OIL COMPANIES INTERNATIONAL MARINE FORUM

FACTORS INFLUENCING ACCELERATED CORROSION OF CARGO OIL TANKS

September 1997

The OCIMF mission is to be recognised internationally as the foremost authority on the safe and environmentally responsible operation of oil tankers and terminals.

The Oil Companies International Marine Forum (OCIMF) is a voluntary association of oil companies having an interest in the shipment and terminalling of crude oil and oil products. OCIMF is organised to represent its membership before, and consult with, the International Maritime Organization (IMO) and other government bodies on matters relating to the shipment and terminalling of crude oil and oil products, including marine pollution and safety.

Table of Contents

Table of Contents (continued)

Section	Contents	Page

1.0 Introduction

Corrosion of cargo tank structure is a fact of life when operating oil tankers in the harsh environment encountered at sea. The internal structure of the cargo tanks, often un-coated, is exposed to potentially corrosive gases, sea water, crude oil and oil products.

The effect of this corrosion over a period of years is to reduce the material thickness and hence the strength of the structure. Classification Society design rules typically incorporate an allowance for corrosion that is based on a certain amount or degree of corrosion. Should corrosion proceed at an accelerated rate greater than that allowed for in the design of the cargo tank structures and be allowed to continue unchecked, then a structural failure with consequent oil spillage, explosion or loss of the ship could be the result

Individual tankers usually exhibit a unique, but controllable corrosion pattern. However, recent experiences of OCIMF members have indicated problems in new single and double hull tonnage from excessive pitting corrosion of up to 2.0 mm per year in the un-coated bottom plating in cargo tanks due, inter alia, to microbial induced corrosion processes. In addition accelerated general corrosion up to 0.24mm per year has been found in vapour spaces. This type of wastage and the increased rate of corrosion, which is much greater than that which would be normally expected, gives cause for serious concern.

Recognising the potentially serious impact of marine incidents, the Oil Companies International Marine Forum (OCIMF), has carried out an investigation into the factors which may be influencing accelerated cargo tank corrosion. The results of this investigation and areas for further study are presented in this paper. Also included are practicable long and short term mitigating and remedial actions which may be considered as appropriate to reduce the rate of corrosion in the cargo tanks of oil tankers.

2.0 EXTENT OF THE PROBLEM.

2.1 Double hull tankers

The normal corrosion rate of uncoated cargo tank deck plating is 0.10 mm or less per year. However, annual wastage rates as high as 0.16mm to 0.24mm have been reported on ships less than 3 years old. This accelerated corrosion rate, which is approximately 2 to 3 times that which would normally be anticipated, is sometimes accompanied by accelerated general corrosion of the vapour space steelwork. In addition to accelerated general corrosion, there has also been an increase in the incidence and severity of pitting corrosion in cargo tank bottom plating. In one specific instance a 150,000dwt tanker is reported as having an average pit depth of between 2.0mm & 3.0mm with a maximum pit depth of 4.0mm. This after only 2 years in service.

In addition to the more conventional corrosion mechanisms**,** a possible contributory cause of accelerated corrosion has been microbial attack from bacteria in the cargo oil. It would appear that, as crude oil is often loaded at temperatures higher than ambient air and sea temperatures, during the loaded passage the temperature of the cargo tank structure is being maintained at higher levels than normal due to the insulating effect of the double hull spaces.

Higher tank temperatures, coupled with residual water in the cargo tank can:

- offer favourable conditions for SRB anaerobic bacteria to proliferate, and;
- activate the formation of corrosive cells on the surface of the inner bottom.

2.2 Single hull tankers

Excessive pitting corrosion in the un-coated bottom plating of single hull tankers less than 5 years old has also been reported. In one particular instance the average depth of pit was 2.0mm to 4.0mm with a density of around 200 to 400 pits/m2 and a maximum pit depth of 7.0mm. This pitting corrosion rate is significantly in excess of that which would normally be expected and has been attributed to microbial attack from bacteria in the cargo oil.

2.3 Shore tanks

Crude oil storage tanks are usually internally coated and this coating is generally very resistant to the breakdown due to the lack of frequent flexing normally associated with the cargo tank structure on board oil tankers. However, shore tanks are not immune to the effects of microbial infection although the outcome tends to display itself as large bio-mass formations which can clog valves, pipelines and filters thus necessitating the tanks be more regularly cleaned out.

3.0 TYPES OF CORROSION

Corrosion in the cargo tanks of oil tankers can generally be classified as general corrosion, local corrosion, pitting corrosion or weld metal corrosion.

3.1 General Corrosion

This type of corrosion generally appears in tanks that are un-coated as a crumbly scale that is evident over large areas and which, when it is dislodged, exposes fresh steel to the corrosion cycle. General corrosion is allowed for in the design and construction of the oil tanker and an average value of in-service wastage is generally accepted as being around 0.1mm/year or less. Classification Society corrosion allowances would typically offer a useful life for structural members of around 20-25 years.

3.2 Local Corrosion

Highly stressed structural components tend to "work" during alternate compression and tension cycles when the ship is in-service. Surface rust or scale on these components becomes dislodged during this flexing process, exposing bare steel to further insidious corrosive attack. To further exacerbate the situation, as the material thickness diminishes, the stress on the component is incrementally raised and the corrosion continues at an accelerated rate. Localised corrosion, in grooving form, occurs at structural intersections where water collects or flows. Grooving corrosion can also occur on the vertical structural members at the water flow path or on the flush sides of bulkheads in way of flexing of plating.

3.3 Pitting Corrosion

Pitting corrosion is a localised corrosion that is more commonly found in the bottom plating of tanks and horizontal surfaces or structural detail where water tends to accumulate. Bare steel plates in cargo tanks are often coated with black rust and a residual waxy oil coating from previous cargoes which tends to protect the metal surface from heavy corrosion. Localised breakdown of these natural tank coatings, particularly in way of cargo bellmouths, or cleaning medium impingement areas, can quickly cause very severe pitting where sea water collects and electrolytic and/or microbial induced corrosion can occur. Severe pitting corrosion creates a tendency for the pits to merge to form long grooves or wide scabby patches with an appearance resembling that of general corrosion. Extreme pitting corrosion in addition to causing loss of structural strength necessitating extensive and costly steel renewals can, if not adequately repaired, lead to hull penetration and a serious pollution incident.

3.4 Weld Metal Corrosion

Weld metal corrosion is an electrolytic action between the weld material and the base metal which can result in pitting or grooving corrosion.

4.0 POTENTIAL CAUSES OF ACCELERATED CORROSION.

OCIMF has examined a variety of causes of accelerated corrosion identified as possible contributing factors for a number of reasons, including:

- evidence obtained when examining the vessel experiencing accelerated corrosion.
- noting the cause to be one which normally contributes to corrosion.
- differences in the design, materials, operating procedures and trading routes between those oil tankers experiencing accelerated corrosion and those which are not.

These causes of corrosion in the cargo tanks include, inter alia:

4.1 Coating not applied

When no protective coating is applied, general corrosion occurs across the full extent of the tank. However it is not un-common to identify particular areas within the tank where an increased corrosion rate can be found. This phenomenon is usually attributable to readily identified localised conditions, for example a cleaning medium direct impingement site or an area where mill scale has become detached.

4.2 Excessive crude oil/water washing

Crude oil cargoes can cause a waxy layer to form on the cargo tank steel structures and this layer helps to inhibit corrosion. However, washing mediums such as hot and cold sea water can remove this protective layer and thus allow the corrosion process to start. The integrity of the protective layer is also reduced by an increased frequency of crude oil washing.

4.3 High sulphur content of cargo oil

Crude oils that contain high concentrations of sulphurous constituents can cause high levels of general and pitting corrosion when these components react with entrained or residual sea water to form acidic compounds. In addition, sulphur is cathodic by nature and can promote the formation of an active corrosion cell.

4.4 Inert gas quality

Inert gas should always have an oxygen content of less than 8% and at these concentrations the rate of corrosion of steel structure should be reduced. However, for corrosion rates to be significantly reduced, the oxygen content should be below 1%. Sulphurous compounds, and soot in the flue gas, if not sufficiently removed in the water washing process, can also cause accelerated corrosion due to relatively strong concentrations of acid compounds being introduced into the tank along with the inert gas. If the quality of the inert gas is allowed to deteriorate due to in-attention or poor maintenance, then the corrosion rate may increase, particularly on the overhead surfaces in the vapour space of the tank where moisture tends to condense.

4.5 Inadequate Earthing/Grounding of Electrical Equipment

Ineffective earthing/grounding of electrical equipment can lead to stray currents circulating in the steel work and these can increase the incidence and severity of pitting corrosion.

4.6 Localised coating defects

Where the cargo tanks have been protected by a coating, local breakdown of this coating can lead to accelerated pitting corrosion due to concentrated electrolytic action in the area of the breakdown.

4.7 Material of Construction

Modern construction techniques include the use of higher tensile steels and these are increasingly being manufactured using the Thermal Mechanical Control Process (TMCP). This steel is one factor which distinguishes new vessels experiencing accelerated corrosion from older vessels which have not. Accordingly TMCP steel is listed as a potential cause of accelerated corrosion until such times as it can be proven not to be a causal factor.

4.8 Microbial attack

A wide range of bacteria can exist in all areas of oil production facilities including the production plant, pipelines, the water injection plant, the reservoir and, of course, in the cargo tanks on board the oil tanker used to transport the oil. Most microbes produce corrosive acidic compounds. Optimal microbial proliferation and subsequent corrosion inevitably relates to a population of differing but mutually inter-dependent bacterial species rather than individual species. The bacteria most frequently associated with corrosion of steel are those that generate sulphides and these are commonly called sulphate-reducing-bacteria (SRB). Under favourable conditions these bacteria can produce prodigious quantities of sulphide which can precipitate out as metal sulphides, dissolved sulphide or hydrogen sulphide.

On board ship, when bacteria find a niche on a steel surface they can proliferate and a corrosion pit develop at the site. Evidence of microbial contamination is confirmed by the presence of bacteria in water samples taken from the bottom of the tank and the presence of active corrosion pits in the bottom plating. Generally, small lumps with a crust of scale over them are evident and underneath this crust, oily sludge and a few drops of water can usually be found.

Pitting corrosion in tanks contaminated with sulphate reducing bacteria (SRB) is caused when a substantial aerobic[1] population of micro-organisms inhabit the tank and create the conditions necessary for SRB proliferation. The environmental conditions preferred by SRB include zero dissolved oxygen, water and the presence of soluble organic nutrients. Aerobic micro-organisms use up oxygen and the oxygen deficient zone formed is anodic in relation to adjacent relatively oxygen rich zones thus causing anodic corrosion pits to develop.

Temperatures above ambient suit most SRB and they are known to inhabit sea water and the produced water associated with crude oil from older reservoirs where the necessary nutrients for their growth may be found. Mesophilic[2] SRB flourish at intermediate temperature ranges, i.e., between 20^{o}C and 50^{o}C and thermophilic[3] SRB exist, and flourish, in much higher temperatures, i.e., above 50^{o}C.

A typical source of the organic nutrients necessary to sustain SRB would be the short-chain fatty acids normally encountered in many formation waters or the organic acids, carboxylic acids and alcohol produced by aerobic bacteria.

[1]Micro-organism that lives only in the presence of free oxygen.
[2]Favouring medium range temperatures.
[3]Favouring upper range temperatures.

During their life-cycle, the anaerobic[4] SRB extract the oxygen from sulphates found in the cargo to oxidise their organic food source and form sulphides, including hydrogen sulphide. These sulphides may be re-oxidised to form acidic sulphates, e.g. sulphuric acid, during the ballast voyage when the cargo tanks are normally empty. This sulphate corrosion cycle requires the existence of aerobic → anaerobic→ aerobic conditions.

Experience would indicate that sufficient oxygen for the aerobic phase will be available even in an efficiently inerted cargo tank. The cycle is therefore self sustaining and continuous as the cargo tanks alternate between empty and loaded conditions.

These corrosive effects may occur in isolation or be widespread at the same time. In any event, as previously indicated, the effect on diminution of scantlings can be quite dramatic with a normal acceptable annual corrosion rate being accelerated by several orders of magnitude.

4.9 Sludge/Scale Accumulation

It is not unusual for significant quantities of sludge and/or scale to be found accumulating in the bottom of cargo tanks. This debris from previous cargoes or dislodged corrosion scale can create an ideal breeding ground for bacteria and which can hide subsequent pitting damage. Accumulated scale/sludge also inhibits proper draining of tanks by blocking drainage holes and creating an uneven surface.

4.10 Water in Cargo Tanks

Residual water in cargo tanks can originate from a number of sources and when it settles out from the cargo can cause electrolytic or microbial influenced corrosion of structural components, particularly on after end tank bottom plating around the suction bellmouths where water tends to accumulate due to the trim of the ship.

The most common sources of water in cargo include the following:

- Condensate leakage from heating coils
- Condensate water from inert gas
- Residual heavy weather ballast
- Residual wash water
- Retained water due to ineffective draining arrangements
- Water entrained in cargo
- Water from the slop tank
- Water leakage from adjacent ballast tanks

4.11 High Humidity

[4]Micro-organism that lives only in the absence of free oxygen.

Excessive residual water creates high humidity conditions in the vapour space when the tank is loaded and across the whole tank in the ballast voyage exacerbating both the general and pitting corrosion processes.

4.12 High Temperature

The wing and double bottom spaces of a double hull tanker act as a thermal barrier which effectively insulates the cargo tanks from the cooling effect of the sea. Consequently, the cargo tank structure is less subject to temperature change reflecting changes in ambient sea temperature and tends to remain close to the cargo loading temperature.

After cargo discharge, the steel structure remains at an elevated temperature for some time until such times as it is cooled by ambient air or adjacent ballast tanks being filled by water. The temperature differential between sea and cargo tanks during the ballast voyage has been reported as high as 15^0C.

High temperatures lead to an increase in general corrosion. It has been reported that the corrosion rate doubles for every 10^0C increase in temperature. High temperatures can also lead to an increased bacterial growth rate and consequent increase in microbial influenced corrosion rates.

Wing tanks of single hull tankers also provide an insulating thermal barrier for centre cargo tanks.

4.13 Structural Flexing

The optimisation of structural design and the use of high tensile steels has led to a reduction in the stiffness of the ship's structural members. The result is an increased degree of flexing which contributes to the shedding of scale on vertical and inverted surfaces. The newly exposed steel presents a renewed opportunity for general corrosion to occur at an accelerated rate.

5.0 ASSOCIATED RISK

5.1 Oil Leakage

Should the pitting and grooving corrosion process be allowed to continue without adequate remedial action being initiated, a pit could develop into a hole and result in the leakage of oil to the environment or into the double hull spaces.

5.2 Steel Renewal

As the corrosion process progresses, severely corroded areas can seriously affect the strength of the structure and may ultimately require extensive and costly steel renewals.

5.3 Structural Failure

Should the pitting corrosion be allowed to continue without adequate remedial action being initiated then each pit could join up with its neighbour until such times as a fault line is formed in the structure. This will cause the material to be extremely susceptible to fatigue failure with attendant consequences. It should be noted that the fatigue life of structural components is reduced in proportion to the cube of the diminution of plate thickness.

6.0 AREAS FOR FURTHER STUDY

A number of the previously identified possible causes of accelerated corrosion warrant further study to determine their relative importance to this issue. As it is possible that the phenomenon is the result of a combination of factors, it is suggested that the effects of some of the following factors may require to be considered simultaneously.

6.1 Temperature Profiling of Cargo Tank

Additional monitoring and review of existing records should be carried out to establish the temperature profile of the cargo tank throughout the loaded and ballast voyages and its effect on corrosion rate. As this data will obviously vary considerably by trading area, the inter-relationship of steel temperature, trading area and incidence of accelerated corrosion should be examined.

6.2 Corrosion Properties of TMCP Steel

The corrosion characteristics of TMCP steel should be studied to determine whether or not they differ from steels manufactured by other methods.

6.3 Flexing of Steel in a Corrosive Environment

The influence of the cyclical loading and deflection of steel structures on corrosion rates should be examined. The degree of deflection of newer high tensile structures vs. older mild steel structures should be quantified to determine whether the deflection contributes to the separation of scale.

6.4 Crude Oil Washing

The effect of crude oil washing on corrosion should be evaluated including:

- the influence of a film of oil on steel;
- The effectiveness of different types of crude oil washing machines, e.g., programmable vs. non-programmable; and
- the impact of crude oil washing on rust scale separation from steel surfaces.

6.5 Coating Effectiveness and Microbial Influenced Corrosion

The effectiveness of coal tar and pure epoxy coatings should be evaluated in an environment that includes microbial influenced corrosion.

6.6 Inert Gas

The composition and moisture content of inert gas should be examined to determine its influence on the corrosion rate as well as methods for decreasing the corrosive constituents of the gas.

6.7 Methods for Controlling Humidity in Inerted Cargo Tanks

Methods for decreasing the humidity level in cargo tanks should be examined, including de-humidification of the inert gas.

6.8 Crude Oil Source

An effort should be made to determine if some crudes are more susceptible to creating accelerated corrosion than others.

7.0 REMEDIAL CONSIDERATIONS FOR EXISTING SHIPS.

Although different ships with specific problems will undoubtedly require specialised attention to determine the best course of treatment to be used, the following remedial methods may be considered:

7.1 Enhanced inspection

Should accelerated corrosion be suspected then an enhanced programme of tank inspection and corrosion data recording should be undertaken to determine trends and the criticality of the situation. In addition, biological samples should be taken during these inspections.

7.2 Pit filling

A common repair method for pitting is to thoroughly clean or blast the surrounding area and fill the pits either by welding or with epoxy filler or by welding and over-coating with an epoxy paint or filler. It should always be borne in mind that localised damage to a coating can cause accelerated pitting corrosion to occur.

7.3 Coating cargo tank vapour space and bottom plating

Experience has shown that grit blasting and epoxy coating of the upper and lower areas of cargo tanks is effective in controlling corrosion. Should this course of action be adopted, an epoxy coating with anti-bacterial properties should be employed. Surface sterilisation may also be necessary in the case of microbial induced corrosion. As with all coating systems it is imperative that this coating be regularly inspected and maintained as appropriate.

7.4 Pitguard anodes

Accelerated corrosion requires the presence of water and for this reason the installation of pitguard anodes, i.e. anodes which are only a few millimetres from the tank bottom, may mitigate the general and pitting corrosion process. It should be noted that anodes are only effective when immersed in water and may not be effective in inhibiting microbial influenced corrosion. Anodes should always be installed and maintained as per manufacturers recommendations.

7.5 Crude oil washing

Crude oil washing can remove the protective waxy layer on steel surfaces thus exposing the steel to corrosion. However, effective crude oil washing may also serve to lessen the conditions that lead to corrosion. Consideration should be given to reducing the amount of deckhead and tank side washing whilst instead focusing the washing medium on the tank bottom to facilitate the flow and discharge of liquids and entrained solids. Attention should also be placed on reaching shadow areas in order to remove ‘dams’ formed by sludge and scale.

7.6 Reducing the temperature of cargo tank structure

Elevated temperatures of the cargo tank structure of oil tankers may be conducive to accelerating general corrosion and the proliferation of microbes influencing corrosion. The temperature of the steel could be reduced by changing out the relatively warm ballast loaded alongside with cooler deep sea ballast on the way to the load port. Another consideration could be to replace the relatively warm inert gas in the cargo tank whilst at sea when the scrubber plant sea temperature is lower.

7.7 Biocide addition to the cargo tank bottom

A broad spectrum biocide may be added to the bottom water in the cargo tank on an on-going basis to ensure that bacteria do not have an environment which will allow proliferation. It is highly likely that these biocides would be harmful to humans and the environment although some less harmful products may be available. A narrow spectrum biocide may be added to the bottom water on an on-going basis to ensure that SRB do not have an environment which will allow proliferation.

7.8 Bacterial conversion (nitrate addition)

A nitrate rich chemical may be introduced to the bottom water in a cargo tank to divert SRB from reducing sulphate to the less harmful reducing nitrate type. Most SRB actually prefer nitrate to sulphate and relatively harmless nitrogen gas and ammonia are the resultant products of reduction, not sulphate.

7.9 Chemical control

Chemical additives (alkaline) may be introduced to the bottom water to modify the pH beyond the range which facilitates the proliferation of SRB and to offer some protection against acidic corrosion.

8.0 NEWBUILD CONSIDERATIONS.

8.1 Design

Careful consideration should be adopted at the early design stage to ensure that the "in tank" drainage is effective and capable of reducing retained water to an absolute minimum. Enlarged and/or additional well placed drain holes in the tank bottom structure will facilitate the removal of liquids from the tank, thereby lessening the amount of standing water remaining after cargo discharge. Enhanced flow rates resulting from improved drainage will also serve to reduce the deposition of solids entrained in the cargo.

8.2 Coating

Consideration should be given to coating the entire internal surface of the cargo tank. If a decision is made to apply a coating to only a portion of the cargo tank then priority should be given to the cargo tank vapour space, bottom plating and all associated structural members. Surfaces should be grit blasted and coated with an epoxy coating which is light in colour.

8.3 Increased scantlings

Cargo tank vapour space, bottom plating and bulkhead plating material thickness could be increased to accommodate increased corrosion rates. Consideration should be given to improvement in structural design such as reduced frame and longitudinal spacing to improve the stiffness of the structure and thereby reduce structural flexing.

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