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VISCOUS-ELASTIC FANTASTIC

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

Corrosion occurs because pipeline coatings, in practice, can fail. This failure strongly depends on the type of coating, the soil conditions (environmental aspect) and, in case of rehabilitation, the circumstances under which a pipeline 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. Experience tells us that many rehabilitated coating failures are caused by failures during application and improper surface preparation (NACE study 1996).

This article is an explanation of the development of viscous-elastic coatings in the pipeline industry for the protection of pipelines and pipeline-related substrates against corrosion, along with their application and properties in practice in the field. The purpose

Table 1. Types of adhesion

Type of adhesion	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' forces	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	Viscotaq

of this article is to explain in simple physical terms the problems with corrosion of steel, the problems of coating rehabilitation on site and how viscous-elastic coatings can overcome the typical problems one is faced with during pipeline coating rehabilitation.

Corrosion

Corrosion, or steel rust, is a chemical, physical process. Iron changes into iron-oxide or iron-hydroxide. Iron oxide and -hydroxide have a drawback in 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 aluminium.

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 O₂. This oxygen, however, is not responsible for the oxidation process at the first instance. In dry environments, many materials, including steel, do not rust. In the desert of Arizona, army components are stored without any protection. The cause of oxidation is to be found in the presence of water rather than that of oxygen.

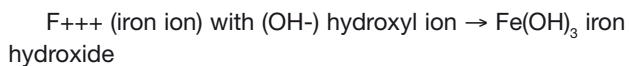
The water molecule H₂O contains oxygen. This oxygen bonds to the iron by means of a chemical process. Chemical engineers may describe the oxidation process in a somewhat different way, namely as the initial loss of electrons. It can be described as follows:



If water is present, water will split into:



The consequent reaction will be:



The H⁺ (hydrogen ion) can react with the electron e⁻ into H₂ (hydrogen). The H₂ consequently can react with

O₂ (oxygen) from the air into H₂O (water), but this reaction does not automatically play a role in the rusting process.

Coating types

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

Factory coatings

- ▶ FBE, HDPE, urethanes, etc.

Field applied coatings

- ▶ Spray coatings like epoxy, urethane and zinc.
- ▶ Residues of refinery such as waxes and petrolatum.
- ▶ Bitumen-based coatings.
- ▶ Single or multiple layer PE/butyl tapes.

The selection of the coating depends on different factors such as:

- ▶ Estimated lifetime of substrate.
- ▶ Environment.
- ▶ Nature of the substrate (material, shape, position).
- ▶ Cost per square metre (coating material and application).
- ▶ Costs of repairs.

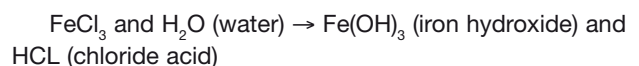
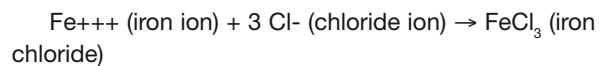
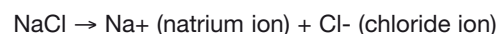
Important phenomena and problems in practice

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. These phenomena are:

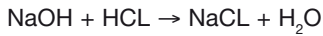
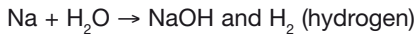
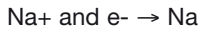
- ▶ Salts and osmosis.
- ▶ Adhesion.
- ▶ Microbiological induced corrosion (MIC).
- ▶ Surface preparation.
- ▶ Water permeability.

Salts and osmosis problems

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



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



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

In the presence of salt, osmosis occurs. Osmosis can be described as a physical phenomenon that exists in the presence of 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. The wall is a barrier between two chambers whereby in chamber A the solvent is present and in chamber B the solvent and the solved substance are present.

The solvent present in chamber A will now move to chamber B. If one starts at the same level in these two chambers, after a while the level in space A will drop but will rise in space 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 100% impermeable to water. Many coating systems, no matter how well they have been applied, do not meet this requirement. One may think of systems based on polyurethanes, epoxies or unsaturated polyester resins and bitumen.

Adhesion problems

Any pipeline coating must have good adhesion to the substrate. Coatings with no adhesion fail automatically. To obtain 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 perfect surface preparation.

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

There are several forms of adhesion, as shown in Table 1. Coatings applied in the field usually adhere to the surface by means of a physical or mechanical fixation. Other types of bonds hardly exist in practice.

Adhesion between hard or semi-hard substances that are used as coatings does not occur in practice. In this case there is always a mechanical fixation, e.g. the use of a primer.



Figure 1. Protection of crude oil pipeline with self-healing coating.

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

Microbiologically influenced corrosion (MIC)

MIC is, to the surprise of many people in the pipeline industry, responsible for almost 50% of corrosion problems.

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 (SRB) resulted in the corrosion failure of cast iron pipes.

SRB are obligatory anaerobic bacteria utilising sulfate as a terminal electron acceptor and organic substances as carbon sources. During the metabolic process, sulfate is reduced to sulfide, which reacts with hydrogen produced by metabolic activities or by cathodic reaction of corrosion processes to form hydrogen sulfide. Hydrogen sulfide is very corrosive to ferrous metals and further reacts with dissolved iron to form an iron sulfide film over the metal substrate. Iron sulfides have relatively low hydrogen evolution over-potential. So a galvanic coupling between iron sulfide 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 APB have dual roles in MIC, causing acid corrosion of many alloys and supplying nutrients and environments to the MIC community bacteria.

Surface preparation

NACE studies have proven that bad surface preparation appears to be a major cause of corrosion problems. Very often field-applied coatings need a perfectly prepared surface on 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 create problems, and rapid disbondment may occur. Surface preparation in-plant is relatively easy to control. Surface preparation in the field however is very often difficult to control and requires skill.

Water permeability

Even if there is the slightest permeability for water, corrosion 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 is always due to a combination of causes and it cannot be stated that only one of the mentioned phenomena is responsible for corrosion of a substrate itself. However, permeability of water is a factor contributing to many corrosion problems. No matter how well a coating has been applied, no matter how the application circumstances could be controlled, corrosion 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 the case of pipeline rehabilitation, this is an even bigger problem, and the application circumstances that are sometimes difficult to control, should be taken into consideration.

Problem prevention

With respect to the above-mentioned phenomena and in order to prevent corrosion during and after rehabilitation, one has to prevent blank steel parts from coming into contact with water. This is essential and must be achieved with a protective coating.

This coating has to be 100% impermeable to water, and must perfectly and permanently match 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 perfect adhesion and reduce the risk of MIC. Moreover, in practice, the application should be easy and reduce the risk of failure.

Many of the existing coating materials do not meet this requirement, especially with field-applied rehabilitation pipeline coatings, and owners are facing problems. With regard to factory coatings, the application circumstances can be controlled, and due to automation, the application is close to perfect. However, although factory coatings can be applied hot and should theoretically identically match the surface of the substrate (provided it has a favourable surface tension compared with 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 by a certain volume shrinkage.

The consequence is that even factory coatings no longer 100% meet the above requirement of a perfect match.

Although much better in quality than a field applied coating, eventually the coating can lose its adhesion in the time, due to volume shrinkage.



Figure 2. Viscotaq is a smart coating with viscous-elastic and self-healing properties.

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 the requirements during rehabilitation, a water impermeable coating that will match the surface of the substrate is needed.

A substance like oil (i.e., devoid of water particles) would possibly fulfil this requirement. However, oil has a too fluid-type character to efficiently act as a coating. A mastic with fluid-type properties with no (or a very low) degree of crystalline behaviour and 'wet' characteristics may however meet this requirement. Such a coating is a viscous-elastic coating.

Viscotaq

Viscotaq has been developed for the protection of under- and above ground substrates against corrosion. The oil and gas market demanded a viscous-elastic coating technology with an acceptable price level. Because a good application of a corrosion preventative coating determines the long-term effectiveness of a coating, the materials chosen have a specific rheological behaviour that allows an easy and faultless application in the field.

Viscotaq has been developed in co-operation with outstanding European polymer laboratories and consists of amorphous a-polar polyolefins. The material has been designed in such a way that the material – as a solid – has a clear viscous and elastic component. As a solid, Viscotaq has a true yield point and under pressure, flow

under pressure characteristics, whereby it flows into the pores and anomalies of the substrate. Due to these properties it has self-healing characteristics.

How can Viscotaq overcome the typical coating rehabilitation problems caused by the mentioned phenomena?

Elimination of salt and osmosis problems

The presence of salt particles on a substrate is not a problem if the coating is impermeable to water and if the salt particles are embodied in the coating. As a result of such impermeability, osmosis will not occur and the embodiment of salt particles in the coating ensures that they are no longer present on the substrate.

Viscotaq is impermeable to water and therefore the hazardous salt particle is neutralised, as water will not travel through the coating. Rinsing with clean water in remote areas is no longer necessary and the risk of application failure is reduced to almost 0%. Extensive tests in this respect have been carried out by Charter Coatings in Canada.

Elimination of adhesion problems

With Viscotaq, volume shrinkage is no longer an issue. Moreover, the distance between the coating and the substrate's surface, essential for a perfect adhesion, is extremely small, as Viscotaq has excellent flow-under-pressure characteristics.

This is one of the reasons that Viscotaq has been developed: it has an adhesion to the substrate's surface 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, Viscotaq is a solid with a high yield point, but retains 'wet' properties and a low surface tension. On many dry and clean surfaces, the material shows flow under pressure as it is a pressure-sensitive adhesive. It flows into the pores of the pipe and is pushed against the substrate by air pressure. This process may take some time due to the viscous-elastic properties, but will always take place. Pressure, for instance, on outer wrap or earth loads, will accelerate this process. A very intimate match exists between the substrate and the coating, which results in an extremely good adhesion. Due to the 'wet' characteristics, adhesion will take place rather quickly and will remain for decades. Due to the use of a 100% inert formulation, the material will not crack nor become brittle, and will remain plastic. The material does not contain any reactive groups and will not deteriorate in the course of time. Viscotaq is 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. This is very difficult and usually leads to a sacrifice of one of the functions.

Elimination of osmosis problems

The use of Viscotaq will eliminate the occurrence of osmosis:



Figure 3. In addition to pipelines, the product is also used for the protection of tank chimes.

1. Viscotaq is impermeable to water, hence has no selective character.
2. Viscotaq is a-polar, i.e., it is water repellent.
3. The extremely good adhesion of Viscotaq and its 'wet' characteristics prevent pressure build-up and the coating to disbond.

In addition, Viscotaq has self-healing characteristics. Minor pinholes are dealt with by the flow-under-pressure properties of the solid coat wrap, and damages will heal automatically.

Elimination of MIC problems

With Viscotaq, MIC does not occur under the coating. The permanent wet coat wrap consists 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-organisms to grow on this material under anaerobic conditions.

Viscotaq is water repellent because of its hydrophobic properties and permeation of water is not possible. It is clear: if no water is present, bacterial life is impossible.

The beauty of viscous-elastic behaviour

To summarise, MIC does not occur with Viscotaq because:

- No water is present at the boundary of the metal/coat wrap.
- No nitrogen is available in the coat wrap.
- No initial bacterial activity is present in the coat wrap.
- The wrap coating molds to the substrate due to the viscous component in the coating. There is a real adhesion with no space for any substance to creep between the layer and the substrate in a cohesive fracture.
- The coat wrap is under permanent pressure.

- The coat wrap is impermeable to water and oxygen.
- No permeability for ionic species from soil e.g. nitrate, nitrite and ammonium.
- There is no water available and the ions are insoluble in the a-polar material.
- Viscotaq is water repellent.
- The material is slightly basic (PH8; unfavourable for SRB).

Elimination of surface preparation problems

Here is the advantage of Viscotaq: the substrate only needs to be clean to level ST-2. Blasting of the surface is preferred but is not necessary in all circumstances.

The coating should be applied above the dew point, and because Viscotaq has a low glass transition temperature, it can be applied within a wide temperature range. It can be wrapped at temperatures of -10 °C but also on surfaces with a temperature of +65 °C. Due to the flow under pressure characteristics and the low surface tension, the material shows a perfect adhesion to all materials, even to PE and PP.

Elimination of water permeability-related problems

Viscotaq is made of amorphous a-polar polyolefins with no reactive groups and free radicals. It has an extreme low permeability to water and is impermeable to moisture under ambient conditions. Due to the absence of free radicals, Viscotaq remains stable for decades and no deterioration of the material takes place. Due to the amorphous structure, the coating shows no crystalline behaviour and will match the surface of the substrate up to a physical molecular level. There is no space for moisture due to the extreme close contact of the viscous-elastic coating and the substrate's surface.

Aggressive soils

Viscotaq is excellent for application in aggressive soils, like Subkha areas in the GCC countries and on the Subcontinent.

Packing

Viscotaq is available as a wrap coating (Viscowrap), as a paste (Viscopaste), as a solid sealant for roofs and tanks (EZ-WRAP), and as a fluid sealant for cable conduits and tanks (ViscoSealant).

As a mastic it can be used to protect tank bottoms, flanges, valves and irregular spaces. As a coat wrap it can be used for the protection of pipelines and large valves.

Conclusion

The following criteria cause a pipeline coating to fail, specifically when applied over-the-ditch as a rehabilitation coating:

- ➔ 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 (salt) (NACE study 1996).

Viscotag overcomes these failure problems due to the following characteristics:

- ➔ Suitable for all situations and applications.
- ➔ No intensive surface preparation is required.
- ➔ Easy to apply.
- ➔ No curing time.

- ➔ Immediate and direct adhesion. No adhesion problems.
- ➔ No reactive groups present in the material, like oxygen or ether groups.
- ➔ Impermeable to water.
- ➔ No volume shrinkage due to its flexible behaviour.
- ➔ No risk of osmosis as salt particles are embodied in the coating and the coating is 100% impermeable to water vapour and oxygen.

As a conclusion, the essential and functional characteristics of Viscotag for pipeline rehabilitation are:

- ➔ Quality: corrosion prevention for decades with a 40 year written warranty*.
- ➔ Safety: easy and safe application without open fire.
- ➔ Health: no risk for the applicant. Non-toxic and inert material.
- ➔ Ease of application: easy to apply.
- ➔ Energy: can be applied without energy.
- ➔ Environment: no pollution of water and soil. **WP**

*If applied to the manufacturer's instructions whereby agreed on in writing.