PERFORMANCE EVALUATION OF CORROSION IN PIPELINE COATING

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ABSTRACT

The performance behavior of four corrosion resistance coating materials applied for protection of pipeline metal was studied. These coatings were: polyvinyl resin, an organic zinc, epoxy resin, an epoxy polyamide and an epoxy ester. The performance of these coatings was evaluated under the same conditions of coating thickness, temperature, pH of corrosion, and exposure time. Considering the particular corrosive medium (acidic or alkaline), the most suitable coatings were ascertained, under the same test conditions. The coatings were applied on a low carbon steel metal (coupon) and immersed in both acidic and alkaline environment of usage. Results obtained indicate that corrosion rate decreases with increase in coating thickness beyond which it begins to increase. The results also showed that corrosion rate increases with temperature and acidity (decrease in pH) and also with increase in duration of usage. Based on the results obtained; at moderate pH range between $5 - 6$, epoxy polyamide offers the best protective ability hence recommended for pipeline system in a low pH environment. Also, it was observed that in low carbon steel systems immersed in sea water (alkaline) environment with pH 8 for a period of $14 - 84$ days, the organic zinc exhibited the best protective ability, thus, would be recommended for pipeline systems in sea water environment under a longer exposure time.

INTRODUCTION

1.1   Background of Study

Corrosion is considered to be one of the major reasons for the failure of pipeline while they are in use. This has numerous costly implications, depending on the use of the pipeline. For a pipeline used to transport hydrocarbon products, this results in loss of the product being transported, environmental pollution, health and fire hazards. And for the owner of the pipeline, loss of huge investments made on the pipeline.

First attempt to control pipeline corrosion relied on the use of coating materials with the reasoning that if the pipeline metal could be isolated from contact with its surrounding earth, no corrosion could occur, this concept is entirely reasonable and logical and in many instances, the most effective measure that can be taken for the protection of pipeline in a corrosive environment.

A coating is any thin material, applied as a liquid or powder which on solidification, is firmly and continuously attached to the structure in which it is designed to protect and which prevents contact of the environment with the structure. The coating acts as a barrier to prevent chemical compounds and/or corrosion current from contacting the pipeline material. Coating may be applied to enhance appearance, increase the capacity of pipelines, prevent deposition, prevent contact, contamination, or prevent corrosion. For this study coating applied for protection against corrosion are of interest more than the others, however corrosion control coatings may also improve appearance.

1.2   Objective of the Study

The objective of this study is to investigate the performances of various kinds of coating materials applied for protection of pipeline metal against corrosion, and possibly ascertain the most suitable coating that withstands the particular environment (acidic or alkaline environment). This would be achieved by studying the effects of temperature, exposure time (durability), pH of corrodant and coating thickness on the performances of the various coatings applied on low carbon steel metal immersed in the specific corrosive medium. Also, the corrosion rate would be obtained, in order to evaluate the best coating materials at the different process conditions.

1.3   Research Methodology

This study would be done experimentally to achieve the desired objective. Specifically, sample test in field method would be employed.

1.4   Scope of Study

Various kinds of materials are used for the protection of pipelines from corrosion. These are; coal tar, wax & vinyl tape, asphalt all of the early YOs and the more recent ones like polyethylene, fusion bonded epoxies and polyurethane-6. This project studies the performance behaviour of four corrosion resistance coatings such as Inter Zinc 72 (organic zinc epoxy

resin), intergard corrosive primer (epoxy polyamide), interprimer-etch, primer (poly vinyl resin containing sulphuric acid), and inter prime CPA 124 (Epoxy ester) coatings.

Acidic and alkaline environment would be used to ascertain the most suitable coating materials under the same condition of coating thickness, temperature, pH and exposure time.

LITERATURE REVIEW

2.1   CORROSION OF PIPELINES

Corrosion of metallic pipelines in moist air is a very common phenomenon, this happens as a result of the pipeline metal not being protected; this constitutes a considerable annual loss to various organizations which have huge investments in pipelines.

Corrosion is defined as the deterioration of a metal by chemical or electrochemical reaction with its environments. This deterioration takes place in different ways, depending upon the corrosive media, temperature, presence of other metals, and other factors.

The process of corrosion can be explained by the electrochemical theory. This presupposes, firstly an aqueous electrolyte and secondly some disequilibrium which is exhibited as a difference of potential causing an electric current to flow between parts of the metal via the electrolyte.

By the electrochemical theory of corrosion, metallic corrosion requires four elements; an anode, a cathode, an electrolyte (e.g. moisture) and an electrical path (e.g. metal) joining the anode and cathode.

The anode is the part of the metal where corrosion occurs. It actually sacrifices itself as it releases positively charged metal ions into the electrolyte and electrons and left behind in the metal. These electrons flow through the metal to protect the cathode. The cathode is protected because various ions or compounds in the electrolyte consume electrons. An electrolyte is a solution capable of conducting electrical current in the form of ionic flow. An electrical path is a connection between that anode and cathode where current in the form of electrons can flow. Free electrons do not flow in the electrolyte, only in a metal path.

Corrosion occurs because anodes and cathodes are inherent in all metals, and all metals are electron conductors. Anodic and cathodic components can be microscopic in size or rather large in some cases. Therefore, three of the four requirements for the corrosion process are inherently present in every metal. The only remaining element required for the corrosion process to begin is an electrolyte. Anodic and cathodic areas develop where chemicals have been deposited, where there are temperature differences and where there are damp areas. Chlorides and other industrial contaminants in the electrolyte can cause an area to become anodic. The contamination may be present on the metal sauce before it is coated or insulated. Once these areas become wet, corrosion begins. The corrosion of metals requires the following conditions:

- An anode, a cathode, an electrical path, and an electrolyte must all be present.
- The anode and cathode must be in contact with the same electrolyte.
- The metal must electrically connect the anode and cathode for electrons to flow; and
- The anodic (oxidation) and cathodic (reduction) reactions must be equivalent and simultaneous

If any of the above components is missing or disabled the electrochemical corrosion process could be stopped. Clearly, these elements are thus fundamentally important for corrosion control.

Corrosion of buried metal pipes occurs in an aqueous environment which becomes the electrolyte. As is well known, soil contains moisture to a greater or lesser degree, and unless this can be prevented from reaching the metal, conditions favourable to corrosion easily arise. The application of a suitable insulating coating: A coating which positively prevents access of moisture to the metal's surface will prevent corrosion.

2.2   Pipelines Coatings

Coatings provide protection against corrosion of metallic pipelines by application on the pipeline surface and thus preventing the pipeline surface from coming into direct contact with the corrosive environment.

The materials that are mostly used as coating are classified under the following five groups:

1. Hydrocarbon Base
   a. Natural - these are primarily made up of repeating hydrocarbon chains. They include:
      i)   Asphalt enamels and mastics
      ii)   Coal tar enamels and mastics
      iii) Greases.
   b. Synthetic: these are classified as synthetic plastic because they are manufacture and not obtained directly from natural sources. Also, there major structure is that of repeating carbon - hydrogen groups that are caused to link together or polymerize by heat, pressure and catalysts. Their starting monomers are generally ethylene, propylene and styrene, they include:
      (i)   Polyethylene
      (ii)   Poly propylene
      (iii) Butadiene - styrene
2. Reins or Plastics - This group represents on of the largest groups of coating materials. They include
      (a) Epoxies
      (b) Acrylics
      (c) Poly ethylene
      (d) Vinyls

      (e) Phenols

      (f) Poly esters

      (g) Chlorinated rubbers

3. Metallic

    (a) Powder Zinc; This represents a unique class of coating containing 60 to 75 percent weight of zinc powder in the dried film. The zinc and binder act as diffusion banner to moisture vapour and salts in marine environments. Also, the zinc pigments corrode sacrificially to protect the underlying steel. Two types of binders for the zinc powder are;

        i. Inorganic binders, which require post curing of the coating after application with alcoholic phosphoric acid.

        ii. Organic binders, which are self curing moisture adsorption.

    (b) Fused, plated or chemically deposited: Done by hot dipping, electrolysis and also by molten or plasma spray. Metals used are; aluminum, Nickel, stainless steel and zinc.

4. Cement and Concrete Sheeting: Cement linings are effective for internal protection of steel tubulars handling corrosive salt waters. They are also used for external protection of well casings, marine pilings and buried.

5. Composite Inorganic – These are mostly factory materials used for wear prevention and protection of steel at high temperatures. They include:

    (a) Ceramic-glass

    (b) Silicons

Michael Henthorne has stated that the selection of an effective coating material depends on the environment in which it is to be used, the method of application and the nature of the bond between the base metal and coating. The physical chemical and thermal properties of the coatings vary under different test conditions (temperature, PH of corrodent etc). Some are more resistance to acidic while others are more resistance to alkaline media. The case of application of these coatings with the available technique is also important for if it is not properly applied, poor bonding with the metallic surface results which can result in cracking of the coating or other defects thereby reducing their productivity. Pour baxi M. illustrated the effects of corrodent the rate of corrosion and its protection by studying the effect of the conductivity, PH, and temperature on corrosion rate. Corrosion rate increases with increase in conductivity of the corrodent. Corrosion rate increases as the PH of water decreases (becomes more acidic), although extremely high PH solutions can also be corrosive.

Corrosion rate also increase in temperature for a closed system because there is no escape of dissolved gases but increases at higher temperatures for open system because of the escape of dissolved gases.

2.2.1 Bituminous Enamels

These are referred to hot applied coatings of coal tar or asphalt, both of which are usually used in combination with reinforcing and protective wrappers. Enamels are formulated with various fillers and extenders of inert materials to produce various grades to sent pipeline conditions. For example, some grades permit application to pipe during periods of low ambient temperature which would result in extreme brightness and cracking. These materials are mechanically brittle and have a relatively low adherence to steel especially at high temperatures. The main drawback of bituminous enamels as far as pipeline transportation and laying operations are concerned, is there mechanical brittleness combined with their relatively low adherence to steel especially at high ambient temperatures.

These coatings are mainly those made with coal tar, they have a very low flexibility at low temperatures that makes bending practically impossible without cracking.

Pollyanna, R. confirmed the good in service performance of bituminous enamels especially for offshore concreted lines even in cases in which the operating temperatures are high. However, most eternal corrosion problems with coating pipelines have been reported.

On a pipelines laid in Iraq, corrosion occurred underneath an over the ditch applied with coal tar enamel coating shortly after installation, which resulted from a complete lack of coal tar on a lateral side, leaving the glass fabric and outer wrap unimpregnated and some rusting were noticed despite a satisfactory level of cathodic protection.

Corrosion under disbandment bituminous coating was discovered on a buried pipeline in Tunisia, after some 20 years of operation while cathodic protection was efficient and routine potential measurements did not reveal any anomaly. It was later found that the corrosion had been caused by massive water entry under fully did bonded coating at the lower pipe side. This shows that when the pipeline temperature is not high, this type of corrosion hazard must be considered as a major drawback making this kind of coating protection much less efficient than the more modern ones.

The risk of corrosion under disbanded coatings is possible lower in offshore pipelines and perhaps practically nil as a result of the nature of seawater. Recent investigations by R. Mollan and S Eliassen showed that cathodic protection is efficient if seawater is stagnant in the crevice and corrosion can occur if circulation exists under insufficiently negatively applied potential.

2.2.2 Polyethylene Coatings

Polyethylene coatings applied in the plant whether by fusion of powder or longitudinal or side extrusion over a copolymer adhesive coat were introduced in Europe. These are used for onshore and offshore pipelines. It is necessary to ensure a high shear strength between concrete and the polyethylene to avoid any risk of slipping in the pensioners if used together with concrete.

Quenelle A. Glonot P, and Sistanz E provided solution to this problem in France in their study, obtaining a rough finish with polyethylene powder, which leads to a shear strength of 100Tm

to be compared with values below 20T 1m with a smooth surface finish. Another solution also used was the reinforcing effect of side extrusion. There has not been a source of particular difficulties in this coating, application but serious adherence problems, mainly related to too low temperature during application, were experienced in 1975 with the first pipeline to be coated by the extension process. it was further stressed that very rapid degradation of polyethylene coated line pipes stored outside occurred and this was attributed to the effect of intense ultraviolet (UV) radiation. This type of coating is hence advice not to be exposed to the sun for long periods.

Roche M. and Samaran J. also showed that the in-service performance of polyethylene coatings has been excellent but a case of massive disbanding consecutive to damage by trawlers was experienced in Italian offshore pipeline and the failure was probably assumed to be from unsatisfactory ageing of the older polyethylene coating systems.

2.2.3   Fusion Bonded Epoxy Coating

These thin coatings were introduced in Europe at the end of the 70's. Epoxies are prepared by the polymerization and cross-linking of aromatic diepoxy compounds. FBE is an epoxy-based powder coating that is used to protect various sizes of pipes used in pipeline construction, concrete reinforcing rebars etc. from deterioration due to corrosion. FBE are in the form of dry powder at normal atmospheric temperature. At coating temperature ranging from 180 - 50%, the contents of the powder melt and transform to a liquid form. The liquid FBE film wets and flows on the steel surface on which it is applied, and soon becomes a solid coating by chemical cross-linking, assisted by heat. This process is known as fusion bonding. The chemical cross-linking reaction taking place in this case is irreversible meaning that once the airing takes place, the coating cannot be converted back into its original form by any means. Application of further heating will not melt the coating and thus it is a thermoset powder coating.

One of the major advantages of this coating is that the mechanical damage remains localized and as a result of the high adherence in both steel and the thickness of the coating, the risk of corrosion beneath disbanded coating is practically ni1l. When the pipes are to be bent or coiled, the thickness must not exceed 500 to 550 Um. Cracking was experienced during the bending of pipes installed on the Liquefied as a result of the increase in film thickness up to 600 to 800 Um done to avoid too many pinholes caused by the poor surface condition of the seamless pipes. Roche M. and Samara J. P during an inspection of the coating of a hot gas pipeline (990C installed on the liquefied) showed the good general behavior of the epoxy used, although some little blisters were found in very localized areas. They equally reveal substantial mechanical damage on a hot oil offshore pipeline (100 to 1100C at riser inlet) laid in Angola during an underwater inspection and attributed the cause probably to rough laying conditions. No blistering occurred on the epoxy coatings through some limited disbanding around the mechanical defects was noticed.

Epoxies have good adhesion to substrates and high resistance to heat and chemicals.

2.3 Properties of Coatings Materials

There are certain properties that are required of a material that could be used for anti-corrosion prevention of pipelines. No one coating possesses all these properties. Coating selection is normally a compromise, based on the environment of use. Some of these properties are listed below.

1. **Resistance to moisture penetration**: Water is one of the components that must be present for corrosion to occur, and it is invariably in must environment in which pipelines are used. A good coating must therefore be able to prevent water prevention through it to attack the pipeline.
2. **Good adhesion to the substrate pipeline**: A coating material must allow good adhesion to the substrate (pipelines). This prevents coating holidays, which cause corrosion.
3. **Fast curing time**: Coatings should also allow fast curing time, in order to prevent changes in coating thickness measurement after curing.
4. **Mechanical properties e.g. toughness and impact resistance**: A good coating must also possess adequate mechanical properties. This includes toughness, impact resistance, wear and resistance.
5. Resistance to acids and other corrosive environmental conditions.

2.4 Guides to Coating Selection

Peabody A. W. stated that coatings, if specifically selected should have the lowest applied cost per unit length of pipe and still have the desirable characteristics of good electrical and mechanical strength and long term stability under the environmental conditions existing. It is therefore necessary to consider the following factors before the selection of any coating:

1. Can the coating having satisfactory corrosion resistance applied by a technique that is available for your requirements?
2. Which coating system (if any) will resist corrosive attack for a minimum, practical period of time?
3. Will the pipeline be operated at temperature substantially above that of normal soils? If so, what is the maximum operating temperature?
4. Is the soil a type which will subject the coating to damaging soil stress?
5. Will the coating be compatible with your services apart from its corrosion resistance (e.g. is abrasion resistance satisfactory)? Each coating system considered must be determined, particularly with respect to limitations beyond which good performance cannot be expected.

The need for an effective coating selection has been emphasized. Here, various coatings have different protective capabilities under rocky conditions, soil stress and varying temperature conditions. If further advised the use of coating system that will resist impact damage and penetration by steady pressure for rocky conditions, materials that resist distortion should be used if soil stress is a problem and materials that will not embrittle and crack at low

temperatures should be used if ambient temperatures are extreme. Also, materials that will not soften and be easily damaged during handling should be used if temperatures are extreme. The principal results for the comparative test programs covering the main families of pipeline coatings have been published.

2.5   Surface Preparation for Coating Application

The success or failure of a coating will often be decided at the surface preparation stage and the cleaning technique will depend primarily upon the following:

1. Condition of the starting surface. It is required to remove oxide scale, heavy rust, etc or just atmospheric dust?
2. Coating for example;
   (a) Is the coating surface ready? Is the surface smooth enough?
   (b) How effective will the coating isolate any residual dirt from the service environment as to prevent it from growing changing volume etc.?
3. Size and location of the article to be cleaned.

Surface preparation can be done by wire-brushing or blast cleaning and the effective procedures to enhance performance have been stress. These procedures are necessary to avoid coating defects like blistering cracking and peel like blistering cracking and peeling or flacking.

2.5.1   Surface Preparation by Blast Cleaning

Blast cleaning involves cleaning of corroded metallic surfaces by the use of abrasives which are sprayed to the corroded surfaces by the use of compressing machines. Suitable abrasives in use include:

1. Sand-when permitted by local authorities.
2. Blast furnace slag
3. Steel shorts
4. Chipped steel wire
5. Copper slag.

Abrasives for blast cleaning shall not contain particles larger than those passing standard sieve series 16 (BS) or 1.00mm and in no case shall the abrasive contain particles smaller than 0.18mm. The abrasive must be free from oil, grease, moisture, etc. which affect the adherence of coating to the steel surface. Re-used abrasive shall be clean and reasonable sharp. They are not rusty, noticeably worn or dull when compared with fresh material.

Steel surfaces to be painted shall be cleaned by means of white metal sandblasting until an even white-metal color is obtained and surfaces shall remain slightly rough in order to guarantee adhesion.

Air compressor shall supply continuous air at specific volume and pressure and the compressed shall be water and oil free. It shall be stated that for effective coating sand-blasting should be

allowed only during daily hours (sunny period) and not on most surfaces which can be moist before coating application.

Sand-blasted surfaces shall be brushed before first coat application and dust removal can be done by means of clean dry compressed air or industrial fan and only dry from sand-blasting before sunset (on the same day) and before rust appearance and no acid wash-up cleaning solutions or solvent shall be used on sand blaster surfaces.

2.6   Application Procedures for Coatings

Extensive study by Peabody, A-WI has reviewed the application procedures which can influence the quality of a completed pipeline coating and they are briefly discussed as;

1. A properly cleaned pipe surface: All oil and grease must be removed by solvent cleaning sand short or girt abrasive cleaning will effectively remove all other material and leave the best surface for acting application. Line traveling cleaning machines equipped with steel brushes and scrapers can be used for cleaning pipelines (coated "over the ditch") on job sites. However, it is not very efficient at removing strongly adherent materials.

2. Careful Priming Technique: Some coating materials used on pipeline require or perform better with a primer of a material designed by the manufacturer to give the best practicable bond between the pipeline metal and the coating. Primer application must be on a previously cleaned dry surface, so priming during raining conditions obviously is wrong. Avoid moisture from early morning dew, condensation under certain conditions of temperature and humidity and (when coating under blow freezing conditions) frozen moisture which may make the pipe appear dry- The application of some primers on such surfaces will lead to poor bonding performance. Some public priming materials have been confirmed to have a limited effective life after application. They tend to go "dead" if application of subsequent coat is delayed so long. repriming is required than if adequate bond is to be attained. On the other hand, with most coating materials, the primer should be dry (unless specially indicated otherwise by the coating manufacturer) before subsequent coatings are applied. This factor is important when hot coatings used will vaporize unevaporated solvents in the primer to cause bubbles or holidays in the coatings.

3. Specifications: No pipeline coating should be done without rigid specifications which spell out every step of the coating procedure to be used. Such specifications are necessary to ensure that the materials being used are applied in a manner which will lead to the best coating of which these materials are capable. The following areas should be covered by specifications.

    (a) Cleaning the pipe surface
    (b) Priming, if required
    (c) The coating materials to be used and (if more than one material the order in which they are to be applied).
    (d) Inspection requirements
    (e) Basis for rejection of unacceptable coating

(f) Backfilling requirements

(g) Procedure for repair of coating defects.

4. Handling, Placing and Backfilling: A good coating may be damaged by rough or careless handling and defect. Free pipeline coating should be lowered into the ditch suing padded slings. The ditch must be free from rock, other foreign matter and projections so that the coated surfaces will bear on a smooth bed. Furthermore, during the entire lowering-in process care must be taken to repair any coating damage detected during the procedure. Severe coating damage can be caused by careless backfilling operation when rocks and debris striking the line break the coating. Only dirty which is free of projects capable of damaging the coating should be allowed to strike the coated pipe directly.

5. Inspection: Proper inspection ensures maintenance of high standards of coating application in accordance with established specifications. It services as a sound basis for acceptance or rejection of the completed coating. The inspector should be on the job always, keeping every phase of the coating operation under constant surveillance.

2.7 The Effect of Electrolyte Composition on Corrosion

There are two aspects to the effects of electrolyte on corrosion, those which affect conducted and those which affect the basic corrosive potential of the system. The latter have to do with the presence or absence of oxidizing agents which are necessary for the carrying out of the catholic part of the corrosion cell reaction.

These factors are usually the most important ones since the anodic reaction cannot occur in the absence of corresponding catholic reaction, regardless of the conductivity of the electrolyte.

Fortunately, it has been shown that only two corrosives (oxidizing agents) need to be considered in the great majority of corrosion problems. These are hydrogen ions (acidity) and oxygen. Since different measures are appropriate to combating corrosions from these two different sources, one of the first steps in combating a corrosion problem should be to determine which corrosive is involved.

2.7.1 Conductivity Effect

The more conductive the electrolyte, the easier current can flow, and if nothing else shows down the corrosion reaction, the faster corrosion will. It is important to realize that the amount of metal which dissolves is directly proportional to the amount of current which flows between the anode and the cathode.

Distilled water is not very corrosive and is not very conductive while salt water is quite conductive and can be very corrosive. The presence of dissolved gases cause a low pH of the electrolyte may make a low conductive electrolyte very corrosive. Conversely, very salty water may be virtually non corrosive if it contains no dissolved gases or other oxidizing agents. The importance of conductivity is its effect on the case of transporting current from the anode to the cathode. The more conductive the electrolyte, the less driving force is necessary to make the corrosion reaction proceed if all other conditions remain constant. In the oilfield, where

mixtures of crude oil and water are concerned, the conductivity becomes more difficult to define. A mixture of a salty, highly conducive water in oil (which is non conductive) may not be corrosive if the water is emulsified in the oil. However, if the water in oil (which is non conductive) may not be corrosive if the water is emulsified in the oil. However, if the water is produced as free as water, a very corrosive condition may exist.

2.7.2   The Effect of pH

The effect of water is commonly expressed as a number between 0 and 14 is the negative logarithm of the hydrogen ion concentration

pH - log (H)

<div align="center">Neutral</div>

The corrosion rate of steel usually increase as the pH of the water decrease (becomes more acidic), although extremely high pH solutions can also be corrosive.

2.7.3   The Effect of Temperature

Corrosion rate usually increases as temperature increases because all of the reactions involved speed up. In a system open to the atmosphere, corrosion rate may increase at first and then with a further temperature increase. The corrosion rate may drop off due to dissolved gases coming out of the solution. If the system is closed, the corrosion rate will continue to increase with temperature because the dissolved gases have no place to go.

2.8   Evaluation Of Pipeline Coatings

The durability of anti-corrosion pipeline coatings are often evaluated by a variety of tests. They are either an accelerated test that mimics the effects of time or by long-term atmospheric exposure to a particular environment. The most common type of evaluation tests are as follows;

1. Abrasion Resistance of Pipeline Coatings: The test is done on coated pipelines due to the fact that most pipelines are used in environments in which they are either buried or put just above the soil. And as such sands and other abrasives usually come in contact with them. This test method is an accelerated test procedure for determining the relative resistance of steel pipeline coatings to an abrasion environment.
2. Water Penetration of Pipeline Coatings: The presence of water is a major cause of corrosion to pipelines and other steel structures. When a pipeline is coated with a coating material, the coating must not allow water to come into contact with the pipeline. The coating acts as barrier, and its effectiveness in preventing water from

penetrating through it to cause corrosion on the pipeline substrate is usually evaluated by this test method. The method covers the determination of the apparent rate of depth of water penetration into insulating coatings applied to pipe.

3. Impact Resistance of Pipeline Coatings (Falling Weight): Various things could happen to a pipeline coating during its service life, which could influence its performance. One of such is solid objects falling on the coating, just after installation or while in use. A good coating should be able to withstand the impact of all kinds. This test method evaluates the stability of coatings and their impact resistance. It is determined by evaluating the energy required to rupture coatings applied to pipe under specified conditions of impact from a falling weight.

4. Holiday Detection in Pipeline Coatings: Coated steel pipes are exposed to variety of conditions in their journey from the coating plant to being buried in the ground and finally being put into operation. The coating is subjected to impact from other pipes and objects abrasion from being dragged around in contact with sharp objects, high shear stresses, temperature extremes, corrosive mediums, and electrical fields from cathodic protection systems. The results can be coating damage in the form of holidays, disbandment, material deterioration, and weakened coatings that fail prematurely during pipeline operation.

5. Outdoor Weathering on Pipeline Coatings: This test method is intended to define conditions for the exposure of coated pipe to weather. This test method specifies qualifications for the samples, procedure to be followed in exposure to weather and produce for evaluating effects of exposure including visual examination and other tests. Some of such evaluation tests normally carried in coated pipelines are:

6. Salt Spray: Also known as salt fog testing, is generally conducted according to ASTM Standard B 117. Testing of this type is considered useful when evaluating the behaviour of materials subjected to a marine environment.

2.9 Corrosion Rate Calculation

Corrosion rate R, is given as

R   =   mils per year (mpy)

Where

W   =   weight loss => mg
D   =   Density of Specimen => g/cm^3
A   =   Specimen Area => in^2
t   =   Exposure time => hrs
A   = $\frac{\pi}{2}(D^2 - d^2) + t\,\pi D + td$
D   =   Diameter of specimen
d   =   Diameter of mounting hole
t   =   thickness

Conversion

Inch   =   2.54cm
Inch   =   1000mil
1g   =   1000mg
365 days   1 yr

MATERIALS AND METHOD

3.1   Materials

The materials and equipment used in this project were mainly obtained from Willbros Nigeria Limited and the Nigerian Agip Oil Company. The brine (sea water) of PH 8 was obtained from the sea at Agip's Jetty Port Harcourt Base. The material's and equipments used for the coating performance tests include measuring tapes, vernier caliper, marking chalks, measuring cylinders, Beakers, Brine (sea water) of PH 8, sulphurric acid, plastic containers,, air tight stainless steel containers with a hook for the attachment of coupons underneath the cover coating e.g. integard corrosive primer (epoxy polyamide resin) inter zinc 72 (organic Zinc epoxy resin), interprime etch primer (polyvinyl resin) interprime CPA 124 Orange (Epoxy ester with red lead pigments) painting brush, wire brush, cleaning rag scraping knife, distilled water, hand clips, buffer solutions, cutting machines, magnifying glass, elco-meter.(thickness guage), autoclave, electronic balance, and pH metre.

3.2   Samples Preparations

Low carbon steel of density 7.82 g/cm3 were cold-cut to the sizes of 76mm x 25mm x 3mm using a cutting machine. These were cold-cut in order to maintain the same metallurgy of the steel throughout the experiment and to avoid the probable effect of heat affected zone on corrosion. The samples were then surface prepared according to the specifications given in the international protective coatings manual and stored in air-tight plastic containers to avoid atmospheric oxidation.

3.3   The Effect of Coating Thickness on Corrosion Protection (Coating Performance)

The samples were prepared as described in section 3.2 above. They were then weighed using sensitive electronic and identification numbers with weights attached on them. The mixing and the application of the various coatings were done in accordance with American Society for testing and materials (ASTM). The samples were thoroughly cleaned with a dry rag before coating application in order to enhance its bonding with the metal and after the cleaning operations; they were immediately coated to avoid atmospheric oxidation. The coatings were applied to the prepared surface, weighed and identified. Samples were coated to be the following thickness of 20, 30, 40, 50, 60 and 70 microns respectively by means of painting brush. Each coated samples was tagged with a paper bearing its weight before coating. The coated dried samples were fully immersed in air tight plastic containers containing euphoric acid of PH 5 for three months with the samples properly identified. Each coated samples was

placed in a separate container to avoid any probable chemical reaction among the coating which might affect their performance and their identification papers were properly attached. After the three month, the samples were removed, care being taken to retain the identification papers on the container of each sample.

3.4   Temperature on Corrosion Effect of Protection (Coating's Performance)

The specified thickness for each coating was ensured throughout the experiment by the use of elco-metre. Each coated sample was identified by an attached paper bearing the weight before coatings application, type of coating, application time and date.

After drying to specifications the samples were fully immersed in identified air-tight stainless steel containers containing sea water (brine) of pH 8. Adequate care was taken to ensure non direct constant of the coupons to the metallic containers by hanging them inside the container using. polymeric ropes. This was done to avoid galvanic corrosion.

The containers were properly identified and the autoclave was fixed to the required constancy in power supply during this test. These immersed inside the autoclave were allowed for two weeks at temperature of 30, 40, 50, 60, 70, and $80^{0}c$ respectively.

3.5   The Effect Of Ph On Corrosion Protection (Coating Performance)

The samples were prepared as described in section 3.2. They were then weighed using a high sensitive electronic balance and their weights identified the mixing and coatings applications were in accordance with the ASTM Specifications.

The corrodent, sulphuric acid of pH 2, 3, 4, 5 and 6 were obtained from a laboratory and their PH values were re-affirmed using a pH-metre as follows:

1. Connect electrode set to pH metre and immerse electrodes in pH of 7 buffer solution.
2. Set metre switch on battery check position and check condition of battery. Replace if weak.
3. Set metre switch on read position and adjust standardization control till metre reads pH of 7.0
4. Set metre on stand-by-position and rinse electrode with distilled water.
5. Immerse electrodes in PH of 4 or 10 buffer solution.
6. Set metre switch on read position and check the response of the metre (if metre will not respond to proper pH values, the above steps must be repeated, and the temperature control adjusted, until readings correspond to the buffer solutions used or the probe is determined to bad).
7. Set metre switch on stand-by position, immerse electrodes in samples to be tested. Set metre switch to read position. Allow enough time for the metre to stabilize, and read pH values of the corrodent (sulphuric acid). The weighed coated, dried samples were immersed in identified air-tight glass containers containing sulphuric acid of pH 2, 3, 4, and 6 for a period of three months. After three months the coupons were removed from their respective containers and the coatings were visually inspected.

3.6   The Effect of Exposure Time on Corrosion Protection (Coating Performance)

The various specified thickness for the coupon were in strict accordance to the ASTM specifications and this was ensure by the use of elco-metre. The corrodent sea water (brine) of PH 8 was confirmed of its pH using a pH metre and was placed in an air tight glass container. After the drying of the weighted, coated and identified samples, they were carefully immersed in air-tight plastic containers containing sea water (brine) which bears the dates of test period, the weights and type of coatings. The samples were usually inspected using a magnifying glass. The test periods are 2, 4, 8, 10 and 12 weeks and the same experimental conditions were maintained throughout the test.

RESULTS AND DISCUSSION

4.1   The Effect of Coatings Application Thickness on their Corrosion Protection Ability (Coating Performance)

Table 4.1 and figure 4.1 show the performances of the various coatings (intergard corrosive primeer, interzinc 72, interprime CPA 124 ee orange) applied on low-carbon steels and immersed in sulphuric acid of pH 5.

At a coating thickness of 20 microns, the interprime ee tech primer exhibited the best corrosion protection ability with a corrosion rate of 0.407 mpy while the intergard corrosive primer exhibited the least protective ability with a corrosion rate of 0.671mpy. At 30 microns thickness, the best protective coating was interprime CPA 124 ee orange with a corrosion rate of 0.273mpy while interprime etch primer was the least protective with a corrosion rate of 0.53mpy.
At 50,60, and 70 microns thickness, intergard corrosive Primer was the best protective coating with corrosion rates of 0.327, 0.307, and 0.422 mpy respectively.

Interprime CPA 124 orange is most protective at 40 microns thick, intergard corrosive primer is most protective at 60 microns thick and interzinc 72 is most protective at 50 microns thick. The thickness at which interprime etch primer is most protective is assumed to be below 20 microns thick and this deviates its graph from others. The relative decrease in productivity of this interprime etch primer with increasing coating thickness could be attributed to its high phosphorus content which catalyses the entry of hydrogen into metal which leads to disbandment. Visual observation of the coatings after removal from the medium showed that wrinkling and fine-hair cracks were intense on the interprime etch primer.

Table 4.1: Effect of Coating Thickness

Type of coating	Original mass w (G)	Final mass w(G)	Mass loss W(G)	percentage mass loss	Coating thickness (microns)	Density (G/cm³)	Exposure time (HRS)	Corrosion rate (MPY)
Inter Primer Etch Primer (non-ferrous)	47.807	47.719	0.088	0.1841	20	7.82	2160	0.407
	47.806	47.693	0.113	0.2364	30	,,	,,	0.522
	47.820	47.704	0.116	0.2426	40	,,	,,	0.536
	47.818	47.683	0.135	0.2823	50	,,	,,	0.626
	47.805	47.666	0.139	0.2908	60	,,	,,	0.646
	47.826	47.672	0.154	0.3220	70	,,	,,	0.715
Interzinc 72	47.824	47.689	0.135	0.2823	20	,,	,,	0.630
	47.828	47.701	0.127	0.2655	30	,,	,,	0.591
	47.823	47.713	0.110	0.2300	40	,,	,,	0.511
	47.836	47.748	0.088	0.1840	50	,,	,,	0.407
	47.828	47.705	0.135	0..2572	60	,,	,,	0.571
	47.807	47.683	0.124	0.2594	70	,,	,,	0.576
Interprime Cpa ee Orange	47.830	47.701	0.129	0.2697	20	,,	,,	0.596
	47.836	47.741	0.095	0.1986	30	,,	,,	0.442
	47.824	47.765	0.059	0.1234	40	,,	,,	0.273
	47.816	47.724	0.092	0.1928	50	,,	,,	0.427
	47.830	47.718	0.112	0.2342	60	,,	,,	0.521
	47.806	47.691	0.115	0.2406	70	,,	,,	0.531
Intergard Corrosive primer	47.841	47.686	0110	0.4052	20	,,	,,	0.671
	47.805	47.694	0.111	0.2322	30	,,	,,	0.516
	47.811	47.722	0.089	0.1861	40	,,	,,	0.416
	47.825	47.754	0.071	0.1485	50	,,	,,	0.327
	47.835	47.769	0.066	0.1380	60	,,	,,	0.307
	47.824	47.733	0.091	0.1903	70	,,	,,	0.422

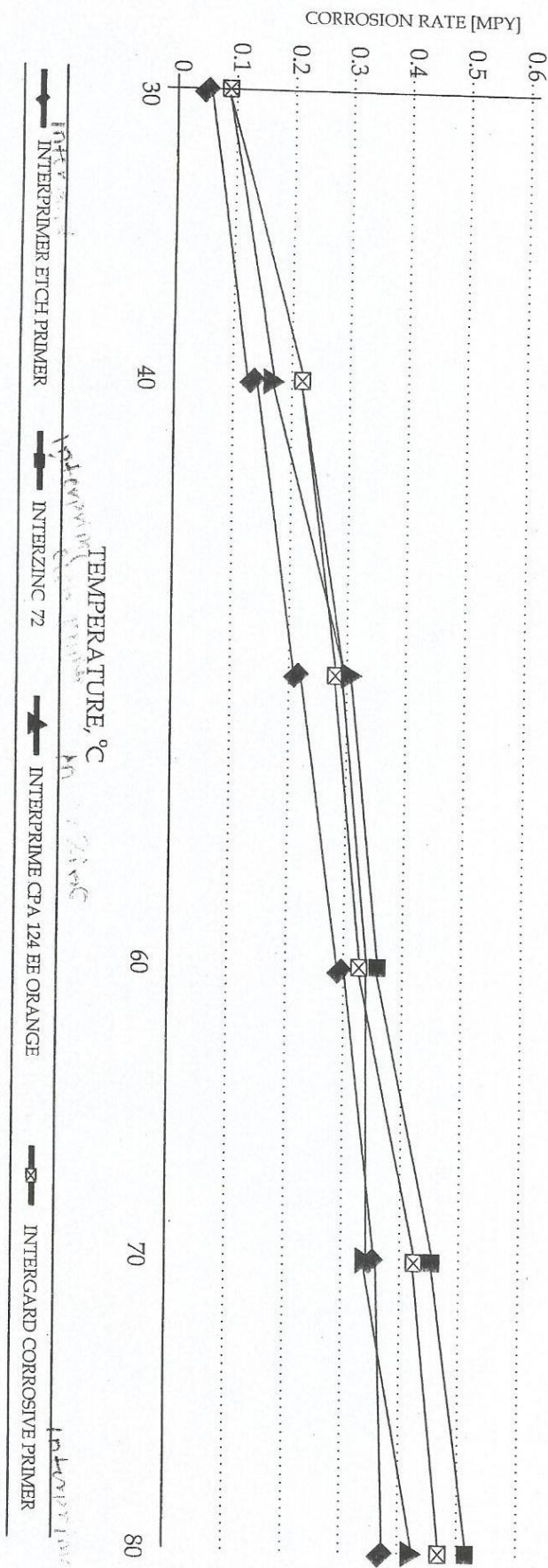EFFECT OF COATING THICKNESS ON CORROSION RATE
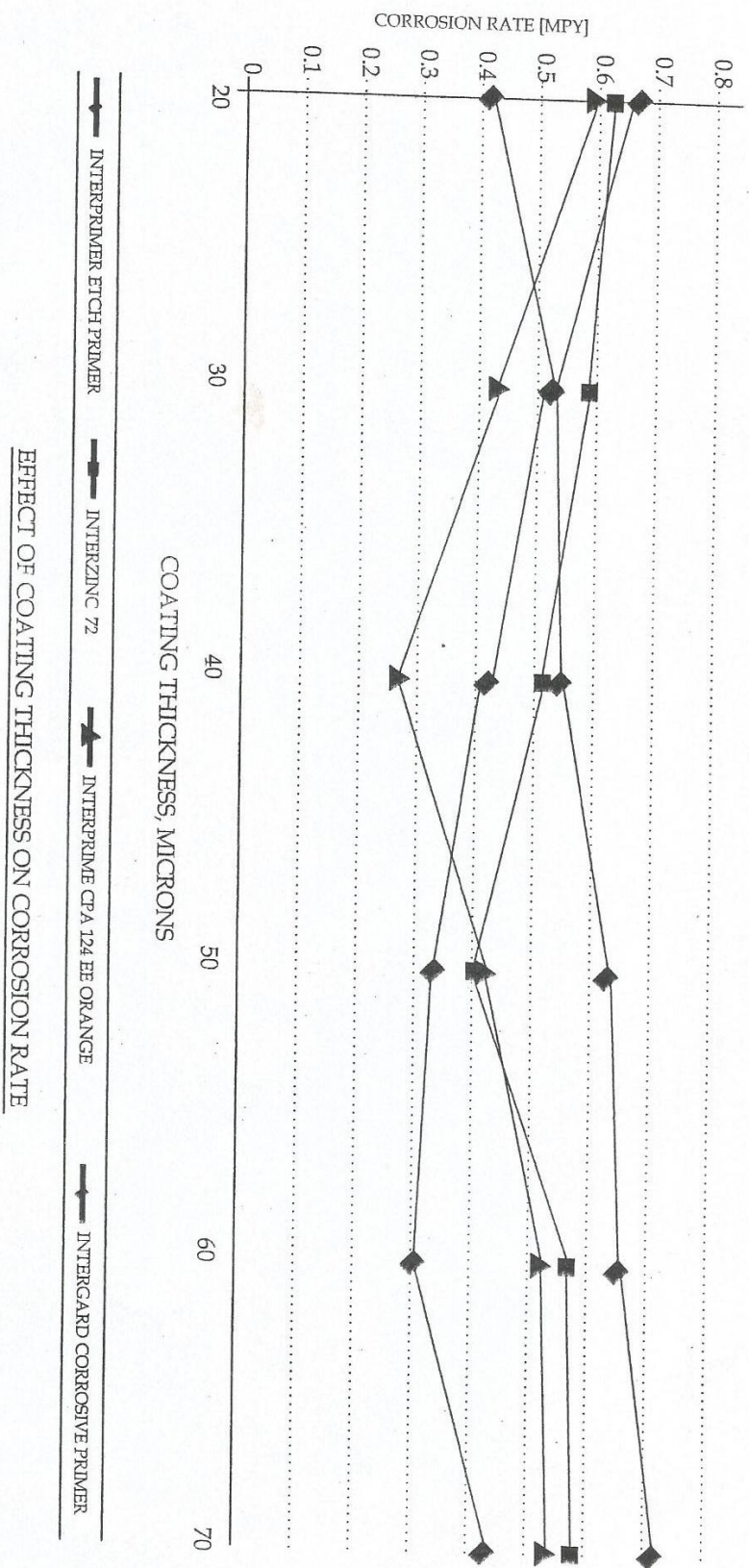
4.2   The Effect of Temperature on Corrosion Protection (Coating Performance)

Table 4.1 and figure 4.1 and show the performance of the various coating when applied on low carbon steel and immersed in sulphuric acid of pH 5.

At 30^0C in temperature, the most protective coating is the integard corrosion primer with a corrosion rate of 0.059 mpy while least protective coating is the interprime CPA 124 ee orange with a corrosion rate of 0.089 mpy.

Table 4.2:   Effect of Temperature (Exp. Time is 2 Weeks)

| Type of coating	Original mass w (G)	Final mass w(G)	Mass loss W(G)	percentage mass loss	Temp of corrodent (c)	Density (G/cm^3)	Corrosion rate (MPY)
Interergard corrosive	47.830	47.828	0.002	0.0041	30	7.82	0.059
	47. 828	47.824	0.004	0.0083	40	,,	0.119
	47.829	47.813	0.007	0.0146	50	,,	0.208
	47.820	47.810	0.010	0.0209	60	,,	0.298
	47.819	47.807	0.012	0.0250	70	,,	0.357
	47.831	47.818	0.013	0.0271	80	,,	0.437
Inter prime etch primer (non-ferrous)	47.821	47.8181	0.003	0.0062	30	,,	0.089
	47.833	47.826	0.007	0.0146	40	,,	0.208
	47.826	47.816	0.010	0.0209	50	,,	0.208
	47.830	47.818	0.012	0.0250	60	,,	0.357
	47.819	47.804	0.015	0.0.313	70	,,	0.417
	47.820	47.803	0.017	0.0355	80	,,	0.506
Interzinc 72	47.826	47.823	0.005	0.0062	30	,,	0.089
	47.811	47.806	0.005	0.0104	40	,,	0.149
	47.831	47.821	0.0010	0.00209	50	,,	0.298
	47.821	47.810	0.011	0.0230	60	,,	0.327
	47.809	47.797	0.012	0.0250	70	,,	0.357
	47.818	47.804	0.014	0.0292	80	,,	0.089
Interprime CPA	47.831	47.828	0.003	0.0062	30	,,	0.089
	47.820	47.813	0.007	0.0146	40	,,	0.208
	47.830	47.821	0.009	0.0188	50	,,	0.286
	47.824	47.813	0.011	0.0230	60	,,	0.427
	47.827	47.813	0.014	0.0292	70	,,	0.417
	47.829	47.813	0.016	0.0334	80	,,	0.476

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EFFECT OF TEMPERATURE ON CORROSION RATE

4.3   The Effect of pH on Coating Corrosion Protection (Coating Performance)

Figure 4.2 and table 4.2 show the corrosion resistance of the various coatings (integard corrosive primer, interzinc 72, interprime etch primer, and inter prime CPA 124 ee orange) applied on low carbon steel and immersed in sulphuric acids of pH 2, 3, 4, 5, and 6 for the period of three months.

Table 4.3:   Effect of Coating Thickness

Type of coating	Original mass w (G)	Final mass w(G)	Mass loss W(G)	percentage mass loss	pH Corrodent	Density (G/cm³)	Exposure time (HRS)	Corrosion rate (MPY)
Inter Primer Etch Primer (non-ferrous)	47.842	47.700	0.142	0.2968	2	7.82	2160	0.660
	47.848	47.727	0.121	0.2528	3	,,	,,	0.561
	47.804	47.717	0.087	0.1820	4	,,	,,	0.407
	47.826	47.777	0.049	0.1025	5	,,	,,	0.228
	47.832	47.792	0.040	0.0836	6	,,	,,	0.188
	47.843	47.694	0.149	0.3114	8	,,	,,	0.690
Interzinc 72	47.855	47.633	0.222	0.4639	2	,,	,,	1.028
	47.855	47.656	0.199	0.4158	3	,,	,,	0.923
	47.833	47.693	0.140	0.2927	4	,,	,,	0.650
	47.836	47.748	0.088	0.1840	5	,,	,,	0.407
	47.832	47.763	0.069	0.1443	6	,,	,,	0.322
	47.806	47.697	0.109	0.2280	8	,,	,,	0.506
Interprime Cpa ee Orange	47.816	47.409	0.407	0.5812	2	,,	,,	1.887
	47.807	47.582	0.225	0.4706	3	,,	,,	1.043
	47.833	47.648	0.185	0.3868	4	,,	,,	0.859
	47.786	47.691	0.095	0.1988	5	,,	,,	0.442
	47.971	47.772	0.051	0.1065	6	,,	,,	0.238
	47.830	47.662	0.165	0.3512	8	,,	,,	0.779
Intergard Corrosive primer	47.824	47.629	0.195	0.4077	2	,,	,,	0.903
	47.830	47.678	0.153	0.3178	3	,,	,,	0.705
	47.804	47.708	0.096	0.2008	4	,,	,,	0.447
	47.787	47.740	0.047	0.0984	5	,,	,,	0.218
	47.832	47,798	0.034	0.0710	6	,,	,,	0.158
	47.869	47.727	0.142	0.2966	8	,,	,,	0.660

EFFECT OF pH OF CORRODENT ON CORROSION RATE
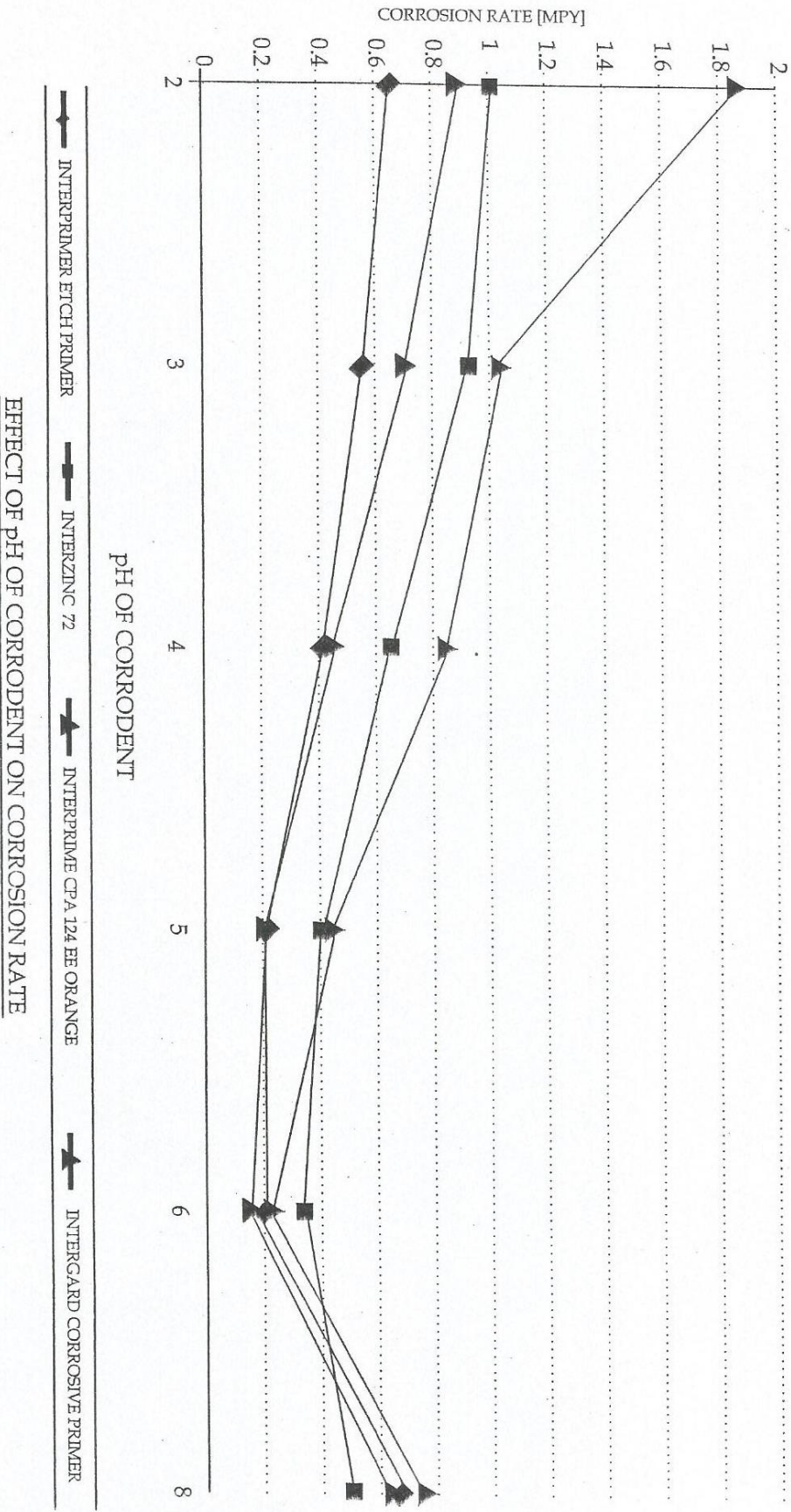
4.4 The Effect of Exposure Time on Coating Corrosion Protection (Coating Performance)

Table 4.3 and figure 4.3 show the corrosion resistance of the various coatings (intergard corrosive primer, interzinc 72, interprice etch primer, and interprime CPA 124 ee orange) applied on low carbon steel and immersed in brine (sea water) of pH 8.

At 14 days, both intergard corrosive primer and interzinc 72 coating are the most protective coating with a corrosion rate of 0.029 mpy respectively while the least protective was the interprime etches primer with a corrosion rate of 0.089 mpy. The second most protective coating was the interprime CPA 124 ee orange with a corrosion rate of 0.059 mpy.

Table 4.4: Effect of Exposure Time on Corrosion Rate

Type of coating	Original mass w (G)	Final mass w(G)	Mass loss W(G)	percentage mass loss	Exposure time (HRS)	Density (G/cm³)	Corrosion rate (MPY)
Inter Primer Etch Primer	47.864	47.863	0.001	0.0020	336	7.82	0.029
	47.796	47.791	0.005	0..0164	672	,,	0.074
	47.830	47.803	0.027	0.0564	1008	,,	0.268
	47.852	47.809	0.043	0.0898	1.344	,,	0.320
	47.799	47.710	0.089	0.1861	1680	,,	0.530
	47.860	47.727	0.133	0.2778	2016	,,	0660
Interzinc 72	47.796	47.795	0.001	0.0020	336	,,	0.029
	47.801	47.798	0.003	0.0062	672	,,	0.044
	47.824	47.807	0.014	0.0292	1008	,,	0.139
	47.797	47.770	0.027	0.0564	1344	,,	0.204
	47.841	47.780	0.061	0.1275	1680	,,	0.363
	47.799	47.697	0.102	0.2133	2016	,,	0.506
Interprime Cpa ee Orange	47.811	47.808	0.003	0.0062	336	,,	0.089
	47.988	47.781	0.007	0.0146	672	,,	0.104
	47.799	47.769	0.030	0.0627	1008	,,	0.298
	47.832	47.760	0.063	0.1317	1344	,,	0.432
	47.831	47.720	0.111	0.2320	1680	,,	0.460
	47.820	47.662	0.157	0.3283	2016	,,	0.690
Intergard Corrosive primer	47.801	47.799	0.002	0.00441	336	,,	0.059
	47.805	47.795	0.010	0.0209	672	,,	0.149
	47.820	47.793	0.027	0.0564	1008	,,	0.268
	47.823	47.760	0.063	0.1317	1344	,,	0.469
	47.831	47.720	0.111	0.2320	1680	,,	0.661
	47.820	47.662	0.157	0.3283	2080	,,	0.779

EFFECT OF EXPOSURE TIME ON CORROSION RATE
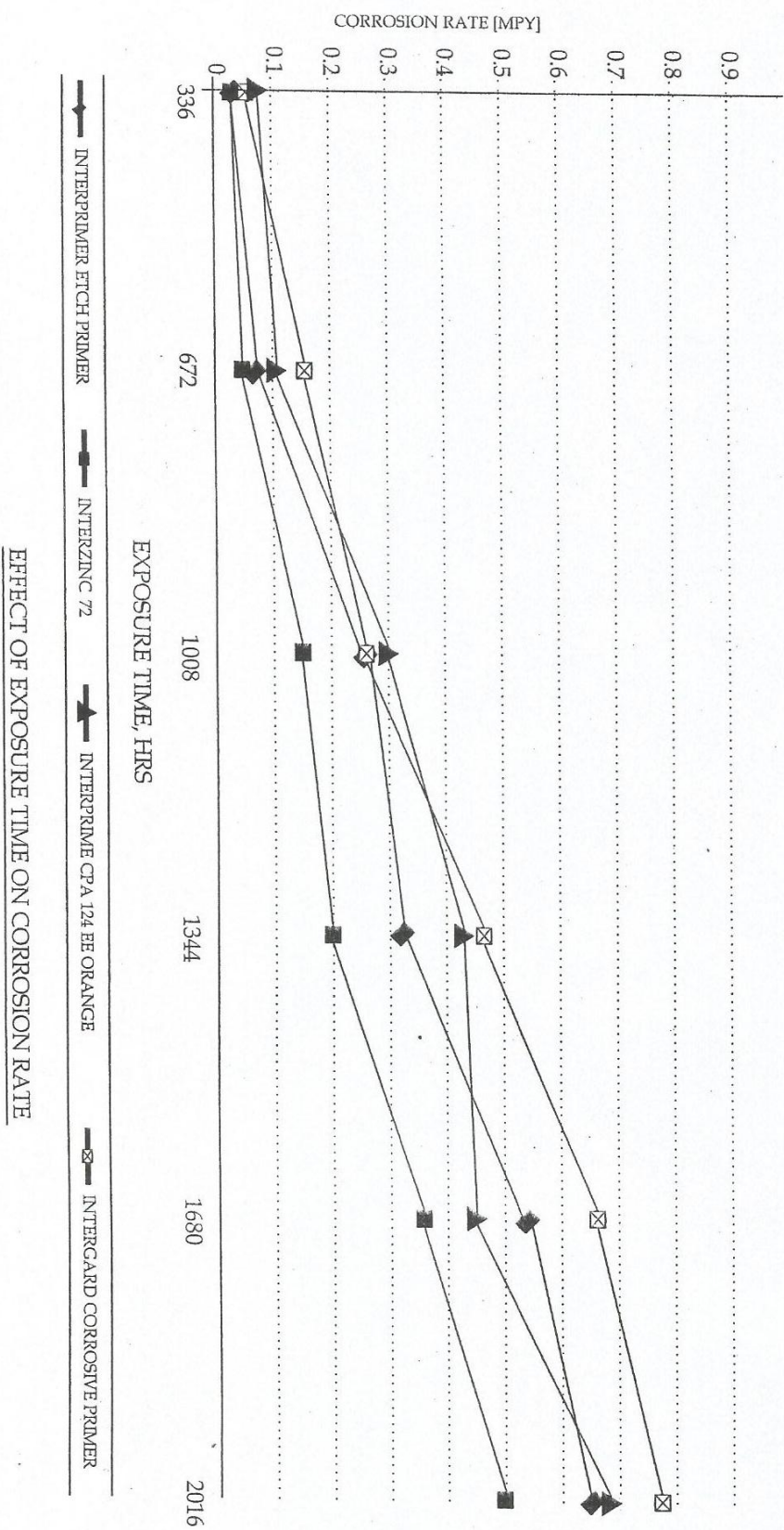
4.5 The Effect of Coatings Application Thickness on their Corrosion Protection Ability (Coating Performance)

It was generally observed from the graph that the corrosion rate decreased with increase in coating thickness until at certain thickness it started increasing. An exception to this was the inter prime etch primer in which the corrosion rate increased with increase in coating thickness. The initial decrease in corrosion rate could be caused by the decreased rate of metal corrodent contact. The rate at which the corrodent penetrates the metallic surface is reduced with increase in coating thickness.

The decrease in performance (i.e. increase in corrosion rate) of the various coatings when certain thickness are exceeded could be explained by the principles of absorption.

Careful visual inspections were taken on the coatings surfaces on removal from the medium with the aid of a magnifying glass and the followings were observed.

1. Fine-hair cracks were observed on the coatings but it was not intensive on the interprime etch —primed coupons.
2. Some brownish sports were observed on the surfaces of the inter prime etch primed coupons.
3. Wrinkling were intensive on the interprime etch-primed coupons

After the visual inspections, the coatings were scraped off and wire brushed to the same surface condition before coatings applications. They were weighed immediately using a very high sensitive electronic balance and their weights recorded on their identification papers.

4.6 The Effect of Temperature on Corrosion Protection (Coating Performance)

There is generally an increase in corrosion rate with an increase in temperature for all the coating. At 400 C in temperature, the best protective coating was the intergard corrosive primer with a corrosion rate 0 0.119 mpy while the least protective was the interprime CPA 124 ee orange with a corrosion rate of 0.208 mpy. At 50 C in temperature, the protective was the interprime etch primer with a corrosion rate of 0.298 rnpy. At 60, 70 and 80 C in temperature the most protective was the intergard corrosive primer with corrosion rates of 0.298, 0.357, and 0.287 mpy respectively while the least protective coating was the interprime etch primer with corrosion rates of 0.357, 0.447, and 0.506 mpy respectively.

Corrosion inhibitors have temperature limits above which they lose their effectiveness and frequently change their chemical composition. This temperature may vary for any one inhibitor depending on pressure, presence of water, or other conditions. Thus the performance of these coating vary with temperature.

Like most chemical reactions, corrosion generally increases with temperature. A rough "rule of thumb" suggests that the reactions rate doubles for every ten degree centigrade rise in temperature.

In this test, the graphs indicate that generally, corrosion rate increases because the test was a closed system, in a system open to the atmosphere, corrosion rates may increase at first and then decrease with further temperature increase. As the solution gets hotter, the dissolved gases tend to come out of solution, decreasing the corrosivity of the water. Thus the corrosivity of the water may increase at first due to the increase in temperature, then begin to decrease as the water approaches the boiling point due to the decreased gas concentration. In a closed system, corrosion rate do not exhibit this behaviour since system pressure prevents the gases from escaping from the solution. Thus corrosion rates increase with temperature as obtained in the graphs.

Comparative performances of the various coating could be attributed to their structures. In general, it is found that materials having polycrystalline or multidimensional network structures have a high glass transition temperatures (Tg), melting point and high compressive strength. The bond strength between the coatings and the metal could affect their performance as higher dissociation energies are needed for stronger bonds.

The relative performances of the various coatings could be attributed to the above mentioned factors. Coatings with high carbon-carbon, dissociation energy, close crystal packing, and defect-free polymer chains are likely to perform better if adequate adhesion to the metal exists.

After two weeks in an autoclave, the coupons were removed using a hand clip and the surfaces were visually inspected and the followings were observed.

i. It was observe that blistering (small holes) were on the coatings except on the interprime etch-primed coupons which have started peeing.
ii. Find hair cracks were equally observed using the magnifying glass.

The samples (coupons) were then scraped off through wire-brushed to the same surface condition before coating application and reweighed using the electronic. The weights were recorded on their identification papers and the corrosion rates computed as previously discussed.

4.7 The Effect of pH on Coating Corrosion Protection (Coating Performance)

At pH of 2, the interprime etch primer was the most protective coating with a corrosion rate of 0.660 mpy while the least protective coating was the interprime CPA 124 ee mpy orange with a corrosion rate of 1.887 rnpy. The second most protective coating was the intergard primer with a corrosion rate of 0.705 mpy and the third best was the interzinc 72 with a corrosion rate of 0.903 mpy.

At pH of 3, the best protective coating was still interprime etch primer with a corrosion rate of 0.56 mpy while the least was interprime CPA 124 ee orange with a corrosion rate of 1.043 mpy. The second most protective coating was the intergard primer with a corrosion rate of 0.705 mpy and the third best was the interzinc 72 with a corrosion rate of 0.923 mpy.

At pH of 4, the best protective coating was the interprime etch primer with a corrosion rate of 0.407 mpy while the least protective was the interprime CPA 124 ee orange with a corrosion

rate of 0.859 mpy. The second most protective coating was the intergard corrosive primer with a corrosion rate of 0.447 mpy and the third best was the interzinc 72 with a corrosion rate of 0.650 mpy. At pH of 5, the intergard corrosive primer was the most protective coating with a corrosion rate of 0.218 mpy while the least protective was the interprime CPA 124 ee orange with a corrosion rate of 0.442 mpy. The second best was the interprime etch prier with a corrosion rate of 0.228 mpy and the third best was the interzinc with a corrosion rate of 0.407 mpy.

At pH of 6, the most protective coating was the intergard corrosive primer with a corrosion rate of 0.158 mpy while the least protective was the interzinc 72 with a corrosion rate of 0.158 mpy while the least protective was the interzinc 72 with a corrosion rate of 0.322 mpy. The second best performed coating was the interprime etch primer with a corrosion rate of 0.488 mpy and the third best was the interprime CPA ee orange with a corrosion rate of 0.3238 mpy.

Generally, the graphs indicate an increase in corrosion rate with a decrease in pH value. It was observed that brownish discoloration was of most intense on the interprime CPA 1124 epoxy ester coated coupons. Equally observed using a magnifying glass was small spots on the coatings surfaces which was pronounced for coated coupons immersed in mediums of pH 2 to 4. After the visual observation, the coupons coatings were scraped off, weighed and their weights recorded on their respective identification papers. The corrosion rates were calculated as previously discussed.

4.8 The Effect of Exposure Time on Coating Corrosion Protection (Coating Performance)

At 28 days, the most protective coating was interzinc 72 while the least protective was the interprime CPA 124 ee orange. The second most protecting coating was the intergard corrosion primer with a corrosion rate of 0.074 mpy and the third most protective was the inteprime etch primer with a corrosion rate of 0.104 mpy.

At 42 days, the most protective coating was the interzinc 72 with a corrosion rate of 0.0139 mpy while the least protective was the interprime etch primer with a corrosion rate of 0.298 mpy. The intergard corrosive primer and the interprime rate of 0.268 mpy respectively. At 56, 70, and 84 days, the most protective coating was the interzinc 72 with corrosion rates of 0.201, 0.363, 0.506 mpy respectively and the least protective coating was the interprime CPA 124 ee orange with corrosion rates of 0.469, 0.661, 0.779 mpy respectively. The second protective coating was the intergard corrosive primer with corrosion rates of 0.320, 0.530, and 0.660 mpy respectively. It was observed that no visible spots or stains were on the coating's surfaces after two weeks (14 days). There were spontaneous increases in the rust stain (brownish stains) from the (42 days) of test as was observed by the magnifying glass.

The coatings were scraped off and wire-brushed to the same surface conditions before coatings application and weighed. Their weights were recorded on their respective identification papers and the corrosion rates computed as previously discussed.

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Results obtained show that the corrosion rate decreases with increase in coating thickness beyond which it begins to increase. This initial decrease in corrosion rate was caused by the decreased rate of metal corrodant contact. Thus, for a pipeline metal system the rate at which the corrodant penetrates the metallic surface is reduced with increase in coating thickness.

Also, there is generally an increase in corrosion rate with an increase in temperature for all the coating. In this test, the graph indicates that corrosion rate increases because the test was a closed system. Hence, for a buried pipeline system, corrosion would increase with an increased temperature of the environment.

The results, also showed that corrosion rate increases with a decrease in pH value.

This implies that the rate of corrosion increases, for a pipeline system in an acidic environment (decrease in pH). Results obtained from figure 4.4 showed that the corrosion rate of the coated coupons immersed in brine (sea water) of pH 8 increased with time, signifying a decrease in productivity of the coatings with time. This is a common occurrence that the protective ability of coating usually decreased with time. This reduction is caused by environmental depreciation of the coating.

Coating selection is thus a blend of all these factors put into appropriate consideration.

5.2 Recommendation

Based on the performance evaluation results of the four coating materials under study, as online in tables 4.1 — 4.4 and figures 1-4.4, the following recommendations are necessary in the choice and performance of the coating materials with respect to the nature of the environment - temperatures, pH, coating thickness and the duration or exposure time.

Generally, in low carbon steel systems with pH range of 5, resistance or protection ability increases with increasing coating thickness except for inter prime etch primer which gives the best protection at low thickness of 20 microns and least protection at thickness of 50, 60 and 70 microns. Whereas the intergard corrosive primer gives the best protection at higher thickness below 50-70 (um) microns (Table 4.1 and figure 4.1).

At higher temperature range between 50 - 600 C. (See table 4.2 and fig. 4.2). At low pH range between 2 - 4, the inter prime etch primer offers the best protection vis-a-vis the other competitor materials and is recommendation for pipeline system in a low pH environment.

At moderate pH range between 5 — 6, the intergard corrosive primer offers the best protection hence recommended for pipeline systems in mildly acid environments (See table 4.3 and fig. 4.3).

From this study, it was observed that in low carbon steel systems immerged in sea water (brine) environment with pH 8 between the period of 14 — 84 days, the interzinc 72 offers the

best protective coating compared with the other three competitor coating materials. Sequel to the better performance under a longer exposure time, it would be recommended for pipeline systems in brine or sea water environment with pH 8, and durability a primary factor, (See table 4.4 and fig. 4.4).

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