



Internal corrosion of slurry pipelines caused by microbial corrosion: causes and remedies

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Synopsis

Pipelines are used extensively in industry to convey various products. Internal corrosion of pipelines can lead to perforation and leakage of the product. A growing problem, not often accurately recognized, is internal corrosion of pipelines caused by bacteria.

Microbiologically-induced corrosion (MIC) refers to corrosion caused by a variety of micro-organisms. This form of corrosion is not widely recognized in many industries, although it is widespread and causes many corrosion problems in pipelines, both internal and external. Sulphate-reducing bacteria (SRB) are responsible for the bulk of the corrosion problems caused by MIC. Corrosion caused by SRB is found extensively in water pipelines conveying raw, potable and waste water, as well as in pipelines conveying slurries. This problem also occurs in pipelines conveying crude oil.

This paper describes internal corrosion problems of slurry pipelines caused by bacteria and outlines mitigation methods to improve slurry pipeline integrity, thereby extending the life of such pipelines.

Internal corrosion of ferrous pipelines

There are only a few corrosion mechanisms that cause internal corrosion of pipelines conveying water (whether potable, process or raw), in contact with carbon steel piping.

These are typically as follows:

- ▶ *General (uniform) corrosion*—this form of corrosion typically occurs when the corrosion rate is very high and results in extensive corrosion, which is more or less 'uniform' along the pipeline. An example is low-pH water in contact with unlined carbon steel piping
- ▶ *Localized corrosion*—this form of corrosion results in severe corrosion or perforation located in small areas of the pipeline internal surface, with the rest of the internal surface not subject to corrosion. An example is water containing very high levels of chloride ions
- ▶ *Under-deposit corrosion*—this form of corrosion occurs when deposits settle, or are formed on the metal surface, resulting in corrosion beneath the deposits. The deposits may be caused by

- tuberculation, slimes or scale deposition
- ▶ *Microbiological corrosion (MIC)*—this form of corrosion is caused by the presence and activity of micro-organisms on the metal surface. A more detailed explanation of the most common cause of MIC, that caused by sulphate-reducing bacteria, is presented later.

Microbiologically induced corrosion (MIC)

Microbial corrosion refers to corrosion that is caused by organisms, typically bacteria, yeasts, barnacles and algae. It is often abbreviated as MIC, an acronym for microbiologically-induced corrosion or microbiologically-influenced corrosion.

MIC occurs in many environments and on most alloy types, including some non-metallic materials. For the purpose of this paper only MIC that occurs in water systems is discussed.

When a piece of bare metal is exposed in water, whether potable or not, it almost immediately starts to build up an inorganic layer, which consists predominantly of charged inorganic molecules. After a further period of time, organic matter starts to attach onto this surface and the thickness of the layer increases. Aerobic species (organisms that need oxygen to survive) such as slime-forming bacteria then start to colonize the layer, which is referred to as a biofilm. Thereafter, once the biofilm has reached a certain thickness, sulphate-reducing bacteria (SRB) colonize the biofilm and locate themselves at the interface between the biofilm and the metal substrate.

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Internal corrosion of slurry pipelines caused by microbial corrosion:

SRB are anaerobic (thrive in oxygen-deficient environments) and therefore locate themselves at the interface where they are protected from the aerated water by the biofilm. The available oxygen is used by the aerobic species in the biofilm, such that the base of the biofilm is anaerobic.

SRB derive their energy by converting sulphates (and phosphates) into sulphide, which then reacts to either form hydrogen sulphide or iron sulphide. (The iron sulphide is the black layer which is present in tubercles created by SRB). Hydrogen sulphide is extremely aggressive to many metals.

As the SRB grow, they form a tubercle, consisting of corrosion product and biofilm, which shields them from the bulk environment and assists their growth. Corrosion then occurs beneath the tubercle and often manifests as a pit beneath the tubercle. However, the pit is often visible only once the tubercle has been removed.

The presence of tubercles has two main consequences:

- ▶ Firstly, they protect the bacteria from the bulk environment. It is therefore not possible to kill SRBs located beneath tubercles. The tubercles have to be removed either mechanically or chemically, to allow access to the bacteria beneath for biocides (or other means of control) to be effective
- ▶ Secondly, they provide an ideal micro-environment for corrosion to continue and accelerate, and since localized corrosion, such as pitting, is autocatalytic, once started, very high corrosion rates can be experienced, which can cause perforation in a short period of time.

SRB are ubiquitous and also have the ability to enter a dormant phase when conditions change and become non-ideal for their growth. The possibility of SRB growth therefore always exists.

There is also a misconception that SRB cannot be present in potable water since it is chlorinated. This is not true. Chlorination of potable water systems can be effective in controlling pathogenic bacteria, but does not necessarily kill SRB.

It should also be emphasized that when corrosion is referred to as being caused by SRB, it is usually a community of different types of bacteria that is involved. There are also other species of bacteria that can convert sulphates to sulphides, and they can therefore also cause corrosion. Most tests, however, only check for the presence of SRBs. It must also be stressed that bacteria need the presence of water to survive. They will therefore not be active in non-aqueous media.

SRB corrosion is almost always observed on carbon steel piping that is unlined. The source of the bacteria is the feed water, which may be supplied from a lake, river or dam. It may also be due to the hydro-testing procedure carried out during commissioning of the pipeline.

The author has undertaken extensive research into microbial corrosion caused by SRB and some of the published literature emanating from this work is shown in the References.

Identification of MIC caused by SRB

In the field, corrosion caused by SRB can be readily identified

by the presence of tubercles of varying size and shape. Once broken, the centre of the tubercle usually contains soft black products. Beneath the tubercle there is an adherent thin black layer, which can be easily removed. Once the black layer is removed, the shiny grey metal surface is revealed, which has been undergoing corrosion. This typical morphology is shown in Figures 1 and 2.

To be absolutely certain that SRB are present, it is necessary to remove tubercles and corrosion products from the field using aseptic techniques, and culture them in microbiological laboratories equipped for testing for SRB.

Examples of SRB corrosion of slurry pipelines

We have undertaken a number of investigations into internal corrosion of slurry pipelines caused by sulphate-reducing bacteria. Due to client confidentiality, the actual locations cannot be revealed.

What was common in all lines was the presence of tubercles caused by SRB. This occurred irrespective of whether there was a thick scale layer or not. It would appear that the bacteria are able to locate themselves at the base of the scale layer and after a certain period, the tubercles will increase in size. This is shown in Figures 3 and 4.



Figure 1—SRB tubercles, shown by black arrow, inside pipeline

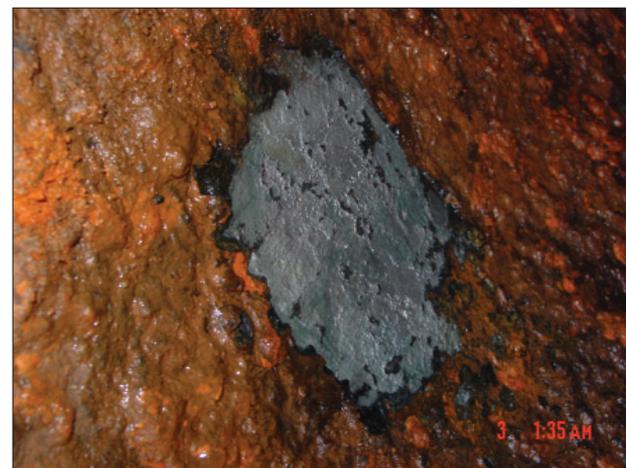


Figure 2—Typical morphology once tubercles have been removed

Internal corrosion of slurry pipelines caused by microbial corrosion:



Figure 3—SRB tubercles growing within a grey scale



Figure 4—Internal metal surface after scale and tubercles have been removed. Note circular metal loss in the form of pits

Once the tubercles have been removed, there is localized corrosion in the form of pits on the metal surface, directly beneath where the tubercles were located, as shown in Figure 4.

Recently, we undertook a detailed investigation using long-range ultrasonic testing (LRUT) of a slurry pipeline and detected severe metal loss. Spool pieces were removed for further evaluation and the typical morphology of the corrosion is shown in Figures 5 and 6.

Remedial actions

Integrity assessment

It is often required to determine the integrity of slurry pipelines in order to assess the risk of leakage or rupture. In many cases, pipeline operators use conventional ultrasonic probes to undertake spot tests on individual pipe lengths to check the remaining wall thickness. This approach is not really suitable for an accurate risk assessment as it is a ‘hit and miss’ affair. The probe may not be located directly over

the worst (deepest) pit and therefore may not be recording the actual worst case wall thickness, which results in an overestimation of remaining life. Leakage and failure may therefore occur unexpectedly with onerous consequences for the pipeline operator and embarrassment for the maintenance staff.

It is technically far superior to use long-range ultrasonic testing (LRUT), sometimes referred to as guided-ultrasonic testing (GUL), which allows the complete pipeline length to be analysed so that all the regions where the pipe wall has thinned can be located. Each individual pipe length is tested and the wall thickness of the whole pipe surface area evaluated. For example, on a 356 mm diameter pipeline with pipe lengths of 9 m, using conventional ultrasonics with a 1 cm² diameter probe, taking readings at the two ends and in the middle and four readings at each location, i.e. 12 readings in total, results in 0.00012% of the total surface area being tested, whereas LRUT would test 100% of the total surface area.



Figure 5—Internal corrosion, leading to perforation of slurry line caused by SRB



Figure 6—Localized corrosion in the form of pits of slurry pipeline caused by SRB

Internal corrosion of slurry pipelines caused by microbial corrosion:

In the example mentioned above, the pipeline owner used the conventional non-destructive testing (NDT) methodology to replace any pipe lengths that showed a wall thickness below 4 mm. When a sample of 100 pipe lengths was tested with the LRUT technique, 28% of the pipe lengths showed thicknesses below 4 mm, with many having a wall thickness of 2.5 mm. The pipeline owner thus had an incorrect sense of security using the conventional ultrasonic methodology and was in fact at risk of pipeline failure without being aware of this.

Pigging

It is difficult to remove SRBs once they have become established. Simply injecting biocides into the slurry will not work because the bacteria are located beneath the tubercles. In order to get to the bacteria, the scale and tubercles need to be removed. This can be achieved using hard pigs and the degree of abrasion can be designed to suit the application.

Once the scale and tubercles have been removed, it is possible to pump appropriate chemicals through the pipeline to kill the bacteria.

Chemical cleaning

We have found that an alkali wash after pigging is very effective in killing SRB. The high-pH kills the bacteria and it is also usually easier to dispose of alkali solutions than to dispose of acid wash effluent. We would therefore not usually recommend an acid clean of slurry pipelines, particularly when the slurries that are conveyed by the pipeline are basic in nature such as lime.

Biocides and inhibitors

Although it is possible to use biocides to kill and/or control the numbers of bacteria and inhibitors to reduce the rate of corrosion, their use in once-through systems is limited for the following reasons:

- ▶ The volumes of chemicals required in once-through systems can make treatment prohibitively expensive
- ▶ Treatment and disposal of the chemicals at the end of the pipeline may be problematic and expensive
- ▶ SRB can adapt to biocides. This necessitates that biocide treatment regimes are rotated between oxidizing and non-oxidizing biocides.

It is therefore more practical to batch biocides, if they are going to be used, between cleaning pigs, following hard cleaning of the pipeline first to break down the tubercles.

Combination of techniques for proactive pipeline management

In order to adopt a proactive approach to slurry pipeline leaks and failures an integrated management philosophy is recommended. This approach consists of the following phases:

- ▶ Appropriate NDT using long-range ultrasonic testing, complemented by conventional NDT should be used as a baseline to quantify the integrity of each pipeline length. On buried pipelines this requires excavation at intervals ranging between 30 and 70 metres
- ▶ Scale and tubercles caused by SRB should be periodically removed using hard pigs

- ▶ The remaining scale and bacteria should be removed and/or killed using biocides or alkali washes, batched between cleaning pigs in order to reduce costs
- ▶ Passivation of the steel surface is achieved by the use of alkali washes and this will delay the onset of microbial corrosion
- ▶ As each pipeline is unique due to its site-specific operating parameters, the growth of the biofilm/scale can be measured using an appropriately designed exposure programme. This will assist in determining the frequency with which the scale and bacterial removal will need to be undertaken as part of ongoing maintenance of the pipeline.

Conclusions

Severe internal corrosion, leading to perforation and leaks of slurry pipelines can, in some instances, be caused by microbial corrosion, as was shown in the examples presented in this paper.

Sulphate-reducing bacteria are responsible for the bulk of the microbial corrosion problems experienced in slurry pipelines.

Conventional NDT techniques typically used by slurry pipeline operators have severe limitations in assessing the actual integrity of slurry pipelines and all integrity plans based solely on such techniques may result in a false sense of security.

A proactive approach has been outlined in this paper, which uses a combination of techniques to determine a baseline integrity status of the pipeline.

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