How Viscous Elastic Coatings (VEC) eliminate typical problems when rehabilitating coatings in the field

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Abstract

NACE studies have proven that when rehabilitating coatings in the field there is a higher risk of coating failure due to the presence of salts, improper surface preparation, application failures, adhesion problems and microbiological induced corrosion (1). Therefore rehabilitation of coatings in the field usually will lead to a relative short life time of a coating.

The invention of so called viscous elastic coatings make it possible to eliminate the above mentioned phenomena. Viscous elastic coatings are usually amorphous polymer polyolefins that have an extreme low permeability to moisture and gas and hence eliminate the danger of present salts and microbiological induced corrosion. Viscous elastic coatings are not crystalline by nature, have the ability to flow under pressure, have a very low surface tension and therefore an immediate adhesion without mechanical fixation to any pipeline substrate and hence eliminate adhesion problems. Because of their ability to "wet" the surface, viscous elastic coatings can even to be applied onto non blasted surfaces whereby surface related problems are eliminated. Moreover their easy application eliminate the risk of application failures. Hence viscous elastic coatings offer the applicant and pipeline owner a failure free solution when rehabilitating coatings in the field, even when ambient conditions are hard.

Introduction

Corrosion causes billions of dollars damage every year. Pipeline sections have to be taken out of operation and often larger sections must be replaced due to serious corrosion damage. New coatings must be applied over-the-ditch and in some cases serious damage and injury is caused to substrates and installations in operations and people involved.

One of the reasons for corrosion of pipelines is that their protective coatings in practice fail. This failure strongly depends on the type of coating, the pipeline's soil conditions (environmental aspect) and, in case of rehabilitation, the circumstances during which a pipeline's coating was rehabilitated on site. In practice the application circumstances and surface preparation appear to be a critical part of a proper long lasting performance of a rehabilitated coating . Practice learns that many rehabilitated coating failures are caused by failures during application and improper surface preparation (1).

This paper explains the development of viscous elastic coatings for the protection of pipelines and pipeline related substrates against corrosion and their application in the field. Due to their

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immediate adhesion, extreme low impermeability for moisture and gases, cold flow behavior and no absolute necessity for blasting, viscous elastic coatings can overcome typical problems that we face with coating rehabilitations in the field.

This paper is divided into three sections :

1. A brief introduction into **corrosion** and explanation on coatings types;
2. Consequent an explanation on some **phenomena** that are encounter in practice and that play an important part in coating failure , specifically when pipeline coatings are rehabilitated in the field. Discussed are phenomena like the presence of salts and osmosis, applications failures, surface preparation problems, water permeability and microbiological induced corrosion;
3. An explanation why **viscous elastic coatings** have the ability to eliminate the problems resulting from the phenomena discussed under section 2 when rehabilitating coatings in the field.

1. Corrosion

Corrosion of steel, or in a more popular expression rust, is a chemical-physical process (2).

Iron changes into iron-oxide or in iron-hydroxide. Iron oxide or -hydroxide have the drawback that their volume is larger than that of steel, their original state. Hence no protective layer will exist that can stop the corrosion process, as is the case with aluminum.

Which components are responsible for corrosion? Corrosion is also described as oxidation, i.e. the material bonds with oxygen. Air contains oxygen, chemically described as O_2. This oxygen however is not responsible for the oxidation process at first instance. In dry environments, many materials, also steel, do not rust. In the desert of Arizona army components are stored without any protection. The cause of oxidation rather is to be found in the presence of water than that of oxygen.

The water molecule H_20 contains oxygen. This oxygen bonds to the iron by means of a chemical process. A chemical engineer may describe the oxidation process in a somewhat different way, namely as the initial loss of electrons and it than can be described in the following way :

1. Fe (iron) $\rightarrow$ Fe^{+++} (iron ion) + 3 e^- (three electrons)

If water is present, water will split into:

2. H_2O (water) $\rightarrow$ H^+ (hydrogen ion) + OH^- (hydroxyl ion).

The consequent reaction will be :

F^{+++} (iron ion) reacts with OH^- (hydroxyl ion) $Fe(OH)_3$ (iron hydroxide)

3. The H^+ (hydrogen-ion) can react with the electron e^- H_2 (hydrogen).

The H_2 consequently can react with O_2 from the air into H_2O, but this reaction does not automatically play a role in the rust process.

In order to prevent corrosion one can protect the bare substrate by means of a coating. Several coatings are available and one can roughly distinguish between the following types :

Factory coatings

- FBE, 3LPE, Polyurethane, etc.

Field applied coatings

- Spray coatings like Epoxy, Urethane, Zinc
- Residues of refinery like Waxes, Petrolatum.
- Bitumen based coatings
- Single or multiple layer PE/Butyl tapes

The selection of the coating depends one different factors like there are :

- Estimated life time of substrate
- Environment
- Nature of the substrate (material, shape, position)
- Costs of per square meter (coating material + application)
- Costs of repairs

2. Some phenomena that we encounter in practice

There are a few phenomena that play an important part in the corrosion process and that should be taken into consideration when discussing pipeline coatings, their application and the corrosion process, especially in the field. These phenomena are :

A. Salts and osmosis
B. Adhesion
C. Microbiological Induced Corrosion (MIC)
D. Surface preparation
E. Water permeability

A. Salts & osmosis

The presence of salt, for instance NaCl solved in water, plays an important role in a corrosion mechanism :

4. NaCl $\rightarrow$ Na^+ (natrium ion) + Cl^- (chloride ion)
5. Fe^{+++} (iron ion) + 3 Cl^- (chloride ion) $\rightarrow$ $FeCl_3$ (iron chloride)
6. $FeCl_3$ and H_2O result in $Fe(OH)_3$ (iron hydroxide) and HCL (chloride acid)

This chloride acid accelerates the process ion which iron electrons are lost :

7. Na^+ and e^- give Na
8. Na + H_2O $\rightarrow$ NaOH and H_2 (hydrogen)
9. NaOH + HCl $\rightarrow$ NaCl + H_20.

Salts particles are present in most of ambient situations and are difficult to remove. Even rinsing a blasted pipeline coating with clean water will not remove all salt particles and contaminations in the voids of the blasted pipe. As salts attract water and as many pipeline coatings are not 100% water vapour or water impervious the presence of salt is always a risk in practice.

Salt attracts water and water vapour and with the presence of salts the phenomenon of osmosis occurs. Osmosis can be described as a physical phenomenon that exists if the following elements are present:

1. A semi-permeable “wall”, better described as a selective filter. This wall will allow the solvent of a solution to penetrate but keeps the solved substance out.
2. This wall is a barrier between two areas whereby in area A the solvent is present and in area B the solvent and the solved substance are present.
3. The solvent present in area A will now move to area B.

If one starts at the same level in these two areas, after a while the level in area A will drop but will rise in area B. This results in a pressure difference which is known as osmosis. Osmosis is a well known phenomenon and a problem with coatings if in water solved substances are present under the coating on the substrate.

Therefore layers of coating should be as much as possible impervious for water. Many coating systems, no matter how good they have been applied, do not meet this requirement. One can think of systems based on polyurethanes, epoxies or unsaturated polyester resins and bitumen.

B. Adhesion

Any pipeline coating must have a good adhesion to the substrate . Coatings with no adhesion fail automatically. To obtain a good adhesion in practice is not easy. The reason for this is that the application circumstances must be taken into consideration and that many coatings require a perfect surface preparation.

Also the difference between surface tensions of the different materials (surface and coating material) play an important factor in adhesion failures.

There are several types of adhesion known in physics:

Table 1 - Types of adhesion

Type	Description
Chemical bond	Two different or equivalent atoms form a bond. A covalent bond existing from one couple of electrons
Ionogenic bond	Two different ions with opposite values form a bond.
Metal bond	The atomic structure with free electrons
Van Der Waals bond	Causes a cohesion : attraction between atoms of same substances.
Hydrogen bridges	Causes adhesion : attraction between atoms of different substances.
Mechanical fixation	With primer
Physical fixation	Viscous elastic coating

Coatings applied in the field usually adhere to the surface by means of a physical or mechanical fixation. Other type of bonds hardly exist in practice.

Adhesion between hard or semi-hard substances that are used as a coating do not occur in practice. In this case there is always a mechanical fixation, e.g. by means of a primer.

Generally one can say that a proper adhesion in practice is not as simple as it seems as usually two different types of materials with different surface tensions are tried to bond together. And their tendency will always be to delaminate.

C. Microbiologically Influenced Corrosion (MIC)

MIC is, most to the surprise of many people in the pipeline industry, responsible for almost 50% of the corrosion problems (3). MIC is the term used for the phenomenon in which corrosion is initiated or accelerated or both by the activities of micro-organisms. The first MIC case was discovered in 1934 where Sulfate Reducing Bacteria (SBR) resulted in the corrosion failure of cast iron pipes.

SRB are obligatory anaerobic bacteria utilizing sulfate as a terminal electron acceptor and organic substances as carbon sources. During the metabolic process, sulphate is reduced to sulphide, which reacts with hydrogen produced by metabolic activities or by cathodic reaction of corrosion processes to form hydrogen sulphide.

Hydrogen sulphide is very corrosive to ferrous metals and further reacts with dissolved iron to form an iron sulphide film over the metal substrate. Iron sulfides have relatively low hydrogen evolution over-potential. So a galvanic coupling between iron sulphide film and the nearby metal substrate is set and corrosion is accelerated. Other important micro-organisms are formative Acid Producing Bacteria (APB) capable of forming organic acids (e.g. acetic, formic and lactic acids).

These acids and therefore APB have dual roles in MIC, causing acid corrosion of many alloys and supplying nutrient and environments to the MIC community bacteria.

D. Surface preparation

Bad surface preparation is another cause of corrosion problems. Very often field-applied-coatings need an excellent prepared surface of the substrate in order to get excellent adhesion and sandblasting often is required. However remaining pollutions in the voids of the blasted surface and salt particles obvious create problems and rapid disbondment may occur. Surface preparation in-plant is a rather good-to-control process. Surface preparation in the field however very often is a difficult to control job that requires skill.

E. Water Permeability

Even if there is the slightest permeability for water, corrosion once will occur. The presence of water is deadly for a substrate and no matter how good a coating has been applied in the factory, practice shows that disbondment due to the presence of water occurs.

Corrosion always is a combinations of causes and it cannot be stated that only one of the mentioned phenomena is responsible for corrosion of a substrate itself. However permeability for water can be considered as a serious hazard of many corrosion problems. No matter how good a coating has been applied, no matter how the application circumstances could be controlled, corrosion once will occur if water or water vapour is able to travel through a coating, especially if salt particles or pollutions are present in the voids of the blasted substrate. In case of pipeline rehabilitation this is even a bigger problem as a the application circumstances, that are sometimes difficult to control, should be taken into consideration.

In respect to the above mentioned phenomena and in order to prevent corrosion during and after rehabilitation, one hence has to prevent that blank steel parts come into contact with water. This is essentially and must be done by a protective coating. But this coating than has to have an extreme low permeability to moisture and will have to perfectly match and remain matching the surface and pores of the pipeline: the distance between the surface of the substrate and the coating should be as small as possible. It should have a perfect adhesion and reduce the risk for MIC. Moreover in practice the application should be easy and reduce risk of failures.

Many of the existing coating materials do not meet this requirement and especially with field applied rehabilitation coatings pipeline owners are facing problems. In case of a factory coating , the application circumstances can be properly controlled and due to automation the application is close to failure free.

But although factory coatings can be hot applied under control and theoretically should match the surface of the substrate (provided they have a favourable surface tension in comparison to the substrate’s surface tension), in practice even with factory coatings a chemical reaction or physical cooling down will follow and both phenomena (physical cooling down and the chemical reaction) are accompanied with a certain volume shrinkage. The consequence is that even factory coatings do not 100 % meet the above requirement of a perfect match anymore. Although much more better in quality than a field applied coating eventually the coating can lose its adhesion in the cause of time, due to volume shrinkage.

With field rehabilitation coatings the above mentioned requirement is even more difficult to meet. Application circumstances are not always perfect, the application is sensitive to failures and in order to fulfil our above mentioned requirements during rehabilitation we should search and develop a water impermeable coating that will match the surface of the substrate and approach this surface as near as possible up to a “molecular” level.

A substance like oil (that is without the presence of water particles) will possibly fulfil this requirement. Oil however has a too fluid type character to seriously act as a coating. A mastic with fluid type properties with no or a very low degree of cristalline behaviour and wetting characteristics may however meet this requirement. Such coating is a viscous elastic coating

4. How viscous elastic coatings eliminate the phenomena of section 2

Viscous elastic coatings have been developed for the protection of under- and above ground substrates against corrosion. Because a good application of a corrosion preventative coating determines the long term effectiveness of a coating, a choice has been made for materials with specific rheological behaviour that allow a easy and failure free application in the field. Viscous elastic coatings consist of amorphous a-polar polyolefins. The material has been designed in such a way that the material - as a solid - has both elastic and fluid type properties, in rheology terms used indicated as G’and G”. As a solid viscous elastic coatings have a true yield point and under pressure a cold flow characteristics, whereby it flows into the pores and anomalies of the substrate. Due to these properties it has self healing characteristics.

Let us have a further look how viscous elastic coatings deal with the specific phenomena discussed in section 2 of this paper.

A. Elimination of salt and osmosis

If the coating is impermeable for water and if the salt particles are embodied in the coating, the presence of salt particles on a substrate is not a hazard anymore. Due to such an impermeability osmosis will not occur and embodiment of salt particles in the coating make sure they are not present on the substrate anymore.

Viscous elastic coatings have a very low permeability to moisture and therefore the hazardous salt particle is neutralized as moisture will not travel through the coating.

Rinsing with clean water in remote areas is not necessary anymore and the chance that applicants cause failures is reduced to zero.

The use of viscous elastic coatings eliminate the phenomenon of osmosis because:

1. Viscous elastic coatings have a very permeability to moisture, hence have no selective character.
2. Viscous elastic coatings are a-polar, i.e. they will reject moisture.
3. The extreme good adhesion of viscous elastic coatings and their wetting characteristics prevent pressure to build up and the coating to disbond.

Due to their impervious character the phenomenon of osmosis does not occur. Besides viscous elastic coatings have self healing characteristics. Minor pinholes will be dealt with by the wetting and viscous properties of the coat wrap and damages will heal automatically.

B. Elimination of adhesion problems

With viscous elastic coatings volume shrinkage is not an issue anymore. Moreover the distance between the coating and the substrate's surface, essential for a perfect adhesion, is extremely small as viscous elastic coatings have excellent wetting characteristics.

One of the reasons that viscous elastic coatings were developed is that they have an adhesion to the substrate's surface (initially caused by so called Van Der Waal Bonds) but a cohesive fracture : when peeled off, the material will break apart and a remaining film is left on the pipe. From a rheological point of view, viscous elastic coatings are a solid material with a high yield point however with remaining wetting properties and a low surface tension.

On many dry and clean surfaces, the material shows cold flow as it is a pressure sensitive adhesive. It flows into the pores of the pipe and is pushed to the substrate by means of air pressure. This process may take some time due to the viscous elastic properties, but will always take place. Pressure, for instance an outer wrap or earth loads, will accelerate this process. A very intimate match between the substrate and the coating exist which results in an extreme good adhesion. Due to the wetting characteristics, adhesion will take place rather quickly and will remain for decades. Due to the use of an inert formulation, the material will not crack, not become brittle and remain plastic. The material does not contain any reactive groups and will not deteriorate in the course of time.

Viscous elastic coatings are protected by an outer wrap for mechanical protection. In this way the main function (corrosion prevention) is separated from the mechanical protection whereas many coatings try to combine both purposes in one material. From a rheological point of view this is very difficult and usually leads to a sacrifice of one of the functions.

C. Elimination of microbiological induced corrosion (MIC) problems

Viscous elastic coatings are the only type of coating where MIC does not occur. The permanent wetting coat wrap consist of an organic polymeric composition with inorganic filler material. It is proposed that if no nitrogen nutrients are available in the coating substance, it is impossible for micro-organism to grow on this material under anaerobic conditions. Viscous elastic coatings are water repellent because of its hydrophobic property and permeation of water can be neglected. It is clear: if no water is present, bacterial life is impossible.

In a nutshell one can say the MIC does not occur with viscous elastic coatings because :

- No water is present at the boundary of metal/coating.
- No nitrogen is available in the coating.
- No initial bacterial activity is present in the coating.
- The coating intimates extremely with the substrate due to its fluid type behaviour. There is a real adhesion with no space for any substance to creep between the layer and the substrate and a cohesive fracture.
- Coat wrap is under permanent pressure.
- Coat wrap is impermeable for water and oxygen.
- No permeability for ionic species from soil e.g. nitrate, nitrite, ammonium.
- No water available and the ions are insoluble in the a-polar material.
- Viscous elastic coatings are water repellent.
- Material is slightly basic (pH 8 which is unfavourable for SRB).

D. Elimination of surface preparation problems

Here is another advantage of viscous elastic coatings : the substrate should be clean to a level SSPC-3 (this is sufficient for initial adhesion). Sandblasting is not mandatory but strongly advised. Removal of sand, loose parts and grease however is sufficient for initial adhesion. The coating should be applied above the dew point. And because viscous elastic coatings have low glass transition temperature it can be applied within a wide temperature range.

It can be wrapped at temperatures of -30° C but also on pipes having a temperature of +70° C. Due to the cold flow characteristics and the low surface tension, the material shows a perfect adhesion to all materials, even to PE and PP.

E. Elimination of water permeability related problems

Viscous elastic coatings are made of amorphous a-polar polyolefins with no reactive groups and free radicals. It has an extreme low permeability for water and is impermeable for moisture under ambient conditions. Due to the absence of free radicals viscous elastic coatings remain stable for decades and no deterioration of the material takes place.

Due to the amorphous structure the coatings has no cristalline behaviour and will wet the surface of the substrate up to a physical molecular level. One can say that there is not even space for any moisture anymore due to the extreme close contact of the fluid type coating and the substrate's surface it is also therefore that viscous elastic coatings are excellent for application in aggressive soils.

Conclusions

Pipeline coatings fail, specifically when applied over the ditch as a rehabilitation coating, for the following reasons :

- Wrong material choice for application.
- Bad surface preparation.
- Wrong coating application.
- Curing times (liquid coatings) and curing failures (sand and mosquitos in non cured coating.
- Adhesion failures.
- Vapor, UV and Oxygen reaction (hydrochloric acid, brittleness)
- Liquid Absorption: swelling of coating
- Soil Stress (mainly in clay soils)
- Volume shrinkage
- Osmosis (whereby salt plays a role)

Viscous elastic coatings can overcome these failures by their following characteristics ;

- Lesser sensitive to surface preparation (SSPC-3 is sufficient).
- Very easy to apply, less risk for application failures.
- No curing times, hence no risk for mosquitos, sagging or overspray of liquids
- Immediate and direct adhesion, hence elimination of adhesion problems.
- No reactive groups present in the material like oxygen or ether groups, hence stability over decades and no reaction with free radicals that are present.
- Impermeable for water, hence no risk for osmosis.
- No volume shrinkage due to its permanent fluid type behaviour, hence no delimination problems.
- No risk of osmosis as salt particles are embodied in the coating and the coating is 100% impermeable for water vapour and oxygen

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