integrity of the coating is preserved at the time of lowering the pipe into the trench, installing and commissioning of the coated pipe.

Standards for Polyethylene Tape Coatings (oil/gas/water to NACE & AWWA standards):
The pertinent standards for PE tape coatings are NACE (National Association of Corrosion Engineers), AWWA (American Water Works Association), CSA (Canadian Standards Association), EN (European Norms) and ISO (International Standards Organization) as derived over the past 62 years. These standards provide the guidance and framework for the industry as a minimum requirement for plant and field applied PE tape coatings and other all other types of corrosion coatings as used in the oil, gas and water transmission industry; they are also applicable for field Joint coatings and for reconditioning of aged pipelines. From the first edition of the above standards to present and current revision, there has been a diligence to improve the performance of the coatings. Such technical properties that have been addressed and incorporated in revisions are such properties as Adhesion, Cathodic Disbonding, Water absorption, Water Vapor Transmission rate and UV stability. Other properties that have been addressed by the manufacturers are the use of liquid adhesives and thermal, hydrolytic and oxidative stability. The
current coating standards have established the essential and critical requirements for PE tape coatings materials and total coating systems including all aspects of the coating and its application; surface preparation, coating application methodologies, pipeline ROW techniques, physical properties of the components and total coating system, testing methods, handling, transportation, and packaging. The properties of Polyethylene tape coating systems in accordance with NACE, AWWA, EN and ISO standards are given in in the applicable standards. A review of the technical parameters of these types of coating standards demonstrate that PE tape coatings as designed have good properties to provide long term corrosion properties and meet US Government Department of Transportation (DOT) and Federal Energy Regulatory Commission (FERC) requirements; and international standards. Typical properties of a PE anti-corrosion tape coating are given in Table 1.

<table>
<thead>
<tr>
<th>Table 1 Physical Properties of an Inner-Wrap Tape (AWWA C-214, 2014 Revision)</th>
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<tbody>
<tr>
<td>Property Requirement:</td>
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<tr>
<td>Width deviation - 5% of width or - ¼”, whichever is smaller</td>
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<tr>
<td>Thickness 19-22 mils</td>
</tr>
<tr>
<td>Adhesion (with Primer) 200 oz./in</td>
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<tr>
<td>Water Absorption (24 hrs.) 0.2 %, maximum</td>
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<tr>
<td>Water vapor transmission 0.2 perm [1.15x10-11 kg/(Pa.s.m2)] maximum</td>
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<tr>
<td>Dielectric Strength 6000 volts/tape thickness</td>
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<tr>
<td>Insulation resistance 500,000 mega ohms</td>
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<tr>
<td>Tensile Strength 20 lb./in</td>
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<tr>
<td>% Elongation 100 minimum</td>
</tr>
<tr>
<td>Non-polyolefin content 3.5% maximum</td>
</tr>
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As standards they state the minimum requirements, but how does this translate to in-service performance and long term results? To establish long term performance, there have been numerous visual examinations (bell-holes) of long term in service PE tape coating systems. In addition to visual inspections, analytical analysis to determine the stability of the coating using differential colorimetry, thermogravitric analysis, infra-red spectroscopy and in-ground cathodic protection current demands.

1. Visual examinations of in service buried pipe over many years have shown that PE coatings remains intact and providing corrosion protection to the steel pipe. In the case of PE pipeline coatings, the integrity has not been compromised and the adhesion of the coating to the pipe has been maintained. There are no defects in the coating and the CP current requirement has not increased.

2. Analytical analysis of the coating using OIT (oxidative induction time measured by DSC) and IR shows the coating has retained its stabilizers and that the coating is flexible and has not degraded. There is no crazing or cracking of the pipeline coating. IR analysis shows no evidence of significant oxidation on the surface of the Polyethylene backing film, which is corroborated with the OIT results.

3. Cathodic protection current demand from operating pipelines show those PE anti-corrosion coatings remained low over the 30 years of service which is consistent with a coating that is stable and maintains its integrity and no loss in physical properties.
From the review of PE tape coatings spanning 62 years of service, it shows that PE coatings are suitable and “Fit for Purpose” as a coating to protect steel pipe in the oil, gas and water steel pipeline Industry. PE tape coatings have been proven to be an efficacious and safe coating for steel pipelines. PE tape coatings can be applied effectively, timely and in a cost effective manner providing long term corrosion protection.

**Hot Applied - Heat Fused Plant Applied Polyethylene Tape Mainline Coating Systems:**
A translation of the traditional PE tape coating is a Fused PE hot applied mainline coating. In this case the total coating system has the same components as a standard ambient temperature tape coating system, but the difference is that the fused PE coating system utilizes hot melt adhesives (not a traditional pressure sensitive adhesive) on the anti-corrosion inner-layer and mechanical outer-layer coating system. When applied this coating system creates higher adhesion, improved mechanical toughness and robustness and long term corrosion protection. The fused PE tape coating system has been used extensively in the oil, gas pipeline industry for the past 20 years. The use of the fused PE tape coating system has been used in the water industry internationally and on specific water projects in North America. The fused Polyethylene tape coating system meets all applicable NACE and AWWA standards.

The properties of Heat-Fused PE tape coating systems is in accordance with AWWA standard (AWWA C-225) and applications are shown in **Figures 8 & 9.** A review of the field performance show that Fused PE tape coatings like the traditional PE tape coatings have properties to provide long term performance. The advantage is the mechanical toughness and robust properties especially at the RO and its inherent corrosion protection properties.

![Figure 8 Fused PE Plant Applied Coating](image_url)
Double Faced Tape coating systems for Field Joint Coatings & Rehabilitation of Pipelines:
The use of 3-Ply Double Faced tape (DFT) coatings has been used in the pipeline industry for the past 25 years. The Double Faced Tape coatings emerged from the German standards, whereby there was a demand in coating specifications for higher adhesion at the overlap to address the concern of potential water migration under the tape coating during in-service performance. The DFT coatings was built upon the technical platform of a polyethylene tape backing and 2 layers of butyl based adhesive combined into a one tape system, The DFT is the corrosion barrier and the use of a mechanical PE outerwrap layer can be used to provide additional mechanical protection to the DFT. This type of coating system has been used in the international oil, gas and water steel pipe industries for Field Joint Coatings (FJC’s) and rehabilitation of pipelines. The governing standards for DFT coating systems are EN and ISO standards. Application of DFT coatings are shown in Figures 10. These types of coatings are used primarily for FJC and for rehabilitation of pipelines for coating of aged pipe with a DFT coating system using the Over-the-Ditch coating method.
Other Types of Pipeline Coatings used in the Oil, Gas and Water Industry:

A. **Fusion Bonded Epoxy (FBE)** coatings have been used in the pipeline industry since the early 1980’s. They were used on the Alaska Oil Pipeline and used primarily as a mainline new construction pipeline coating. FBE coatings are applied principally in plant applied facilities due to the process of application. FBE coatings have been used in the field for Field Joint Coatings, but it is predominately as a mainline plant applied coating. FBE coatings have proven performance in the oil and gas industries and used rarely in the water industry. FBE coatings meet NACE, AWWA, CSA, EN and ISO standards.

B. **Extruded Polyethylene (Ext PE)** coatings have been used in the oil, gas and to some extend in the water steel pipe industry. Extruded PE coatings can be 2-Layer or 3-Layer systems. All Extruded PE coatings are plant applied with direct extrusion of the adhesive and polyethylene applied direct to the pipe in a side-head method. The 2-Layer PE coatings have a layer of butyl adhesive extruded directly onto the cleaned pipe, followed by direct extrusion of Polyethylene over the butyl adhesive. The application is applied in a side-head method and in a spiral application resulting in an overlap configuration on the pipe. The 3-Layer PE coating system is a thin layer of FBE applied by direct powder application, followed by direct extrusion of a hot melt adhesive followed by direct extrusion of Polyethylene over the hot melt adhesive. Both coating systems are used in the oil and gas industry and to a limited extend in the water industry. Major usages of 3-Layer PE coating are in the international markets. Like PE tape coatings, Extruded PE coatings have been used extensively for the past 25 years and have proven corrosion protection. Extruded PE coatings meet NACE, AWWA, CSA, EN and ISO standards.

C. **Heat Shrink Sleeves (HSS)** are used predominately as Field Joint Coating for the oil, gas and water industry globally. HSS unlike other PE coatings are radiation crosslinked polyolefin backings coated with different rheological adhesives (PSA’s to Hot Melt adhesives). Heat shrink sleeves are wrapped onto the pipe and a flame torch is used to heat the HSS. The results are a product that shrinks upon heat application. Recent advances with HSS in the USA water industry are to use a new construction concept of “Weld after Backfill”. This technique allows the FJC to be coated, the pipe buried and welding of the pipe is done afterwards. This technique new as it is has been used on major water projects in the USA. Heat Shrink sleeves have been used for the past 45 years with proven performance. HSS coatings meet NACE, AWWA, CSA, EN and ISO standards.

D. **Liquid Polyurethane (PU)** coatings are used in the Water Industry for the past 15 years. PU coatings are plant applied and applied by spray technique on a continuous basis. PU coatings can be used for both external and internal coatings. PU coatings are continuous monolithic coatings and do
not use a mechanical outer layer; they are a one layer coating system. PU coatings have proven performance as a corrosion coating for water transmission pipe, as both external and internal coating of pipe. PU coatings meet NACE and AWWA standards.

**E. Liquid Epoxy (LE)** coatings are normally used in the pipeline industry as a Field Joint Coating, as a coating for pipeline rehabilitation and for coating pipeline specials and irregular pipe geometries. LE coatings are normally applied in the field with spray, brush or roller and have cure times of several minutes to hours. LE coatings are also used in the HDD (Horizontal Directional Drill) and bore applications for oil and gas pipes during the pipeline construction. LE coatings are applied over FBE and other mainline coatings for bore application to provide mechanical protection to the mainline coating during the boring application. For bore applications, the LE is applied either in the field or in a plant coating facility. Additionally, LE coatings are used for pipeline rehabilitation in field applications. LE coatings are continuous monolithic coatings and do not use a mechanical outer layer; they are a one layer coating system. Liquid epoxy coatings have been used extensively in the oil and gas pipeline industry; and have proven long term corrosion protection properties and performance. Liquid epoxy coatings are in accordance with NACE and AWWA standards.

**F. Visco-Elastic (VE)** coatings were introduced to the pipeline industry approximately 10-15 years ago mainly in field applied methods as a Field Joint coating and reconditioning of pipelines. These types of coatings have inherent soft low viscosity adhesives, which under low to zero stress will cold flow. The properties of visco-elastic coatings are that the adhesive remains fluid and with age and time it does not cure or harden. Visco-Elastics coatings will flow when a defect in the total coating system occurs, resulting in a “self-healing” characteristic, which is unique to these types of coatings. Visco-Elastics coatings do require a mechanical outer layer to provide mechanical protection and to provide compression forces to insure cold flow of the adhesive if there is damage to the total coating system. Visco-Elastic coatings have proven long term performance and meet NACE, EN and ISO standards. AWWA standards are in the process of being drafted.

**G. Coal Tar and Asphalt** Coatings were used in the very early days of pipe corrosion coatings. Today they are used on a limited basis due to environmental concerns. Traditionally, Coal Tar coatings are field and plant applied coatings for both mainline, field joints and specials pipe. Coal Tar coatings have a good history and performance in protecting steel pipe in the oil, gas and water industry. Coal Tar coatings meet NACE and AWWA standards. Today Coal Tar coatings are not a predominate coating due to environmental concerns and US government regulations

**H. Wax** coatings are field applied coatings and mainly used for irregular geometric pipe, such as pipe specials, tees, valves, bore pipe, and compressor stations. The advantage of wax coatings are ease of application and flow of the coating onto the irregular structure. Wax coatings are used today and meet NACE and AWWA standards.

**Summary and Conclusions:**
The coatings reviewed in this paper show that all of types of anti-corrosion coating have proven long term properties as governed by applicable standards; as measured by analytical test methods; and proven with in-service performance in combination with cathodic protection. Polyethylene tape coatings have excellent inherent properties that provide sound long term corrosion protection. All anti-corrosion coatings as reviewed here have shown to be effective coatings based upon their chemistry, application methods and intrinsic properties. All of the coatings discussed have been used in the pipeline industry with proven performance from 10 to 60 years, and providing the pipeline owner a long term solution to protection of their infra-structure investment.
References:
5. ANSI/AWWA C-214-14 Standard “Tape Coating System for the Exterior of Steel Water Pipelines”