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Microbiological Induced Corrosion in Newly Built Tanks

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ABSTRACT

Localized (Pitting) corrosion in the annular plates of uncoated tanks was detected in newly built tanks sequel to hydrostatic testing. The causative factor was detected as microbiologically induced corrosion (MIC).

This form of corrosion results from the activities of microbial colonies, normally a mix of possibly aerobic and anaerobic microbes that exist in both sessile and planktonic forms.

Stagnant and/or low flow conditions play a key role in MIC initiation. Sulfur, H_2S, ammonia, hydrocarbon & acids also provide nutrient sources for sulfate-reducing bacteria (SRB). Carbon steel and stainless steel equipment including pipelines, piping and storage tanks face significant challenges from Microbiological Induced Corrosion (MIC) both prior to and during service due to several factors which are described in this paper.

This paper also outlines some of the major metallurgical, corrosion, prevention, mitigation and inspection issues that are commonly associated with Microbiological Induced Corrosion.

Keywords: Microbiological, Pitting, Storage, Water, Aqueous, Organic, In-Organic, Hydro test, Damage Mechanism.

INTRODUCTION

The kinetics of metal corrosion are influenced by microorganisms adhering to interfaces and forming bio-films, the bio-films create the chemical environment for initial pitting and microbiologically induced corrosion (MIC) to occur [1]. Corrosion rates are therefore affected by microorganism activity and factors such as energy sources, carbon sources and water influence the corrosion rate in addition to by-products produced by microorganisms such as electron donators and acceptors [2].

MIC is usually encountered in piping, exchangers, tanks, equipment and the fire water system. The untreated, stagnant and low flow areas of water are the prime source of MIC on carbon steel, low alloy steel, stainless steel, 300 SS, 400 SS, aluminum, copper and some nickel base alloys.

The aqueous environment with lack of oxygen, high salinity, low pH value and warm temperatures are critical factors in promoting bacteria and hence required proper control to avoid MIC. MIC is most often found in heat exchangers, water at the bottom of storage tanks, piping with stagnant or low flow condition. MIC is also found in equipment where the hydrotest water has not been removed or equipment has been left outside and unprotected.

MIC corrosion is usually observed as localized pitting under deposits or tubercles that shield the organisms. Damage is often characterized by cup-shaped pits within pits in carbon steel or subsurface cavities in stainless steel. Systems may become “inoculated” by the introduction of organisms that multiply and spread unless controlled. Different organisms thrive on different nutrients including inorganic substances (e.g., sulfur, ammonia, H_2S) and inorganic substances. In addition, all organisms require a source of carbon, nitrogen and phosphorous for growth. Ingress of process contaminants such as hydrocarbons or H_2S may lead to a
significant increase in biofouling and corrosion.

Product storage tanks and water cooled heat exchangers in any unit where cooling water is not properly treated are particularly susceptible to MIC

MICROBIOLOGICALLY INDUCED CORROSION (MIC) - CARBON STEEL

It is obvious that microorganisms are a large diverse group of microscopic organism such as viruses, bacteria, fungi, algae and diatoms that with exception of viruses exist as single cells or cell clusters. A single microbial cell is typically able to carry out its life process of growth, energy generation and reproduction independently of other cells, either of same kind or a different kind. Microorganisms are fundamentally influenced by the availability of molecular oxygen and the temperature.

The main type of bacteria associated with corrosion failures are sulphate-reducing bacteria (SRB), metal reducing bacteria (MRB) and metal-depositing bacteria (MDB) such as Iron-oxidizing/reducing bacteria, magnesium oxidizing bacteria as well as acid producing bacteria (APB) such as sulfur oxidizing bacteria secreting organic acids. Different types of bacteria often coexist in a community within the biofilm. Products of one electrochemical reaction can initiate a metabolism of another type of bacteria. The complex microbial community enables bacteria species to exist in some chemical environments. The conditioned biofilm allows additional adsorption of microbial cells from the bulk liquid. The microorganisms then produce adhesive substances such as extra cellular polymeric substances (EPS) or slime [2, 3].

SRB (Sulfate Reducing Bacteria) are associated with a group of ubiquitous, diverse anaerobes that reduced oxidized sulfur compounds, such as sulphate, sulphite and thiosulphate as well as sulphur or nitrate to H_2S [2, 4]. SRB are strictly anaerobic with some genera which can tolerate oxygen and are able to grow at lower oxygen presence up to 0.5 mg L^{-1} [1]. This bacteria usually results in formation of pitting on the carbon steel material with low presence of oxygen specifically in storage tanks which have a lower oxygen content, relatively warm temperature, moisture and microbiological influence factors such as low redox potential of around -100 mV or less [4]. The basic mechanisms are associated with cathodic depolarisation by enzymes and anodic depolarisation from corrosive iron sulphides.

MRB (Metal Reducing Bacteria) are microorganisms which promote the corrosion of iron and it alloys through dissolution of corrosion resistant oxide films from the metals surface. MRB

particularly damaging to metals with protective passive layers such as stainless steels, MRB such as Pseudomonas and Shewanella bacteria are able reduce the manganese or iron oxide to metal ions [5]. Once the oxide film is attacked the material is then exposed and vulnerable to metal reduction and further corrosion.

MDB (Metal Depositing Bacteria) such as Gallionella and Leptothrix are the microorganism which oxide metals such as iron and manganese. Fe^{2+} ions either dissolve with bulk medium or are oxidised by MDB to form Fe^{3+} precipitates on the metal surface. Manganous ions can similarly be oxidised to manganic ions with associated manganese dioxide deposits. These depositions will lead to differential concentration corrosion due to the cathodic,magnesium oxides and aerobic bacterial respiration causing oxygen depleted areas which acts as anodes [6].

APB (Acid Producing Bacteria) and Fungi produce inorganic or organic acid as by-products of metabolism. Microbial produced inorganic acids are nitric (HNO_3), sulphurous (H_2SO_3) sulfuric (H_2SO_4), nitrous (HNO_2) and carbonic acid (H_2CO_3). Nitric and sulfuric acid salts are easily dissolved in the water reducing the pH. The protective layer of calcium carbonate will subsequently be easily dissolved in the water which aids the corrosion to be more aggressive during these phenomena [7, 8].

Pitting can be initiated by a small surface defect, being a scratch or a local change in composition, or damage to protective coating. Polished surfaces display higher resistance to pitting. Figures 1 & 2 shows the characteristic pits and halo effect of corrosion found on the bottom plate of a storage tanks that has been affected by microbiological activity during the storage of fluid after only a couple of years in service[15].

Figure 1: <u>Pitting on the Bottom Plate of Storage Tank due to MIC</u>

Pitting corrosion, or pitting, is a form of extremely localised corrosion in which small pits or holes form in the metal. The mechanism for pitting corrosion is the de-passivation of a small area, which becomes anodic while the remaining undamaged area becomes cathodic, leading to very localised galvanic corrosion. The corrosion penetrates the mass of the metal, supposedly due to gravity, with limited diffusion of ions at the base of the pit causing a concentration of ions. The mechanism of pitting corrosion is similar to crevice corrosion [9].

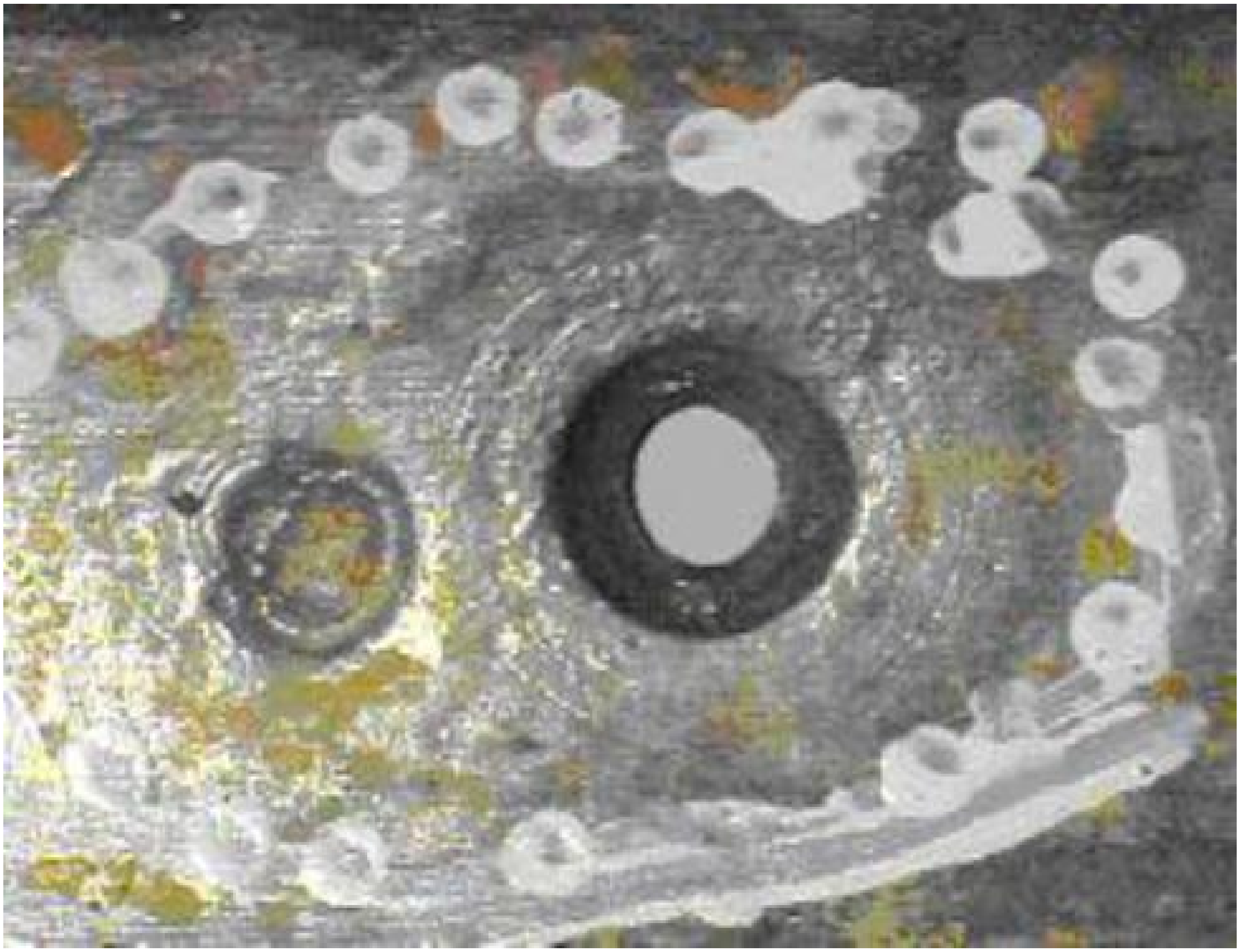

Figure 2: Pitting on the Bottom Plate of Storage Tank due to MIC

The pitting process is considered autocatalytic as the local conditions are altered once a pit starts to grow such that further pit growth is promoted. The dissolution of metal causes the pit to become enriched in metal cations, whilst depleted in cathodic reactants such as Oxygen. Cation hydrolysis results in localised acidity and causes the concentration of anionic species such as chloride within the pit to increase due to electro migration to balance the charge concentration. This aggressive chloride and acidic environment prevents re-passivation and promotes propagation of the pit [10, 11].Pits often grow with a porous cover making visual detection extremely difficult, so that the awareness of the severity of attack is overlooked and the likelihood of catastrophic failure is enhanced [11]. The material loss at the surface is relatively small in proportion to the damage to the deeper structure of the metal.

CASE STUDY ON MICROBIOLOGICAL INDUCED CORROSION OF STORAGE TANK

Pitting corrosion was observed in one of bottom annular plates in tanks sequel to hydrotesting, during the final inspection for one of the tanks prior to commissioning & startup activity, the pitting corrosion was observed on the bottom plate at various locations with different depth and thickness. Considering this fact all other tanks which were ready for final inspection were inspected and found with the similar pitting corrosion spread across the bottom plates. Hence based on this finding the details investigation was carried out to analysis the root cause for subjective pitting corrosion on these bottom plates of tanks.

Based on these initial observations root cause analysis was carried out for the subject tanks in order to confirm the damage mechanism. Confirmation of the source of bacteria to confirm MIC is essential and then providing corrective action and preventive methods for all the tanks & piping for the plant. Detail investigation was carried out to confirm material composition, testing methodology, quality of water, water treatment, surface defects, surface damages, depth of defect, drying methodology, environmental condition, water analysis-MIC, liquid sampling and solid sampling of the affected tanks.

PRIMARY OBSERVATION

Material of Construction for this tank was carbon steel with grade of ASTM A516 Grade 70. Plates were traceable by their heat number for each of this tank subject to investigation, The material for this plates has been rechecked and found satisfactory with respective to the approved drawings, data sheet, fabrication, Material Test Certificate and other applicable testing procedures. Further to this investigation unused plates bearing similar heat numbers were visually examined from the stock yard and found as satisfactory and did not exhibit any appearance from pitting or mechanical damages.

During the investigation, it was observed that the appearance of the pits was surrounded by shiny brownish appearance and spread across the tank with the density of 25-50 pits per square meter. More number of pits is observed at the location where stagnant or low flow condition of water can easily be take place on the bottom plate of this tanks. Refer to Figures 3 & 5 which indicate about the affected tanks with pitting corrosion on bottom plate of the tanks with brownish shiny appearance.

It was also observed that the affected area was found in wet condition, in spite of the fact the hydrotesting and drying activities were done from very long time, This wetness area can also be easily felt by the bare hand movement on the affected portion and easily observed in deep pitted area of the bottom plates. Refer to Figure-2

During visual examination of this affected area, it was observed that the length of pits usually varied from one spot to other and they were interconnected with each other and this pits are encircled with appearance of shiny brownish color around the pits. Apart from this it was observed with mechanical damages presented on the some of the locations on the bottom plate of tanks, which might have occurred during the fabrication stage due to poor workmanship while performing welding as well as by improper application of scaffolding pipes used during fabrication stage. Refer to Figure 5.

The depth of pits was measured by using ultrasonic examination along with mechanical caliper, which resulted in the range between to 2-3 mm approximately, which clearly showed the sign in loss of the assigned corrosion allowance on the bottom plate of this tanks prior to putting the tanks in to service. Similarly mechanical damages were also measured which have depth with loss of metal in range of 1-2 mm approximately. Refer to Figures 6 & 7.

Based on the above observation, the tanks which are in fabrication stage or ready for hydrotesting were examined on the bottom plates for pitting corrosion, however there were no signs of pitting corrosion more ever we noticed few mechanical damages on the bottom plate of tank.

SECONDARY OBSERVATION

The hydrotest water used for testing these tanks was raw untreated well water which was dumped in the open pond,. The ponds are artificially created without any chemical dosing or any biocide treatment. This water has been supplied by the water tanker to the site without any cultural examination for MIC. However the water was examined for other parameters such as chloride, total dissolved salts, hardness, total alkalinity, sulfate and other applicable parameters to designate the quality of water.

The quality of water used for hydrotesting was found with high chloride content of 277.7 mg/L, as per the lab report, exceeding the API 650 recommended limit of 50 ppm [12]. However, this constraint is specified for the protection of stainless steel components susceptible to chloride stress corrosion cracking.

The tested water has been stored for several days in the tanks without any biocide treatment and has been recirculated for testing as well rinsing for other tanks installed in the refinery, Figure 4 will provide the complete detail of hydrotesting sequence which was been carried out in the refinery for the affected tanks, All of the tanks were affected by pitting corrosion in similar fashion on the bottom plate of the tank. The water source used for testing was untreated well water which had been stagnant in the tanks for a period of more than 100 days during and after testing. The tanks were open to the atmosphere after the completion of test with stagnant water present on the bottom plates.

As mentioned above the water for hydrotesting was stagnant without any treatment such as biocide or oxygen scavenger for a period of over 100 days. This period of time is not permitted in accordance with API 650 [12] which specified a maximum exposure time of 7 days for hydrotesting due to the possible corrosive effects. This testing period is extended to 21 days if potable water is employed for Hydrotesting as recommended [12], however as per the lab reports the tested water used for this tanks were never been classified as potable quality of water.

Secondly it is to be noted they are no filters used during the filling and transferring of the water from one tank to another. Therefore sedimentation, particle and bacteria are carried from liquid sulfur tank 3 to all other tanks downstream as shown in Figure-9.

Rinsing water used after the completion of hydro testing was done using the same water as had been used for testing. Particularly as the drying was not sufficiently carried out this provides a favorable reason for the source of the bacteria growth as this water had settled on the bottom of tanks. Post hydrotesting rinsing should usually be carried out using fresh potable water (API 650) with the intention to remove all debris and particles which were accumulated during the hydro testing.

The drying procedure had been employed, however the pits were observed in wet and moist conditions suggesting the lack of integrity in the drying procedure. After further observation of the tanks it was revealed that the growth of pits around the bottom of plate tanks was aggressive and affecting to the entire bottom plates of the tanks. Further to this the water was not treated with biocide and oxygen scavengers were not added to the water. These would have suppressed bacteria growth and MIC.

Preservation and Lay-up procedure was not indicated in any of client specification, testing procedure or method statements. Improper drying and leaving stagnant water provide a environment for microbiologically activity to form on the bottom plate of tanks.

Based on the facts indicated in primary & secondary observation, All the supply of source water used for hydro testing were examined by HACH Rapid Test Kits for sulphate reducers, iron reducers and slime forming bacteria. All the water tested samples were found positive and demonstrated that the presence of bacteria in the water.

CONSCLUSION ON CASE STUDY

Primary & secondary observations during the course of investigation clearly indicate that the pitting corrosion on bottom plate of tanks sequel to hydrotesting was due to MIC,The following facts are considered in formation & initiation of pitting corrosion.

The hydrotest water tested by HACH rapid kit test was found positive, this water has been used for testing for longer period of time without any biocide or chemical treatment. As per the observation this water has recirculated without use of any filter which will carry or transport the bacteria from one tank to other, however there is also no presence of oxygen scavengers used during the testing or after the testing as well, which can easily result in ingress of oxygen into the tanks as they are open to the atmosphere. Hence based on these facts there is definite growth of bacteria and other microbial activities have taken place inside this affected tanks.

One of the most important facts in growth of this bacteria is contributed by the material of construction for this tanks, which is carbon steel grade with ASTM A516 Grade 70, which consists of elements such as carbon, sulfur, nitrogen, phosphorous, which had played key role as energy sources for bacteria contributing to the formation of MIC in the tanks bottom plate. Providing nutrients and reactants for bacteria metabolism is particularly detrimental where the water was stagnant for long periods of time without any treatment.

Based on the observation the drying methodology was also not effective, which contributed to several water pockets on the bottom plate of this tanks even after the drying operation, which had help in the bacteria growth very rapidly and spread across all the places on the bottom plate of tanks. There are few mechanical damages which also provided enough space and entrapment of these bacteria for further growth on this bottom plates.

In combination material of construction as carbon steel with presence of carbon, sulfur, phosphorous & other alloying element, source of hydrotest water, mechanical damage, water pockets, long hydrotest cycles without any biocide treatment and oxygen scavengers, recirculation of water without any filtering, oxygen ingress tanks open to atmosphere, environmental condition, moisture, water, reaction, donator, acceptor and other various factors as discussed in this paper have all contributed to the formation MIC on the bottom plate of tanks

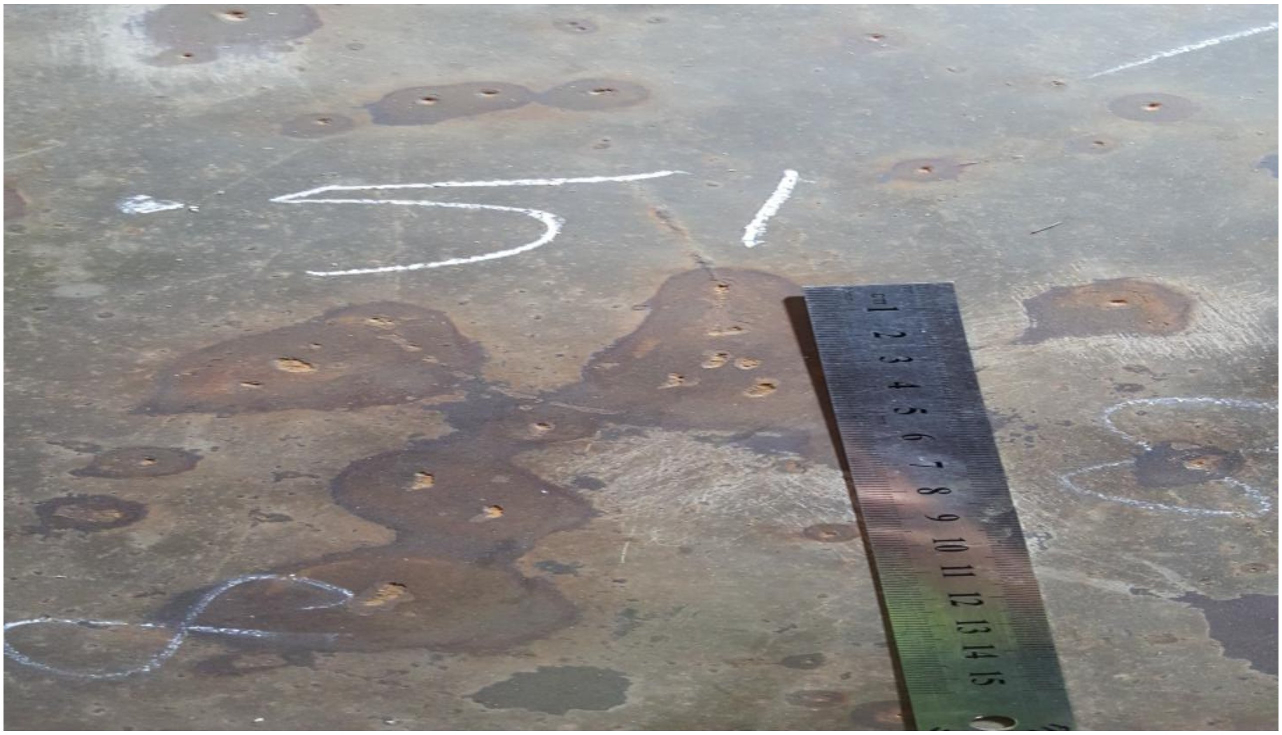

Figure 3: **Affected Area on the Bottom Plate of Tanks (Brownish)**

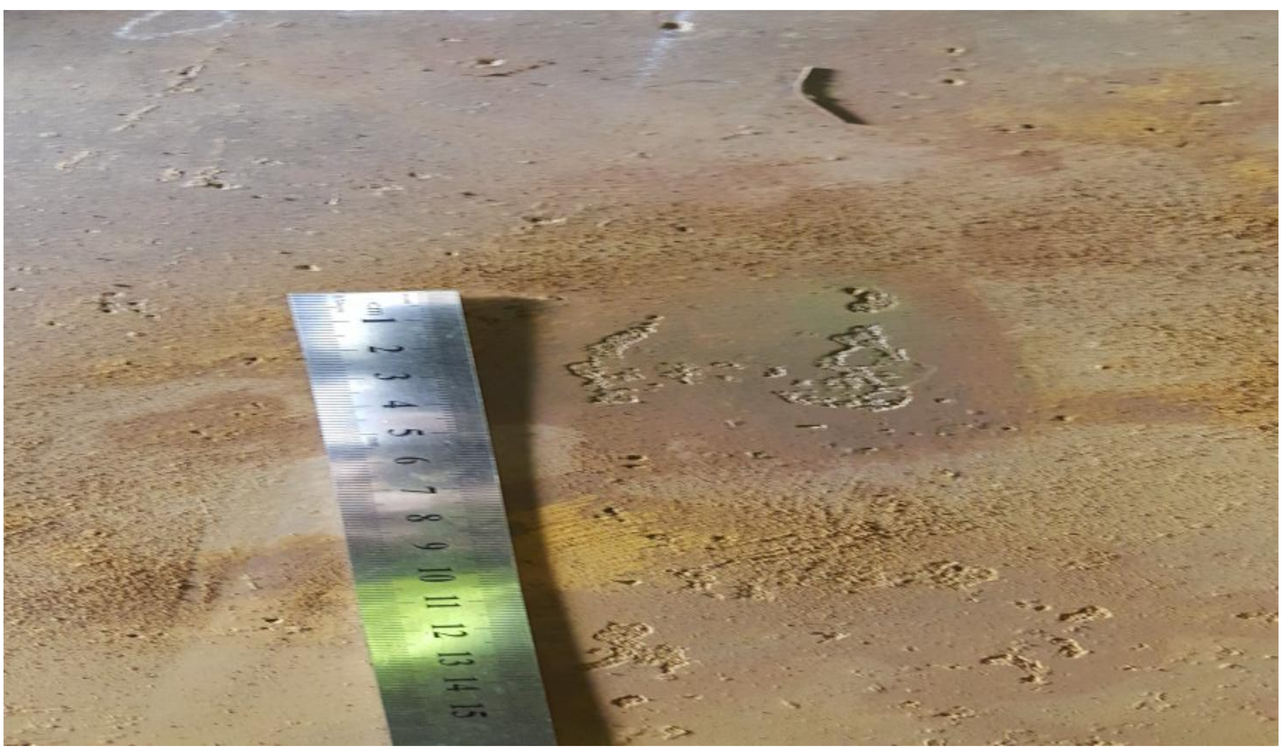

Figure 4: **Affected Area on the Bottom Plate of Tanks (Wet Area After Drying Process)**

Figure 5: **Affected Area on the Bottom Plate of Tanks (Pit Density)**

Figure 6: **Deep Pits along with Mechanical Damages**

Figure 7: **<u>Mechanical Damages</u>**

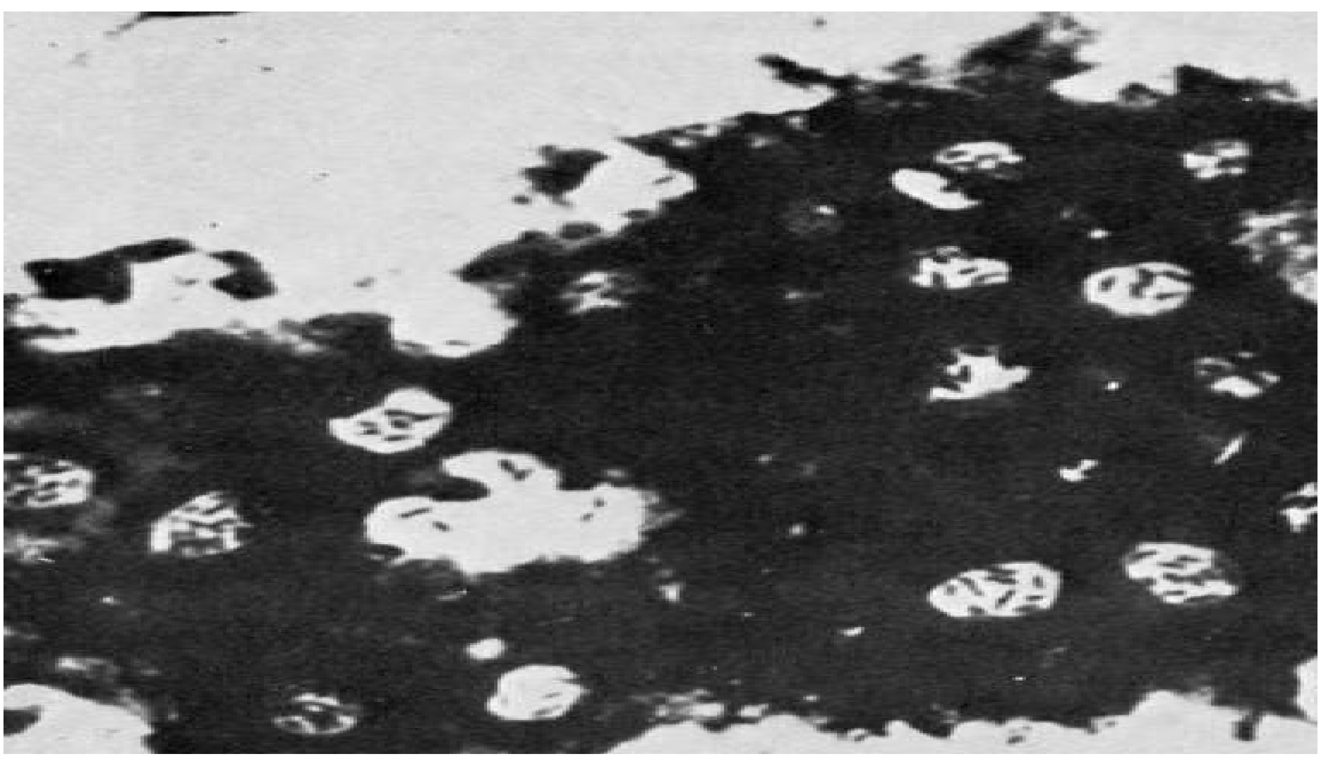

Figure 8: **Magnification of Bacteria Colonies**

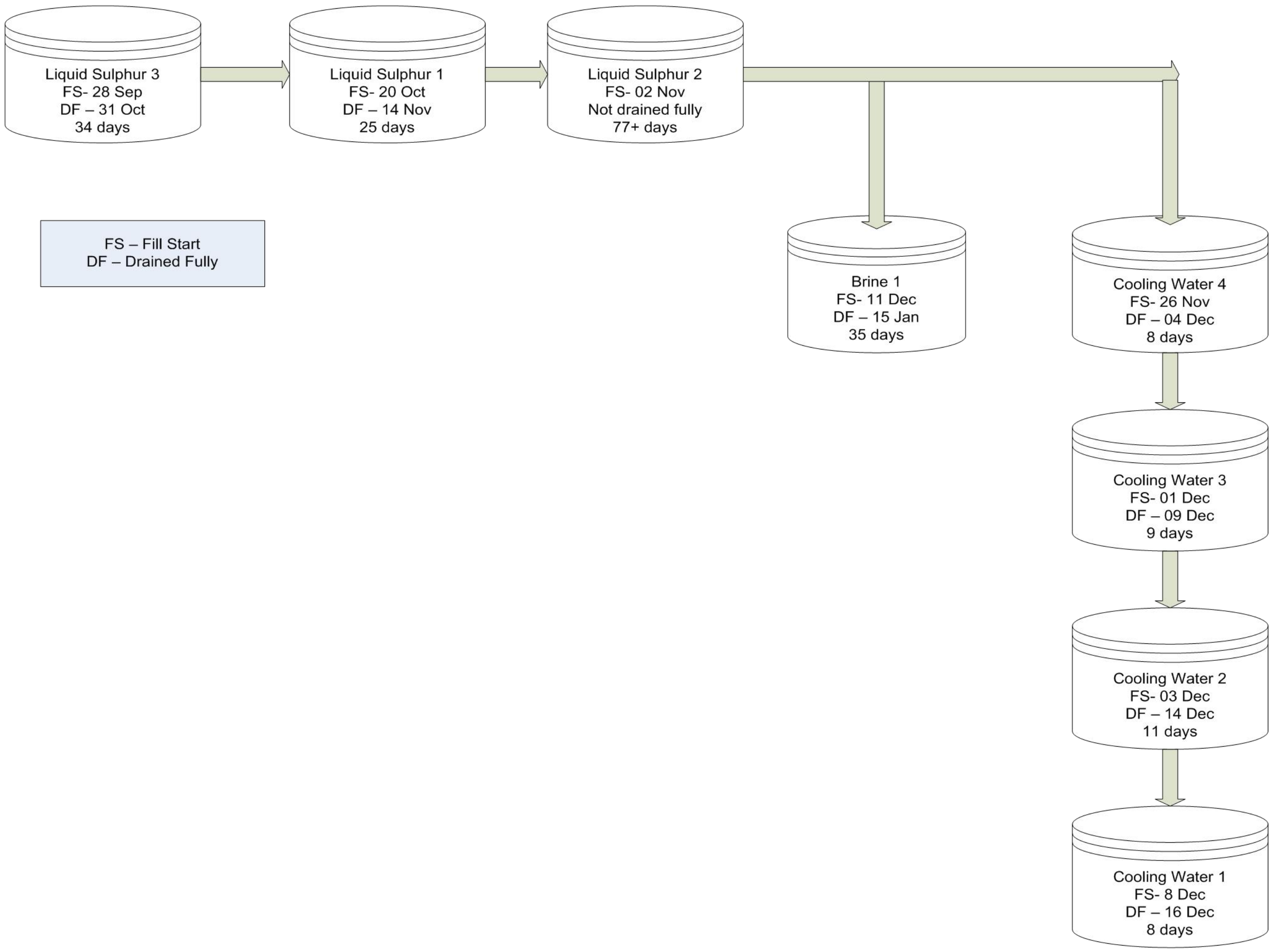

Figure 9: **Hydro Test Sequence Flow chart**

CORRECTIVE ACTION – AFFECTED AREA OF MIC

The following are the corrective action taken in order to mitigate the corrosion issue of the subject tanks.

The affected area of the tanks is to be mechanically white blasted to SA 2.5, to enhance the visibility of the pits on the bottom plates of the tanks.

Visual Inspection was carried out on all portions of the bottom plates, Most sever areas were then identified. Further NDE-UT examination was performed to measure the depth of defects and assess the loss in thickness.

Design life is re-evaluated for worst affected areas from the remaining thickness, the originally assigned corrosion allowance and estimated the rate of corrosion

Pit-sealer was applied across the bottom plate of tanks, which will ensure all the open pits are filled and complete for further coating/painting activities. This will also help in avoiding any further microbial activities and corrosion issue on the bottom plate of the tanks during the service.

However deeper defects were repaired by welding and ground flush and smooth to reduce potential further pitting/crevice corrosion.

Repaired welded area was inspected by Vacuum box test to followed NDE-UT and NDE-MT examination.

Re-Surface preparation was carried on the weld repaired areas prior to re-coating.

Phenolic Epoxy coating was applied across the bottom plate of tanks and up to first course shell of tank with a minimum of 3 coats.

Detailed liquid lining (Coating) procedure was established along with specific instruction in line with NACE SP 0178, NACE RP 0288 & other EN/ISO standard with stringent requirements.

RECOMMENDATION/PREVENTIVE ACTION

Visual examination shall be carried out prior to testing including examination of welding in addition to base metal. All the surface defects shall be repaired prior to testing.

Hydrotesting schedule shall be in accordance with API 650. Water shall not be held in tanks longer that the recommended duration and preventive measure shall be taken in order to avoid future similar corrosion issues.

Water used for testing shall be of the recommended quality in accordance with API 650 and to prevent any contamination from bacteria, however the water shall be thoroughly tested for chloride and microbiological culture from third party inspection laboratory prior to use of source water for testing and cleaning purpose.

Fresh water shall always be used for rinsing and cleaning operation rather than using same water after completion of hydro testing.

Whenever there is transfer of water from one tank to other tank it shall be done by using proper filters to avoid carrying foreign materials from the source tanks. This filter used for filling shall be 50 micron before used in hydro static testing of the tank or equipment.

This transfer water shall be tested prior to filling and the results shall be evaluated based on the water quality requirements.

Drying methods such as blowing and de-watering shall be carry out immediately after completion of hydro testing to prevent the presence of water pockets. This will be achieved by paying particular attention to low spots and crevices. Inspection to assure dryness shall be carried out immediately after drying is complete.

It is recommended for water storage tanks to be lined internally by epoxy phenolic along with cathodic protection system to avoid in service corrosion issues. This should provide a longer operation life based on reliability and maintenance study.

Develop and implement a MIC-prevention water treatment program with proper attention, control and monitoring of bacteria levels. This requires sustained commitment by management and operations. Sampling at the tank outlet provides early indication of bacteria presence. This should be implemented in conjunction with biocide dosing upstream of the tanks.

The Laying Methodology shall be implemented after completion of testing ensuring full drying and also during maintenance periods.

The hydrotest procedure, including the water quality and chemical treatment shall be fully reviewed in accordance with API 650 prior to performing future hydro testing

SUMMARY & CONLUSION

In combination Material of Construction as Carbon Steel with presence of carbon, sulfur, phosphorous & other alloying element, Source of Hydro Test water, Mechanical damage, Water Pockets, Long hydro test cycles without any biocide treatment and Oxygen Scavengers, Recirculation of water without any filtering, oxygen ingress tanks open to atmosphere, environmental condition, moisture, water, reaction, donator, acceptor and other various factors as discussed in this paper have all contributed to the formation MIC on the bottom plate of tanks

Pitting occurred due to the improper hydro testing & drying methods which had contributed to Micro biological induced corrosion pitting on the bottom plates of tanks. It is concluded from facts, findings, inspection and observation in line with international code, standards, specification and practices, the MIC was key factor for this pitting corrosion of tank bottom plates.

There are numerous costs associated with corrosion failures from mitigation to reinstallation that can result in heavy financial loss to the operator. The operating and maintenance cost can be saved by proper implementation of the preventive methods, inspection philosophy and corrosion mitigation strategies during the initial design, detail engineering, fabrication, installation, commissioning and operation of plant. Integrity in applying approved procedures us imperative to ensuring the plants safe operation and reliability. MIC damage mechanism should be considered with utmost care, and an inspection plan should be implemented in order to monitor bacteria levels and prevent further corrosion of the storage tank bottom plates

Works Cited

R. T. Huang, B. L. McFarland and R. Z. Hodgmand, "Microbial Influenced Corrosion in Cargo Oil Tanks of Crude Oil Tankers," in No. CONF-970332--. NACE International, Houston, TX (United States), 1997.

I. Beech, A. Bergel, A. Mollica, H.-C. Flemming, V. Scotto and W. Sand, "Simple methods for the investigation of the role of biofilms in corrosion," Brite Euram Thematic Network on MIC of Industrial Materials, Task Group1, Biofilm Fundamentals, Brite Euram Thematic Network No. ERB BRRT-CT98-5084, 2000. [Online]. Available: http://efcweb.org/efcweb_media/MICbook.pdf. [Accessed 5th January 2017].

W. Gale and T. Totemeier, Eds., Smithells Metals Reference Book, 8th ed., Elsevier, 2004.

D. Féron, B. Kursten and F. Druyts, Sulphur-Assisted Corrosion in Nuclear Disposal Systems: (EFC 59), Maney Publishing, 2011.

M. Davies and P. .. O. v. a. a. Scott, Oilfield Water Technology, NACE International, 2006.

K. A. Zarasvand and V. R. Rai, "Microorganisms: Induction and inhibition of corrosion in metals," International Biodeterioration & Biodegradation, vol. 87, no. ISSN 0964-8305,, pp. 66-74, February 2014.

E. Stansbury and R. Buchanan, Fundamentals of Electrochemical Corrosion. . Online version available at:, ASM International, 2000.

I. B. Beech and C. C. Gaylarde, "Recent advances in the study of biocorrosion - an overview," Rev. Microbiol [online], vol. 30, no. 3, pp. 117-190, 1999.

W. D. (. Callister, Materials science and engineering: an introduction, New York: John Wiley & Sons, 2007.

V. Burt, Corrosion in the Petrochemical Industry, 2nd ed., ASM International, 2015.

S. D. Cramer and B. S. (. Covino, ASM Handbook, Volume 13A - Corrosion: Fundamentals, Testing, and Protection., ASM International, 2003.

Standard, A. P. I 650, Welded Tanks for Oil Storage, Washington: American Petroleum Institute, 2014.

J. S. a. K. M. Z. Mohammed, "Failure Of Above Ground Storage Tanks, A Study," in CORROSION 2007. NACE International, 2007.

Standard, A. P. I 571, Damage Mechanism Affecting Fixed Equipment in the Refining Industry, Washington: American Petroleum Institute, 2011.

Standard, A. P. I 582, Welded guidelines for the chemical,oil & gas industries , Washington: American Petroleum Institute, 2009.

Standard, NACE SP 178, Design,Fabrication and Surface finish Practices for tanks & vessels to be lined for immersion service, Houston, National Association of Corrosion Engineer, 2007