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EVALUATION OF TAPE COATS FOR LARGE DIAMETER WATER TRANSMISSION LINES

Risque L. Benedict, P.E.
Corrosion Consulting Service Corporation
1530 Tioga Trail
Fallbrook, California 92028

ABSTRACT

In polyolefin tapes the cohesion exceeds the adhesion. As a result, corrosion products generated by cyclical wetting and drying will disbond polyolefin tapes. In tape systems, the failure mechanism under excessive cathodic protection also results in extensive tape disbondment and shielding. The failure mechanisms of polyolefin tapes are completely different from coatings like coal tar enamel where the adhesion exceeds the cohesion. With coal tar enamel since corrosion products generated by cyclical wetting and drying eventually destroy the coating, disbondment resulting in shielding generally does not occur. Likewise, excessive cathodic protection results in complete destruction of coal tar by exfoliation. The end result on coal tar will likely require rehabilitation of the damaged coating within a hundred feet (30.5 meters) or so of the rectifier negative drain. On tape coats the radius of coating disbondment can be thousands of feet from the rectifier drain, requiring a corresponding amount of rehabilitation. These failure mechanisms on polyolefin tapes proposed by the author appear to explain the field observations of tape disbondment and shielding noted by pipeline operators, in recent surveys by the American Gas Association Technical Committee and in a smaller scale survey conducted by the author.

Keywords: cohesion, adhesion, shielding (of cathodic protection current), cathodic disbondment, moisture absorption, microbiologically influenced corrosion (MIC), shear stress, plastic deformation, cohesive separation, electroendosmosis, sulfate reducing bacteria, facultative ability, hydrogen overvoltage potential, cathodic protection current throw, cigarette wrap, band-aid repair.

INTRODUCTION

The 60" (1500mm) diameter Ivie pipeline originates at the Ivie Reservoir in Concho County, Texas and proceeds west to San Angelo. From San Angelo, the pipeline reduces to 53" (1300 mm) and terminates between Midland and Odessa, Texas, a total distance of 157 miles (253 kilometers). Freese and Nichols, of Fort Worth, Texas, designed the line for the Colorado River Municipal Water District of Big Spring, Texas. Corrosion Consulting Service (CCS) of Fallbrook, California, was retained to evaluate various piping, pipe coating, and corrosion prevention alternatives for this pipeline project. The Ivie pipeline has an area coated of approximately 12.8 million square feet (1.19 million square meters).

REVIEW

In a previous paper[1], the author concluded that an 80 mil (2.0 mm) three-layered proprietary tape coat system was not a feasible coating system for the Ivie Pipeline. Two criteria were used in arriving at this conclusion. First there was no way to project the proven operating history of thirteen years for the 80 mil (2.0mm) tape system to the desired minimum life of fifty years stipulated by the Colorado River Municipal Water District. The second reason was that the CCS investigation revealed widely differing opinions in customer acceptance of tape coats based on their in-service experience.This survey covered two major user groups, waterworks utility operators and the oil and gas industry. The old expression that "oil and water don't mix" was confirmed by our survey. The majority of waterworks utilities were unaware of tape coated pipe service history in the petroleum industry, and especially that on large projects the oil and gas industries use tape coats on a limited basis for rehabilitation rather than in new construction.

Our independent survey of eight major oil and gas companies operating in the general location of the Ivie pipeline mirrored a previous, more detailed investigation by the American Gas Association Technical Committee[2]. This study by Coulson et al found the following problems in the use of tape coats:

1. Shielding of Cathodic Protection Current;
2. Disbondment at Welds, Dents, etc.;
3. Damage due to Rock Impingement;
4. High Sensitivity to Application Techniques; and
5. Soil Stress Problems.

The Corrosion Consulting Service survey showed that disbondment and subsequent corrosion under disbonded tape coats often could only be detected by a "smart pig" survey.

It was concluded from the previous study that tape coats were by reputation not the coating of choice for new construction on large diameter pipelines. The fact that a number of large diameter water line projects have recently been installed using tape coats was more than offset by the long-term service problems encountered by the oil and gas industry studies. Our 40 year experience with pipeline corrosion problems has been equally divided between waterworks and the oil and gas industry. From our experience, it was clear that the oil and gas industries have funded far more studies on pipe coating and coating performance than have been performed by the waterworks industry. For this reason, the author considered the in-service history on tapes originating from the oil and gas industry more germane. The one exception where the waterworks industry was more knowledgeable was in their use of cementitious coatings. For these reasons, the 80 mil (2.0mm) proprietary tape coating system was not recommended for the Ivie pipeline.[1]

ORIGIN OF TAPE COATS

The origin of tapes for a pipe coating is derived from the successful application of electrical tapes for insulating electrical splices and polyethylene wire insulation. A common electrical splicing technique is the combination of a flexible butyl rubber elastomer compressed with a polyethylene (PE) or polyvinyl chloride (PVC) tape applied under tension. The author has successfully used this kind of splice underground and underwater for approximately 40 years. The high dielectric of PE tapes is well known. This dielectric property of PE tapes is superior to most of the competitive pipe coating materials which are available, for example, coal tar enamels. Users of coal tar enamels compensate by using thicker coatings.

PROPERTIES OF A GOOD PIPE COATING

A good pipe coating should have the following properties: Ease of application for a quality product is essential. This implies that a good quality coating can be achieved with reasonable supervision and inspection. The coating must have resistance to handling damage in the coating, transportation cycle and the laying operation. The coating must be resistant to degradation by weathering. For longevity in burial - service, the coating should be chemically stable* and have low moisture absorption and high resistance to

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*Chemical stability is a "given" with most coatings. During our career, we have encountered at least two coating systems that failed in service because they were chemically unstable.

soil stress. A good coating must exhibit bacteria inertness and have good resistance to microbiologically influenced corrosion (MIC). The coating must be compatible with cathodic protection. Freeze thaw resistance also is required in northern latitudes. There are other qualities of lesser importance, such as resistance to tree root and rodent damage, but for the most part the above described qualities will determine the longevity of the coating after burial.

Figure 1 is a flow chart showing the importance of various properties as they apply to the factory coating, transportation and handling, laying, inspection and in-service cycles. In reviewing these various properties, coal tar enamel, the old standard of the oil and gas as well as the waterworks industries, is used as a comparison.

IMPORTANCE OF COATING DISBONDMENT

A prime objective is application of a coating which is tightly adherent to the pipe. Under adverse conditions, all dielectric coatings can become disbonded. Coating disbondment is not tolerable for two reasons. First, it can be difficult or impossible to prevent corrosion under a disbonded coating with cathodic protection due to shielding. Second, it can be difficult or impossible to monitor any corrosion proceeding under a disbonded coating except by using a smart pig. Smart pigs have never been used in the waterworks industry, at least not on pipe 60 inches (1500mm) in diameter with a mortar liner. A coating that will remain bonded is essential for long service life.

ADHESION VERSUS COHESION

Polyethylene tapes and other polyolefin coatings have an unusual quality possessed by no other type of commonly used dielectric coating because the cohesion of the coating (its ability to adhere to itself) exceeds the adhesion of the coating (its ability to adhere to the pipe). In almost all other dielectric coatings (for example, fusion bonded epoxy, coal tar epoxy, polyurethane, coal tar enamel, and asphalt), the adhesion exceeds the cohesion. When these latter coatings are stressed (particularly in shear), a holiday is usually produced by plastic deformation rather than disbondment. Conversely, tapes usually disbond rather than rupture (i.e., form a coating holiday).

DISBONDMENT FROM CYCLICAL WETTING AND DRYING IN BURIAL SERVICE

In 1985, Benedict[3] proposed cyclical wetting and drying as a mechanism for corrosion on pipelines in burial service. In 1991, Granata[4] proposed a similar mechanism for corrosion failure of automotive coatings in the atmosphere. According to Granata, a wedge effect formed by corrosion products promotes coating disbondment.

On coatings like tapes where the cohesion exceeds the adhesion, much of the disbondment occurs in service underground adjacent to coating holidays perpetrated during the handling and laying cycle. During the wet cycle, water moves in through the coating holiday and corrodes the steel. A wedge of corrosion products forms under the tape. Since the tape's cohesion exceeds the adhesion, the tape disbonds from the metal surface (See Figure 2). During the subsequent dry cycle, atmospheric oxygen is introduced to fuel the corrosion process, and increase the size of the corrosion wedge (See Figure 3). Also, during the drying cycle, the increase in the volume of corrosion products which exceeds the size of the corroded steel, often by a factor of two or more, results in mechanical forces that drive this corrosion product wedge further under the tape coating causing further disbondment (See Figure 4). In coatings like coal tar, where the adhesion exceeds the cohesion, the result of cyclical wetting and drying usually is an enlargement of the holiday by coating exfoliation, rather than coating disbondment.

Tapes are a dual product wherein a butyl elastomer adhesive is factory bonded to a polyolefin tape. Disbondment occurs either between the elastomer and the pipe, within the butyl elastomer itself, or between the butyl elastomer and the tape. Our tests indicate that loss of bond is most likely either between the butyl adhesive and the pipe or within the butyl adhesive itself. In the proprietary tape coating system considered, the 30 mil (0.76mm) anti-corrosive tape consists of 15 mils (0.38mm) of polyethylene and 15 mils (0.38mm) of butyl. A loss of adhesion between the butyl elastomer and the pipe can result in corrosion if moisture, oxygen and/or certain types of bacteria proliferate. If the loss of adhesion is a cohesive separation of the butyl adhesive, the longevity of the tape coating then is time dependent on the diffusion rate of moisture and other corrodants to penetrate the thickness of the thin layer of butyl mastic that remains bonded to the pipe.

SIGNIFICANT DISBONDING (SHIELDING)

All dielectric coatings will disbond given the right conditions. Coal tar enamels, for example, are most likely to disbond during application. This can occur from several causes, including inadequate surface preparation and improper temperature of the coal tar enamel. However, once bonding of the coal tar enamel occurs during application, there are few recorded instances where it subsequently becomes "significantly disbonded". By significantly disbonded, we mean that the ratio of crevice length (of the disbondment) to crevice opening precludes an adequate level of cathodic protection. This is also referred to as "shielding". Tape coats, on the other hand, can become "significantly disbonded", not only during application, but also during storage, handling, laying, from soil stress from the cyclical wetting and drying mechanism previously described at holidays and from cathodic disbondment caused by cathodic protection. Tapes are vulnerable to "significant disbonding" for several reasons. Tapes disbond when subjected to shear stress both because the cohesion exceeds the adhesion, and because their adhesion to the pipe substrate is poor relative to other coatings like coal tar enamel.[5] The "gasket effect" on tapes is essential to maintain their optimum adhesion. When the gasket effect is lost, as for example, by improper tensioning of the tape during plant coating, or by placement of a "Band-aid" field repair in lieu of a "cigarette wrap", that optimum adhesion can be lost. Because other coatings such as coal tar enamels have better adhesion than cohesion, better bond to the pipe substrate, and are not dependent on the gasket effect, they are more immune from "significant disbonding" caused by handling damage, soil stress or cathodic disbondment. Damage does occur on coal tar enamels from these elements of distress, but the result is usually a coating holiday which can be protected by cathodic protection. Thus, the lower adhesion versus cohesion property of tapes is fundamental to their propensity for significant disbondment. Sloan[6] indicates shielding has led to a recent trend to decrease or restrict the use of tape coatings.

TAPE LAP

Another unique property of tapes is the tape lap. Each lap is an area of potential ingress of oxygen, ground water with entrained corrodants and bacteria. The tape lap is also a preferential site for shear stress failure by soil stress. The tape lap is an inherent fundamental weakness of tapes vis a vis monolithic coatings like coal tar enamels, fusion bonded epoxies, etc.

COATING APPLICATION

Conflicting views between the tape manufacturer, the tape applicator, the contractor, and the owner were discussed in a previous paper[1]. There appears to be no single preferred method for application of tapes. One of the good qualities of tape is that the manufacturing process with factory quality control is capable of consistently providing uniform quality of the tape itself. Consequently, the chance of obtaining a defective tape from the tape manufacturer is considered remote. In a coal tar enamel pipe coating operation, certain coating variables must be controlled to obtain a quality coating. Improper temperature is one important variable. If the temperature is too high, the coating can be "coked", with the loss of dielectric properties. If the temperature is too low, loss of bond and poor adhesion can result. The rate of pipe travel and handling of the pipe before the coating hardens by cooling are other variables that must be controlled in the coal tar enamel coating operation. Nevertheless, good application of coal tar enamel is usually attained.

DURABILITY OF COAL TAR ENAMELS

The durability of this coating for over 100 years in service proves that it not only can be applied but also it will endure the rigors required of a pipe coating. It was previously reported[1] that type B coating which is 1/8 inch (3.2mm) coal tar enamel top-coated with 3/4 inch (19mm) mortar lasting over 50 years without any cathodic protection (See Figure 5). Based on this experience we project a life of over 100 years with cathodic protection on the type B coating. According to Bowden[7], there is an active operating pipeline coated with coal tar enamel in San Francisco which is over 100 years old. Many examples of long term coal tar enamel uses are on record. The Bureau of Reclamation reports the successful use of coal tar enamel coatings since 1906[8].

MANUFACTURER OF COAL TAR AND TAPES

Coal tar enamel coatings are manufactured using selected plasticizers and fillers which impart the required properties. For example, certain types of plasticizers and fillers are added to resist softening of coal tar enamels in extremely hot weather, while others are used to prevent the coating from becoming brittle in cold weather applications. In tape coats, variations in properties are achieved by using different polymeric combinations and by adding a different number of layers and thicknesses of the tape coats.

COATING INSPECTION

Holiday detectors usually are employed during the application of coatings. "Jeeping" on a coal tar enamel coating is usually indicative of coking of the coating or a holiday imperfection. It also can indicate that the coating is being applied too thin. In an multiple tape coat system, the use of a "jeep" generally is only effective on the anti-corrosive tape to detect holidays in the coating. The high dielectric provided by additional mechanical barrier layers on the tape coating system precludes a meaningful "jeeping" of the completed product. Visual observation of wrinkles, bulges and tears is more effective in spotting coating defects on tapes than a high voltage detector. Complete puncture of a multiple layered tape coating system from a sharp object is the only defect that a holiday detector can locate better than visual inspection.

EFFECT OF MORTAR COATING

The waterworks industry has been successfully using mortar coatings either alone or as a mechanical barrier to protect the underlying dielectric pipe coatings for over 100 years. A discussion follows on the effect of mortar coatings on handling damage, moisture absorption, soil stress, and resistance to MIC.

Handling Damage

All coatings, including tapes and coal tar enamels, are subject to handling damage during application of the coating, movement around the pipe coating storage yard, loadout, improper bracing and support on trucks, off-loading of the pipe at the construction site, protection of the pipe at the construction site from thermal damage on skids, and finally placement in the trench. In the petroleum industry, field patching on coal tar enamel is the usual remedy for handling damage. After the coated pipe is in the ditch, cathodic protection then is applied to compensate for any further coating damage or in-service deterioration. In the waterworks industry, coating damage is often minimized by placing mortar over the coal tar enamel coating. This is prompted by the enormous weight of the typical large diameter waterworks pipe. The largest that we have ever worked on is 252 inches (6400mm) in diameter and weighs about 200 tons (181 metric tons) per joint of pipe! The Type B coating system has been a long term successful solution in corrosion prevention on water lines for the Metropolitan Water District of Southern California, the San Diego County Water Authority, and the California Department of Water Resources, even without the application of cathodic protection.

With tape coats, handling damage is minimized by employing extra layers of tape as a mechanical barrier. In a typical 80 mil (2.0mm) tape coating system, the outer two tape layers, which usually consist of 30 mils (0.76mm) of polyethylene tape, are primarily included to permit handling without excessive damage. If wrinkling, bulging, tearing, or puncture occurs, the tape coat can be field repaired with a "cigarette wrap".

Our field observations and the experience of other major water agencies in California and West Texas indicate that significant handling damage occurs on large diameter waterworks pipe coated with the tape coating system. The use of impacted mortar over the tape coating system successfully addresses handling damage[1].

Moisture Absorption

Although moisture transfer through pipe coatings is not completely understood, Professor Harris[9] indicates four ways that moisture can penetrate coatings.

1. Capillary flow through "pinhole" holidays.
2. Some coating systems are susceptible to water absorption and/or penetration.
3. Wicking action of exposed fiberglass reinforcing material.
4. Electroendosmosis of water due to cathodic protection.

Comparative tests of moisture absorption between coal tar enamels and tapes show that tapes have much lower moisture transmission characteristics. However, in a previous paper, the presence of moisture passing through an 80 mil (2.0mm) tape coating system on a large diameter water line has been described[1]. Moisture condensation from dew penetrated through three layers of tape. This resulted in corrosion on the pipe within 30 days during above ground storage. Corrosion was on the barrel of the pipe and located a foot or more from the nearest welded seam. Moisture in the tape coat entered through the tape lap. Higher moisture absorption on the coal tar enamels undoubtedly results in a greater cathodic protection current requirement over a period of time than is experienced on tape coats. However, the author recently completed a survey for one of our clients where the coal tar enamel (without the benefit of a mortar overcoat) cathodic protection current requirements were still in a very acceptable range of 17 to 25 microamperes per square foot (183-269 microamperes per square meter) after 20 and 21 years, respectively. We have no data to indicate the effect of one inch (25mm) mortar coating over either the tape anti-corrosive primer or the coal tar enamel for moisture absorption. It is our opinion that, over a period of time, mortar will transmit considerable water and therefore does not serve as an effective moisture barrier when applied over either coating.

Soil Stress

Both the coal tar enamel and tape coating systems are vulnerable to soil stress (shear stress) in soils with a high plasticity index. Klechka[10] indicates that soil shear stress is a major cause of damage on tape wrap. Mortar coatings applied over either coal tar enamel or tape coats should solve any adverse effect from soil stress.

Resistance to Microbiologically Influenced Corrosion

More attention is currently being given to microbiologically influenced corrosion (MIC).[11] The greatest body of knowledge for bacterial caused corrosion on pipelines has been accumulated on sulfate reducing bacteria (sporovibrio desulfuricans). Professor Harris[9] has shown that there are many other forms of bacteria which may be capable of initiating corrosion, especially under disbonded pipe coatings. Professor Harris noted a variety of bacteria under disbonded coatings even though the environment had been rendered highly alkaline by cathodic protection. Short term cultures indicate that sulfate reducing bacteria propagate intensely only in the pH range of 5.5 to 8.5. However, other bacteriologists have noted the facultative ability of many bacteria (i.e., the ability to adapt and thrive in a new environment). Because of this facultative property, bacteria are more likely to pose a long term threat to pipeline coatings. It is well documented that cathodic protection often is incapable of preventing corrosion by sulfate reducing bacteria under disbonded coating conditions. Tape coats have appropriate bacteriacides and inhibitors to resist the proliferation of bacteria. However, any bacteriacide obviously would be leached out over time. Coal tar enamels are more resistant to bacteria than most coatings, including tapes, because they contain large amounts of aromatic compounds, which Professor Harris found to retard many bacteria forms.[12] Unfortunately, these same aromatic compounds have resulted in a ban on coal tar enamel coating operations in the Los Angeles Basin because of environmental considerations.

The long term effect of a mortar coating placed over either the tape coating anti-corrosive primer or the type B coal tar enamel coating is unknown. However, the alkalinity from the pore water of the mortar to the underlying coatings would resist many forms of bacterial attack, at least until the bacteria adapted to their new environment. The addition of mortar coating either to the tape coating anti-corrosive tape or to coal tar enamel is viewed as an advantage to resist microbiological action.

COMPATIBILITY WITH CATHODIC PROTECTION

Coal Tar Enamels

There is long term history of compatibility between pipe coated with coal tar enamel and cathodic protection. Excessively high levels of cathodic protection (i.e., potentials approaching the hydrogen overvoltage potential) can cause disbondment on coal tar enamel coatings. Coating disbondment is confined to the area of overprotection. When the level of cathodic protection returns to normal, then the coated pipe can continue to be protected by cathodic protection, albeit at a higher current. This higher current results from coating destruction and exfoliation. It is good operating practice to avoid the overprotection of all coatings. The effect of one inch (25mm) of mortar over the coal tar enamel coating under cathodic protection is unknown, but it is our opinion that it may have a small beneficial effect because of the alkalinity in mortar. We do not believe that the mortar overcoat will have any effect, either beneficial or detrimental, if the pipe coating is excessively overprotected.

Tape Coats

It is more difficult to analyze the reaction of tape coats to cathodic protection. On the one hand, we have data both from the manufacturer and independent laboratories which indicate that the rate of moisture absorption and permeability to oxygen is so low that it is difficult to comprehend the terms "cathodic protection current requirement" in the ordinary sense. The sophisticated capacitance measurements performed by Kellner[13] on the tape coats as well as the stable cathodic protection current requirements he reports over a period of several years are evidence of why we believe that a properly applied tape coating system has a zero current requirement. Most pipe coatings are semi-permeable membranes. A perfectly applied tape coating system appears to be an impermeable membrane. This observation should not be surprising inasmuch as the tape coating system is a derivative of tapes employed for making high voltage electrical splices.

The measured current density requirements recorded by many operators may be exclusively due to improperly applied areas of tape coats, such as at the pipe joints, or discrete coating holidays. We believe that the factory applied tape wrapped barrel of a pipe has a zero current requirement. If true, cathodic protection on polyolefin coatings is unlike cathodic protection on any other dielectric coating system in common use. For example, in coal tar enamels and most other dielectric coatings, some current passes directly through the coal tar enamel (i.e., semi-permeable membrane) in the areas where the moisture absorption and oxygen have penetrated the coating. This constitutes a "true current requirement" along the entire coated pipeline. For the tape coats, there is no attenuation on a coating that has no current demand since there is no current requirement for areas properly taped, but rather only at holiday punctures and areas of poor coating such as field joints.

As a consequence, there should be no adverse effects on tape coats even at excessively high levels of cathodic protection, unless a defect in the coating exists. Data presented by the tape manufacturer indicates that there is no rapid disbondment effect at holidays due to excessive cathodic protection on the tape coating system[14]. Tests by other independent laboratories on proprietary tape coat systems, however, show accelerated disbondment at holidays in tape coats when excessive cathodic protection is applied. The radius of disbondment was 30.25 millimeters for tapes versus three millimeters for coal tar enamel after 24 months[15]. Also, the rate of tape disbondment appears to increase with time (6% in the first year and 20% in the second year). A similar test on coal tar enamel showed cathodic disbondment decreased with time[15]. In our opinion, the independent laboratory results are probably the correct ones. If our theory is correct, either a holiday or substandard application is required for tape coated pipe to exhibit a cathodic protection current demand.

At excessively high levels of cathodic protection, there will be lifting of the tape coat in the areas adjacent to the holiday just as there is on coal tar enamels. Here the similarity ends.

Figure 6 shows coal tar enamel where adhesion exceeds cohesion prior to the application of excessive cathodic protection. Under excessive cathodic protection, disbondment of the coal tar enamel results in exfoliation from the pipe, creating a larger holiday, or bare area (See Figure 7). Exfoliation occurs because the adhesion of the coal tar enamel exceeds the cohesion. With a constant current source, current density is subsequently reduced by coating exfoliation since the exposed bare area increases. This reduction of current density limits further cathodic protection disbondment. Usually the result is that several hundred square feet of coal tar enamel adjacent to the rectifier drain are dislodged, often requiring coating rehabilitation in this limited area (See Figure 8).

On tape coats where the cohesion exceeds the adhesion, the result of excessive overprotection is quite different. Instead of the exfoliated coating experienced on coal tar enamels, disbondment will spread under the tapes, but the tape will remain intact over the disbonded area. The radius of this disbondment is dependent on both the cathodic protection "throwing power" under the tape and when the tape lap bond is broken as a result of the force applied by the generation of hydrogen gas and/or alkali (hydroxyl ions) under the tape (See Figure 9). The electrochemical reactions resulting in the generation of hydrogen and hydroxyl ions are shown in Figure 9.

On tape coats, this disbondment from excessive cathodic protection will be noted both at holidays close to the rectifier drain and at remote holidays. This is because the tape coat near the drain, while disbonded, has not been exfoliated from the pipe. No coating exfoliation results in no increase in bare area and consequently no reduction in current density when a constant current source is used.

For a constant current source, the radius of the coating damage on tapes will be much greater than on coal tar enamels because of the shielding effect of the disbonded tapes. With a zero current demand for all of the pipe, except holidays a few thousand feet away, there is little potential attenuation. Consequently holidays several thousand feet away are almost at the same excessively "high" potential as the holiday nearest the rectifier drain (See Figure 10).

While the number of square feet of coating damage from the excessive cathodic protection should be about equal for both coal tar enamel and tape coats, the cost of repairing the damaged tape coats is far greater because the radius of damaged tape could be at holidays scattered over thousands of feet of pipeline away from the source of excessive protection i.e., the negative drain of the rectifier (See Figure 10).

Once the excessive cathodic protection level is reduced and the proper levels of cathodic protection are restored, these disbonded areas of tape coats can become a suitable environment for certain types of microbiological attack to proliferate. Corrosion of the pipe then could ensue. Water intrusion under the tape coat would ensure additional coating disbondment. Until the lap of the anti-corrosive tape is broached, there would be no change in the apparent current density requirement on the tape coated pipe due to shielding. It is only after a rupture of the tape lap occurs that an increase in current requirement would be apparent to the operator. Serious corrosion promulgated by MIC could proceed under the tape coat prior to the tape lap rupture.

During our survey of pipeline owners using proprietary tape coating systems, conventional monitoring such as pipe to soil potential surveys did not show any problems on these lines for more than 27 years. Then, in the words of the Company X engineer, "It failed quite suddenly"[1]. Corrosion may have been proceeding for many years on the disbonded areas under the tapes, but due to shielding the corrosion could not be detected by conventional means prior to tape lap failure. Only a smart pig survey by Company X determined that corrosion had occurred under the disbonded tapes. The work of Banach[16] appears to confirm the experience of Company X. Banach reports corrosion under disbonded tape coats in spite of pipe-to soil potential surveys that indicate the pipeline is protected. Banach also reports no evidence of shielding under coal tar, asphalt mastic, epoxy or urethane coatings.

Under similar environments widespread corrosion could occur undetected on large diameter waterworks pipe since there are no smart pigs available. Smart pigs ultimately could be adapted for the Ivie pipeline. The cost would be several million dollars for providing appropriate pig traps, building the line to accommodate the pigs, developing a larger pig, and performing the actual pigging surveys.

If our theory is correct, the use of excessive cathodic protection in conjunction with a tape coating system could be a horrific mistake. Fortunately, there are alternatives such a sacrificial anodes, or potential controlled rectifiers that reduce the likelihood of over protection.

Magnesium anodes provide some assurance that excessive cathodic protection would not occur. There are still circumstances where even magnesium anode cathodic protection probably could produce substantial disbondment for several thousand feet along a polyethylene tape coated pipeline. This would occur in the event that the sacrificial anodes were located in low resistivity soils and a small number of holidays were distributed along a perfectly coated line several thousand feet from the anode location. Since there is no current requirement except at these small holidays, even the application of 50 milliamperes from a single magnesium anode could result in substantial cathodic disbondment at remote holidays. Therefore, while it is clear that magnesium anodes represent a quantum leap in safety over an uncontrolled impressed current system, they are not without risk. We believe that zinc has a low enough potential to be safe. However, there are some practical and economic considerations in using zinc anodes except in low resistivity soils.

DISCUSSION OF MORTAR COATED TAPE COATING ALTERNATIVE AND NO CATHODIC PROTECTION

The Department of Transportation's Office of Pipeline Safety mandates cathodic protection on all interstate pipelines in the oil and gas industries. Similar laws exist within each state for intrastate pipelines. Presently there are no such requirements for cathodic protection on water pipelines. Conventional wisdom indicates that dielectric coated pipelines should not be placed in the soil without cathodic protection. The reason is that the long line galvanic currents concentrate at the few holidays with the result that the corrosion rates are intensified at these holidays. Corrosion perforation of the pipe will occur more quickly on a dielectric coated pipe laid in the soil than on an uncoated pipe[17]. In both cases no cathodic protection is assumed.

However, the Metropolitan Water District's experience with their type B coating (i.e., 3/4 of an inch (19mm) of mortar over coal tar enamel) defies this conventional wisdom since no corrosion leaks have occurred on their coated pipe in over 50 years, even with no cathodic protection. Their experience seems to indicate that the alkalinity from the mortar coating makes a difference. Apparently the mortar alkalinity provides some form of corrosion protection at the holidays in the underlying coal tar enamel coatings.

If this theory is correct, there appears to be no reason why holidays in the 30 mil (0.76mm) anti-corrosive tape coat with one inch (25mm) of mortar overcoat should behave differently. This coating system is shown in Figure 11. We can think of no reason why the alkaline environment provided by the mortar over coal tar enamel would not provide the same corrosion inhibition for a tape system at holidays in the 30 mil (0.76mm) tape coating. This corrosion inhibition from the mortar alkalinity is much less likely to occur if multiple mechanical barrier tape coats are sandwiched between the mortar and the anti-corrosive tape. For this reason, the use of such mechanical barrier tapes under mortar is counter-productive.

SUMMARY

A unique property of tapes is that their cohesion exceeds their adhesion. In addition, tapes have low adhesion to the pipe relative to most other coatings. On coatings like coal tar enamels, epoxies and urethane the adhesion is not only superior to the cohesion, but also these coatings bond more firmly to the pipe. Based on these different properties, the author postulates a wide radius of disbondment failure on tape coats that occurs both from excessive cathodic protection and corrosion caused by cyclical wetting and drying. MIC subsequently may also occur under the disbonded tape. Detection of corrosion under the disbonded tape is only possible by a potential survey after the tape lap is broached, corrosion failure of the pipeline occurs, or by a smart pig survey. Smart pig surveys are currently not available on large diameter water transmission lines with mortar liners. The field observations of both Company X, Banach and the American Gas Association Technical Committee appear to corroborate the mechanisms of tape disbondment and subsequent corrosion failure postulated in the CCS study.

CONCLUSIONS AND RECOMMENDATIONS

Ivie Pipeline

The 30 mil (0.76mm) tape coat with a one inch (25mm) mortar overcoat is a viable system. It should be used with the following caveats. First, the 30 mil (0.76mm) anti-corrosive tape must not be significantly damaged prior to or during the mortar overcoating operation. Second, no cathodic protection should be used initially on the 30 mil (0.76mm) tape coat with a one inch (25mm) mortar overcoat.

Other Pipelines

The use of PE tape coats as a pipe coating should be restricted as follows:

1. PE tapes should not be used for new construction in environments where soil sheer stress is known, i.e., soils with a high plasticity index unless they are overcoated with an inch of mortar used both as mechanical barrier and as a chemical shield.
2. PE tapes without mortar coating should only be used for rehabilitation in cases where the required additional life expectancy is short, i.e., 20 years or less.
3. PE tapes are not compatible with conventional cathodic protection.
4. PE tapes can only be used with closely controlled and carefully maintained cathodic protection such as automatic potential controlled rectifiers or zinc sacrificial anodes.
5. When mortar coatings are employed with PE tapes, the mortar coating should be applied directly over a 30 mil PE anti-corrosive tape without the inclusion of additional layers of mechanical barrier PE tapes.

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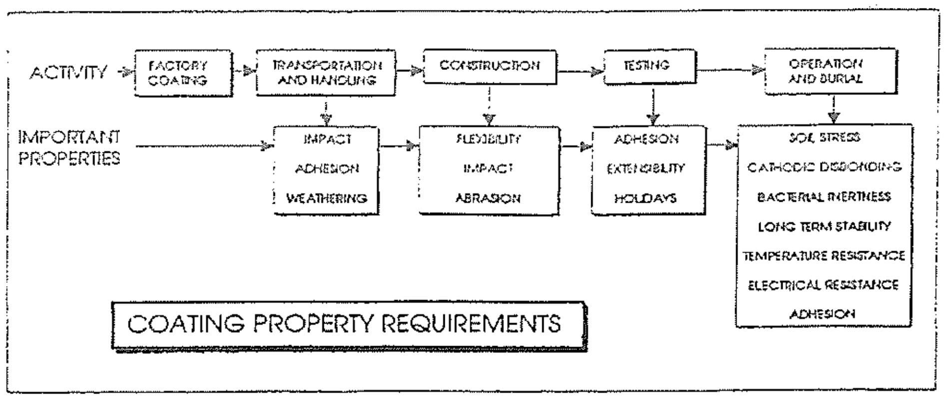

FIGURE 1 - Coating Property Requirements

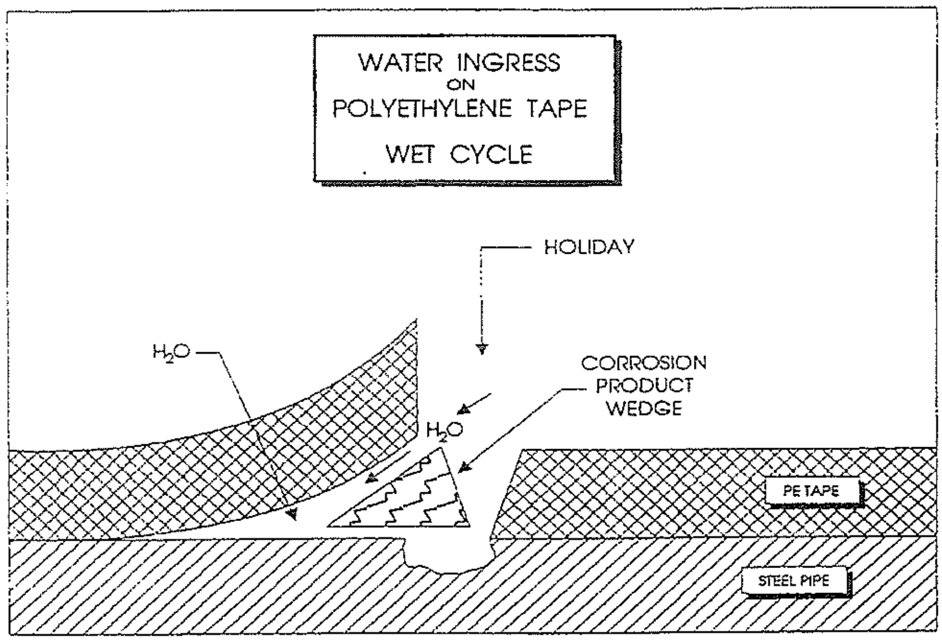

FIGURE 2 - Water Ingress on Polyethylene Tape Wet Cycle

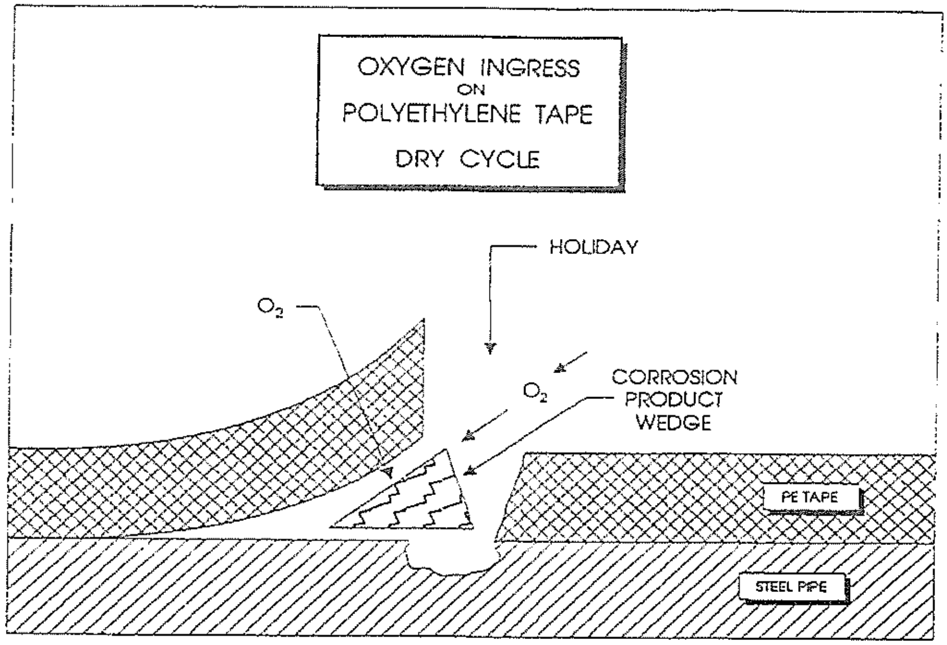

FIGURE 3 - Oxygen Ingress on Polyethylene Tape Dry Cycle

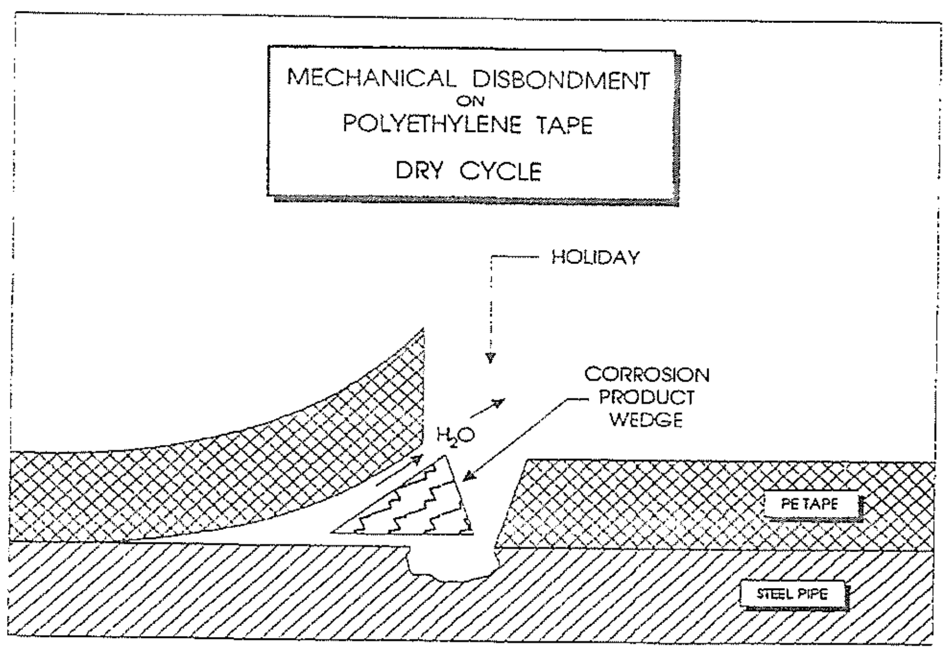

FIGURE 4 - Mechanical Disbondment on Polyethylene Tape Dry Cycle

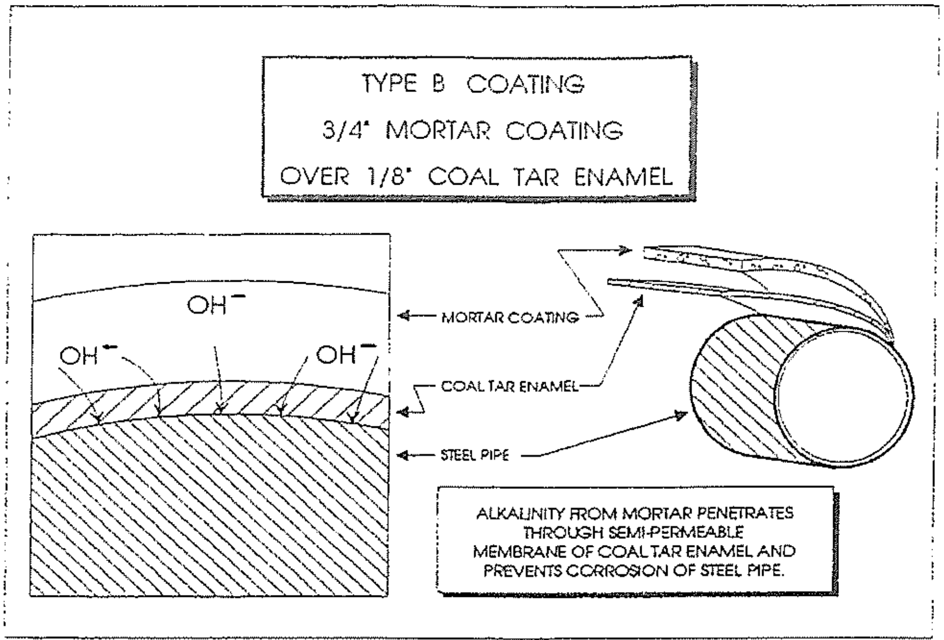

FIGURE 5 - Type B Coating
3/4" Mortar Coating
Over 1/8" Coal Tar Enamel

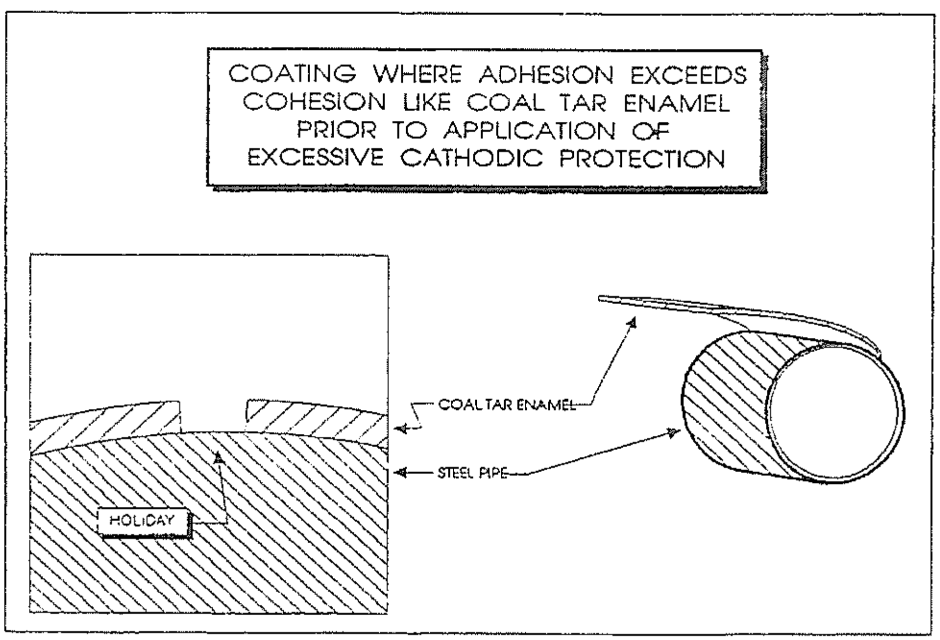

FIGURE 6 - Coating Where Adhesion Exceeds
Cohesion Like Coal Tar Enamel
Prior to Application of
Excessive Cathodic Protection

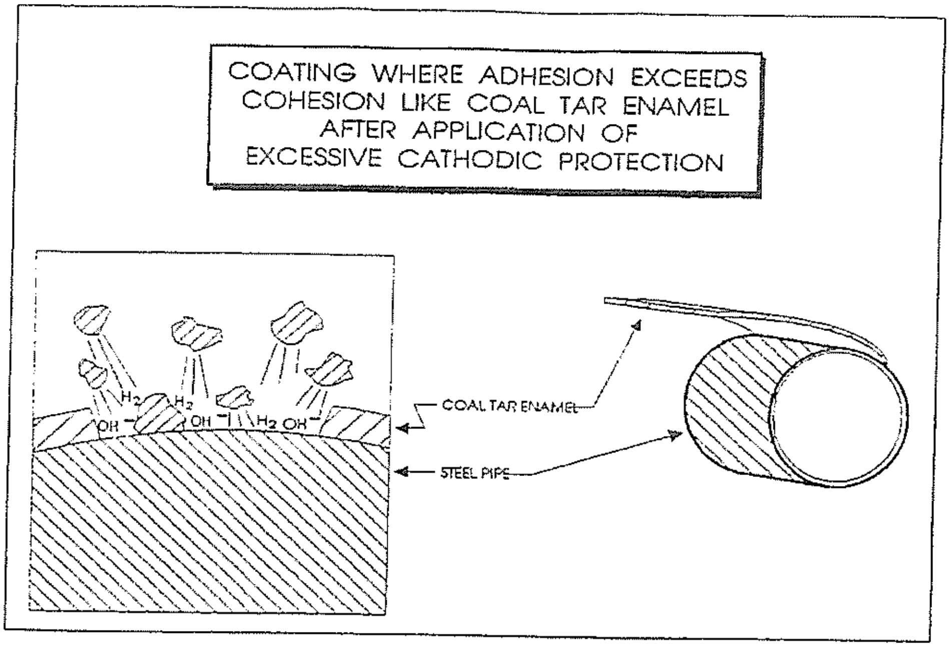

FIGURE 7 - Coating Where Adhesion Exceeds Cohesion Like Coal Tar Enamel After Application of Excessive Cathodic Protection

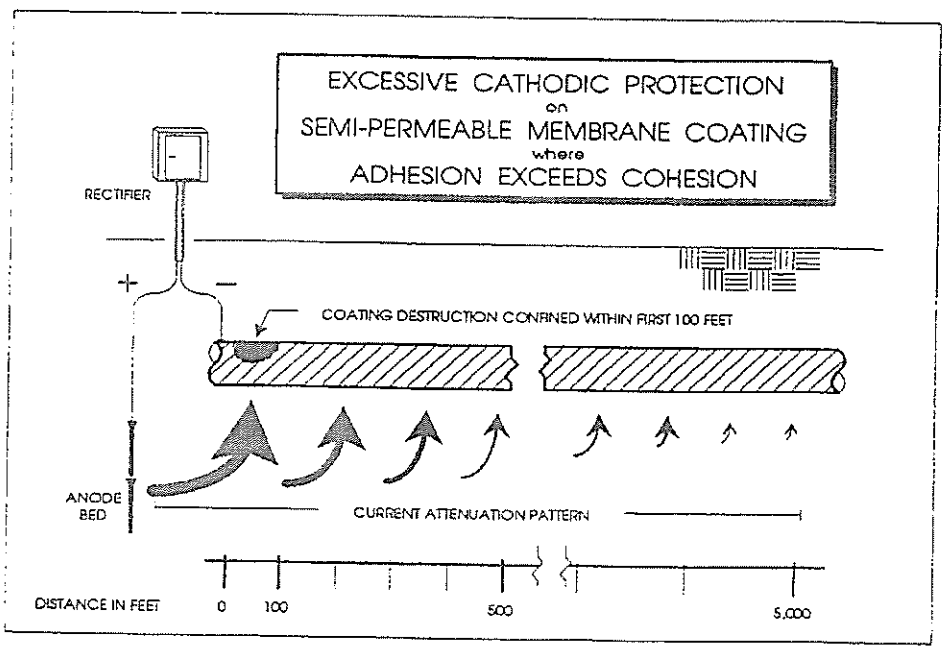

FIGURE 8 - Excessive Cathodic Protection on Semi-Permeable Membrane Coating Where Adhesion Exceeds Cohesion

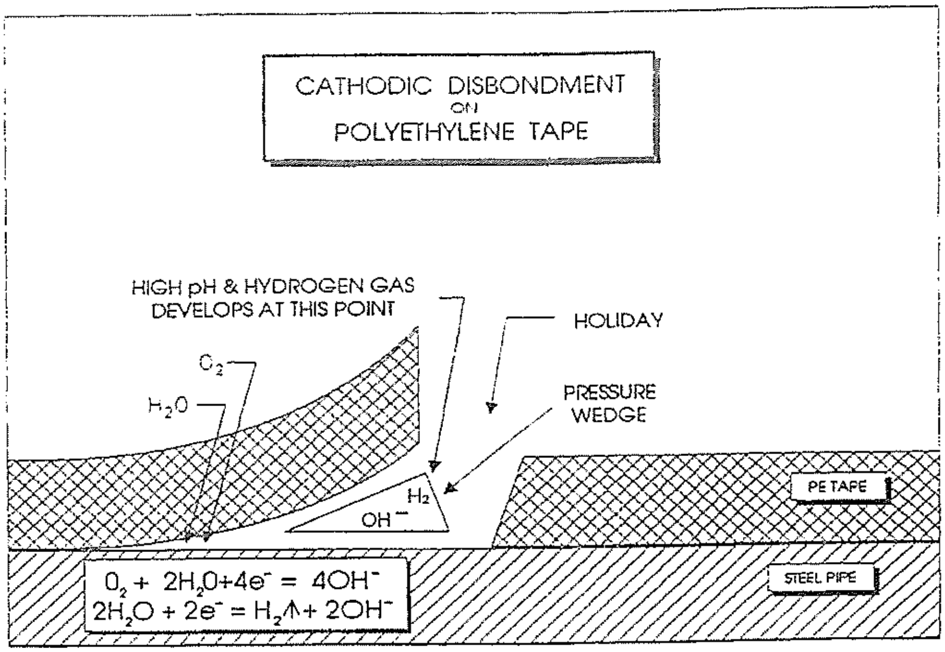

FIGURE 9 - Cathodic Disbondment on Polyethylene Tape

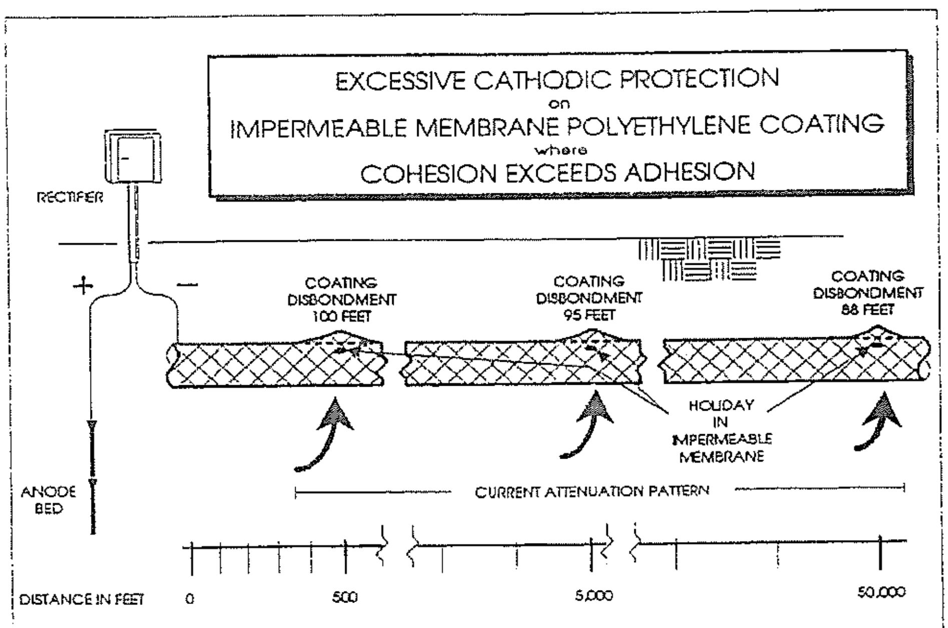

FIGURE 10 - Excessive Cathodic Protection on Impermeable Membrane Polyethylene Coating Where Cohesion Exceeds Adhesion

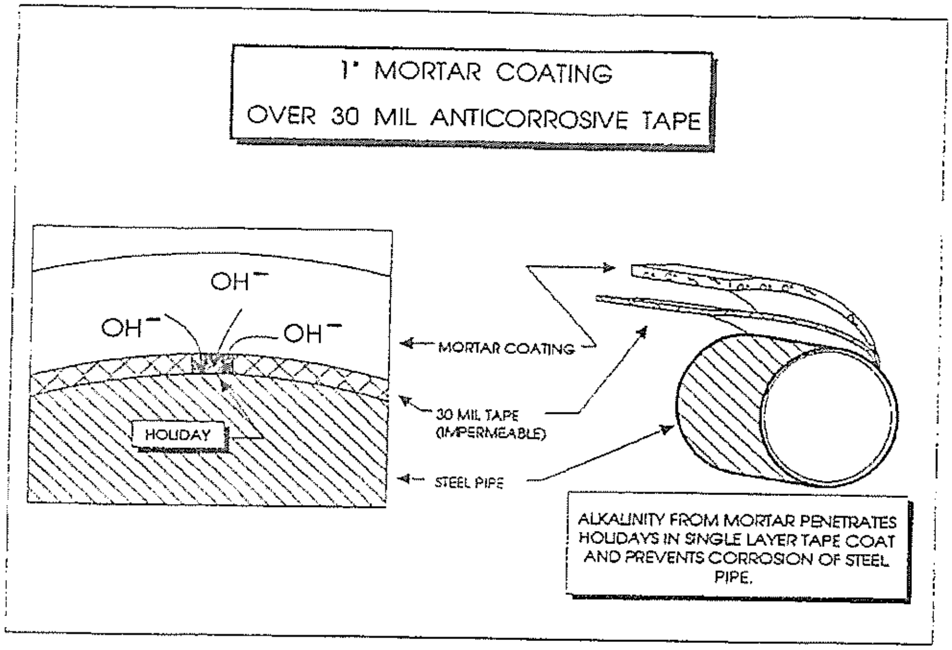

FIGURE 11 - 1" Mortar Coating Over 30 Mil Anticorrosive Tape