A review of the Microbiological Influenced on Corrosion rates in Oil seawater systems and three-phase transport pipelines

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Abstract:

The development of corrosion management system (CMS) to mange and measure the mitigation of corrosion is now standard oilfield good practice, Nevertheless it is not unusual to find that the probability of MIC is not adequately addressed , despite the face that Microbiologically Influenced Corrosion (MIC) is identified as a corrosion risk. The result is that the mitigation of MIC is not measured or assured by the monitoring applied. Comparison of CMS documents illustrates that often there is no attempt to apply predictive models to assess the probability of MIC .The lace of a predication therefore makes measurement of mitigation impossible and this is often reflected by the face that MIC monitoring programmers

Actually measure biocide performance rather than MIC mitigation.

This paper is a review of the chemical treatment of microorganisms and their impact on corrosion rates in the oil industries, methods of controlling them, and how to resist them using chemicals or a change in the design of transport pipes and tanks to prevent their growth and describes how the application of even basic qualitative MIC predictions can greatly improve the management of MIC mitigation and raise the profile of of MIC management within the CMS. Furthermore, the paper provides guidance as to the key monitoring parameter which are required to provide a meaningful statistical measure of MIC mitigation in pipelines transporting a range of oilfield fluids.

Keywords: (Bacteria , corrosion , Microbiologically , pipelines , seawater)

1.Introduction

Reports of corrosion failures implication bacterial activity – in particular the activity of Sulphate-reducing Bacteria (SRB) – continue to be published ensuring widespread appreciation that Microbiologically Influenced Corrosion (MIC) is a significant risk in oilfield operations [1,2,3]. Once any corrosion risk has been identified, controls ,should be applied to mitigate the corrosion mechanism and monitoring performed to confirm and measure the extent of the mitigation; I,e. the corrosion risk should be managed.

Despite being identified in many CMS documents , failures due to MIC continue to be reported, indicating that the MIC risk is not being effectively mitigated, Although reports vary widely , it not unusual to have the incidence of MIC being claimed to result in between 25 – 50 % of all internal corrosion events [4] as shown in figures 1` 2 3 ..

This paper presents an overview of the management of MIC in deferent pipeline systems and discusses how a full understanding of the impact of the pipeline environment on microbiological activity is required to firstly aid in the prediction MIC and subsequently design a mitigation strategy , implement controls and measure performance.

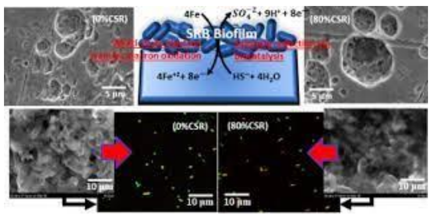

Fig.1 Accelerated corrosion of pipeline steel in the presence of Desulfovibrio desulfuricans biofilm due to carbon source deprivation in CO2 saturated medium -

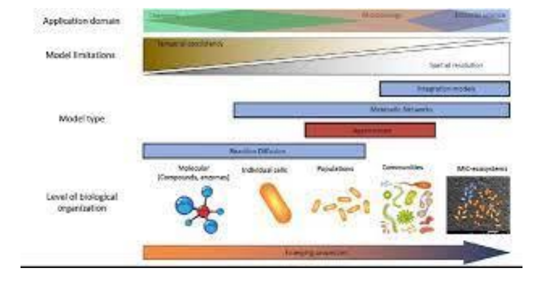

Fig.2 Microbially influenced corrosion— Any progress? – sciencedirect.com

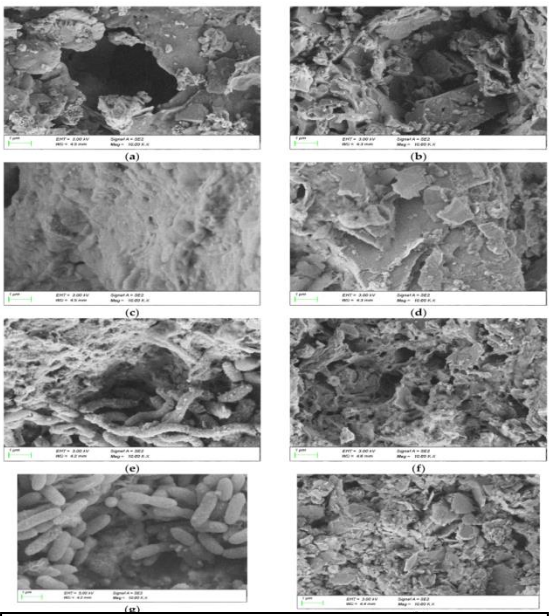

Fig.3 https://www.google.com/url?sa=i&url=https%3A%2F% Fsfamjournals.onlinelibrary.wiley.com

Current Common Practice

Controls to mitigate internal MIC in oilfield pipelines are currently all almost exclusively related to minimizing the numbers and/or activity of Sulphate-Reducing Bacteria (SRB) and to a lesser extent, organic Acid Producing Bacteria (APB). It is proposed that the corrosion mechanism for SRB is related to sulphide production and for APB the acid pH

resulting from carbon dioxide and organic acid production . The assumption is therefore that by maintaining low population numbers for these bacterial communities the production of hydrogen sulphide and organic acid will be minimized and MIC mitigated. A direct means of maintaining low numbers of bacteria is to kill any organisms present in the system by the application of biocides and therefore where controls are applied the injection of organic biocides is the predominant strategy. Determination of the effectiveness of the biocide treatment is most commonly attempted by enumerating the numbers of bacteria in samples of fluids collected from pipeline. Unfortunately this approach is over simplistic.

The effective mitigation of MIC is dependant on a wide number of biotic and abiotic factors many of wich are specific to pipeline operations pipeline design and the nature of fluids and gases transported within the pipeline . Whilst the generic terms SRB and APB are common to all systems it is important to be aware that the SRB and APB present in a cold seawater pipeline will be very different from those present in a main oil pipeline or a hot 3-phase pipeline . Their response to system changes biocide treatments in terms of biocide formulation and injection criteria applied to pipeline transporting very different fluids. This approach is fundamentally flawed and this can be demonstrated by a simple consideration of even only a few of the key parameters controlling SRB or APB activity in different pipeline fluids pH temperature and water chemistry.

Current Prediction and Monitoring of MIC

Whilst the exact mechanisms which affect MIC associated with pipeline are still not clearly understood there is little argument that the rate and form of MIC is not related to the numbers of planktonic bacteria enumerated in synthetic bacterial growth media. However such analyses are by far the most commonly used tools employed to attempt to predict and monitor MIC. At best the enumeration of planktonic bacteria and the collection of fluid samples provides a qualitive measure only of biocide performance and in most cases provides no useful corrosion mitigation data whatsoever.

Of far greater importance are the following ;

- Bacterial activity in biofilms on the pipe walls.

▪ water content and water availability.

▪ water chemistry .

▪ flow velocity.

▪Deposition of solids and scale.

▪ Concentration of dissolved gases (CO_2& O_2).

▪ Temperature, and pH

For this reason , the MIC model presented by Post[5] places emphasis on deposit formation and removal oxygen ingress , flow , velocity , and physicochemical conditions. This was modified by Maxwell [6] to include modules for biofilm development activity and its control.

2. CORROSIVE BIOFILMS

Corrosion is a surface phenomenon and as such the bacteria involved in MIC must also be associated with the surface, in complex community structures collectively known as biofilms [7]. In order to control MIC it is essential therefore , to prevent biofilm development or at least minimize the activity of corrosion related processes within the biofilm to low levels.

When a metal surface is exposed in an aqueous environment a conditioning film will develop almost instantaneously , followed quickly by bacteria cell. If suitable conditions allow , the cells will multiply and the biofilm will grow. Ultimately a multilayered complex mixed bacteria community is produced [8]. A wide number of physical , chemical and biological parameters will all impact on biofilm development ▪ including;

▪ Nature of substratum (mid steel , CRA, etc).

▪ Surface roughness and orientation.

▪ Flow velocity.

▪ Toxicity and stability of substratum .

heterognet

▪ Temperature ,pH , Eh.

▪ Solids.

It can be seen therefore, that biofilm development in oilfield process systems is likely to be heterogeneous due to the differing physicochemical conditions , mechanical design , etc, resulting in a variety of different environmental niches in different system and even in different parts of the same system . Furthermore even where there is consistency in system design and water chemistry , there can still be significant variability in biofilm heterogeneity , both on the macro and micro scale. On an apparently uniform surface , the density of bacterial cells and their activity within the biofilm can vary greatly within very small distance [9].

It is beyond the remit of this short paper to discuss in detail the complexity and heterogeneity of mature biofilms in oilfield systems. It is appropriate to highlight , however that it is this historic lack of understanding of biofilm growth and activity that contributes greatly to the continued poor monitoring ineffective control and an inability to optimize MIC mitigation in the field

3. CLEANING AND SANTITISING (DISINFECTION) STRATEGY (REMOVE, KILL OR INACTIVATE)

Microbiological control in other industries ; e,g. pharmaceutical drinking water, etc, often operates on a dual treatment philosophy; clean and sanities . The treatments differentiate between cleaning (the removal of inorganic and organic debris , including bacterial cells) and sanitizing (the killing of bacteria cells). While the problems of bacterial growth in these other industries may be more related to human health and hygiene issues rather than MIC there remain the common feature that controls are applied to minimize bacterial activity in contaminating biofilms .

In oil field systems there is generally but not exclusively no separate cleaning treatment.

Where cleaning is applied this may be chemically with surfactants and/or scale dissolvers or physically with scrapers and cleaning pigs. In pipelines where the build up of surface attached deposits can result in restrictions in flow, several chemical and physical cleaning processes are commonly practical. Historically however these treatments were performed independently of bacterial control and were , therefore , not evaluated in terms of any antifouling effect or MIC mitigation .However , there is increasing anecdotal evidence that such cleaning procedures can provide significant benefit in MIC mitigation despite the fact that bacterial killing is not taking place.

The strategy for oilfield biocide application has historically been based on killing as many and as broad a spectrum of bacteria as possible whilst accepting that in an open ended flowing system sterilization is impossible . It was generally not highlighted that a disinfection philosophy would require the control of only those bacteria involved in MIC ; e,g, the SRB and/or APB .over the last year, however , this has been addressed as evidenced by the more recent move towards the application of alternatives to biocides; such asnitrite. Nitrite and anthraquinone [10,11,12]. These treatments are applied to achieve a total bacterial kill, but all are targeted at minimizing or preventing SRB activity.

A review of the strategy for bacterial control in the oil industry compared to to the strategies applied in other industrial demonstrates the apparent lack of consideration within oilfield systems for the requirement to physically or chemically clean the surfaces . In other industries there is an appreciation of the requirement to clean; i,e. remove deposits , apply detergents , mechanically abrade, etc. as key prerequisite or synergistic component of an effective antibacterial treatment. This paper includes cleaning when discussing the key parameters which must be evaluated and where possible controlled in order to effectively mange and mitigate MIC in pipelines transporting different oilfield fluids. Such an approach results in redefining the key performance Indicators (KPI,s) associated with MIC mitigation as an important first step in the effective management of corrosive biofilms.

4. MIC IN OIL PIPELINES

Due to the potential economic and environmental impact of a corrosion failure in an oil export pipeline. One might expect that MIC mitigation of such lines would receive significant attention both in terms of prediction and preventative treatment. However this is not always the case. Historically , poor risk assessments concluded that the probability of MIC was minimal and as a consequence there are many oil export pipelines which continue to receive little or no specific bacterial controls.

MIC prediction

Within a crude oil transportation pipeline a key parameter in determining the probability of MIC is water .Without water in the pipeline there will be no bacterial growth or activity. It is not possible to guarantee crude which is completely water free . However the idea that crude oil pipelines with less than 0.5 water will be at only minimal risk of MIC is erroneous.

Even at very low percentage of residual water in the export crude there is often the opportunity for water to settle out in low spots and low flow conditions. Over time therefore given the correct flow conditions the pipeline acts as a separator and ultimately significant volumes of water can become entrained within the line if adequate water removal pigs are not run. Control of contaminating water therefore , should be considered as key within the MIC mitigation strategy for oil lines. This allows the inclusion of parameters such as pigging, flow velocity and crude drying as components within MIC mitigation management.

Nevertheless whilst the role of free water in MIC and other corrosion mechanisms is not disputed a predictive model for MIC cannot rely on water control alone. If the metal surface remains oil wet due to wax deposition smearing of hydrocarbon deposits by the pig, etc. then this could have a very significant effect on the probability of MIC in crude oil pipelines. Thus the application of any qualitative modelling prediction would is not seen to provide any benefit. Rather than have no models however any attempt to apply even a semi-quantitative prediction tool should be supported.

Fluid Chemistry

Subsequent to water control the chemistry of the contaminating water should be considered Sulphate is required if an SRB corrosion risk is to develop. Low buffering capacity of the water is an important factor if APB corrosion mechanisms are considered. However neither of these parameters can be considered simplistically in terms of high and low concentrations of any particular molecule. For example the rate of sulphate reduction is unlikely to be affected by sulphate concentration until the concentration is below 10-20 mg/l. Above this concentration the rate of sulphate reduction and the concentration of sulphate generated are almost completely independent of sulphate concentration. Despite this fact semi-quantitative predictions for SRB mediate MIC appear to relate an increasing probability of MIC with increased sulphates concentration.

Biocide Treatment

The application of effective biocide treatments to oil pipelines is often poorly planned.

The biocide treatment can only effectively mitigate MIC if;

1- It reaches the targeted settled water and

achieves a concentration bactericidal to the problematic organism in that water

2-bacterial activity in the water would has resulted in MIC . In most case biocide addition is based on the concentration of biocide in the fluids and does not consider the partitioning characteristics of biocide into the oil phase, It is important to determine therefore where the water is within the pipeline and the most appropriate chemistry to allow the biocide to be transported to that point. Currently in many cases the biocide selection is based solely on its ability to kill bacteria with no reference to partitioning and stability characteristics .

Batch biocide treatments are most commonly applied with a dose (concentration and exposure time) of biocide determined in a laboratory test and applied with a frequency to suit a calendar regulated regime ,I,e weekly , monthly quarterly . In order to apply an effective biocide treatment however a completely different strategy is required. The biocide dose needs to be determined base upon the ability of the biocide to effectively control a bacterial biofilm generated in the field. Secondly the frequency of the treatments needs to be determined considering the rate of water accumulation in the pipeline the persistency of the chemical at the points where the water is settling and the reinfection and regrowth rates of the surviving bacteria between biocide batches.

Biological Condition of Source Water

In some cases a KPI on the numbers of plancktonic SRB has been employed to accept or reject the fluids entering the pipeline system the strategy being that if the numbers of plancktonic SRP entering the system are maintained at low levels then this will retard the SRB activity in the system and thus mitigate MIC . A typically quoted KPI for such strategies is <100 SRB per ml. Consider however a system pumping 10,000 Bbls fluid per day with a water content of 0.5 % . The numbers of planktonic SRB entering the system would be approximately 8.0x10 6 SRB cells per day. This in itself represents a very modest number of cells and when compared to the fact that an active biofilm can easily contain 10 6 SRB cells per cm2 , it is demonstrable that the numbers[1] of SRB introduced into the system whether higher or lower than the KPI – are irrelevant with regard to MIC mitigation once the system is contaminated.

5. MIC IN SEAWATER PIPELINES

Within a seawater pipeline the strategy formic management is very different to that described above for oil pipelines. Whilst water is still essential for corrosion its presence in the line is unavoidable and therefore water control would not be part of the strategy.

Furthermore there are a number of other factors which simplify the consideration of MIC in seawater injection system allowing perhaps the best opportunity to demonstrate the successful application of an MIC management strategy. These are;

1-Single aqueous phase only.

2-Commonality of water chemistry at numerous locations.

3-Commonality in system design.

4-Limited number of corrosion mechanisms.

A major drawback however is the lack of any correlation between SRB growth and activity and pitting corrosion rates. It is well documented in some systems that even in the presence of high numbers of SRB and the significant development of sulphidic biofilms that MIC pitting may not be encountered. Such observations highlight the role of deposits [13] and residual dissolved oxygen in stimulating MIC attack[14].

MIC Prediction

The Posts and Maxwell models can be applied directly to seawater systems the corrosion rate constant applied by Posts being based on seawater injection system case histories.

Given that the system is properly designed and operating within specification it could be argued that MIC is the predominate corrosion risk in a seawater injection which if nothing else , should highlight the requirement to optimize MIC management in these systems.

Seawater Chemistry

Whilst the inorganic chemistry of seawater may vary slightly in different parts of the world it is unlikely – except in extreme cases – that this would significantly affect the probability of MIC from location to location . Even gross changes to seawater chemistry may have little effect . This is exemplified by the application of sulphate removal as a means of scale control . In this process the sulphate concentration of seawater may be decrease from 2,700 mg/l to as low 25-100 mg/l. Whilst in a stagnant system this would limit the concentration of sulphide generated in a flowing system sulphide reduction activity would continue as sulphate was continuously supplied sulphide accumulation as iron sulphide at the metal surface would not be expected to significantly impacted even by this significant decrease in sulphate concentration.

Biocide Treatment

The application of boicide should in theory provide an effective means of bacterial control given that seawater presents an environment with supposed limited nutritional value . However the oil industry record for mitigating MIC in seawater injection system is poor with many case histories of significant MIC pitting due to the activity of SRB being repeatedly reported over the past 40 years.

This lack of success can be related to many issues but it is certainly the case that the very large scale of seawater injection operation dictates that whilst concentration of nutrient are low the mass of nutrient throughput is very large . Furthermore the application biocides with treatment based on laboratory planktonic kill data and inappropriate batch frequencies have resulted in boicide treatment strategies which are not capable of achieving the required goal.

MIC Mitigation

Published reports and case histories of effective MIC mitigation are rare . There are several reports of bacterial numbers being significantly decreased by the application of more rigorous biocide treatments but this is almost never correlated and calibrated with improved corrosion inhibition . Where MIC mitigation has been reported the systems have complied with one or more of the following;

- Relatively small (≤70,000 BPD) system [15].
- Continuous biocide [16].
- Continuous nitrate.[17]

▪ Cleaning pigs employed [18].

The success in smaller water injection systems may simply be down to simplified logistic which allowed almost 100% availability of planned biocide treatment and an assurance that biocide soaks were performed during every planned shut-down.

In the large systems however biofilm and MIC control only by batch biocide treatments has proven extremely difficult . There are a number of case histories where once biofilm control had been lost it was proven impossible to cost effectively regain control . However as stated previously there is no evidence that MIC rates correlate with SRB or APB numbers and therefore whilst biofilm control might have been lost there was no evidence at what stage MIC was stimulated if at all.

One of the strategies which has been reported as successful is to re-inject a low residual chlorine downstream of the deaerator as an effective means of preventing biofilm development . The may not be application in all systems due to the additional general corrosion which can be encountered due to the presence of residual chlorine in a mild steel pipeline.

In the Norwegian sector of the North Sea several fields have replaced traditional batch biocide treatment with continues nitrate treatment. The addition of nitrate is well documented as a means of remediating sulphide systems and preventing further sulphate reduction activity. Statoil have reported a complete shift in bacterial activity in their water injection systems fro sulphate – reduction to nitrate reduction coupled with the removal of iron sulphide scales and an approximately three-fold decrease in corrosion rates following the introduction of continuous nitrate injection in the Norwegian North Sea fields [20].

Of very significant interest is the anecdotal of the significant impact of pigging in mitigating MIC . It has been reported that MIC mitigation was achieved by what was shown to be a sub-optimal biocide strategy in terms of minimizing sessile SRB numbers, when combined with cleaning pigs , even if these were run only infrequently [18]. The models for MIC in water pipelines place far more significance on the regularity of pigging than on the biocide treatment when predicting MIC mitigation.

One further very important parameter in the mitigation of MIC in seawater lines is oxygen control. It has been that the addition of even small concentration of dissolved oxygen into a system containing sulphide films can result in significantly aggravated pitting [14] . It is proposed that this is due to the oxidation of parts of the iron sulphide film to elemental sulphur. Once again the models gives far more weighting to the presence of even small concentration of oxygen to stimulate MIC than they give to mitigating MIC with biocide treatment

Biological Conditions of Source water

In a seawater system the source water (open seawater) will provide approximately only one viable SRB cell per liter to the bulk phase . However in many seawater injection systems the deaeration tower acts as a large biological reactor and it is not uncommon to find SRB numbers of 10 per ml in the injection water exiting the tower . In a typical system injecting 10,000 BPD, this is equivalent to adding $1.6x10^{11}$ SRB to the bulk phase each day or $1.1x10^{8}$ SRB per minute. Presenting the situation in this manner clearly demonstrates that a typical KPI of ≤10 SRB per ml for a water injection system does not assure minimal SRB activity as it actually allows for a contribution to the biofilm of 100 million SRB per minute.

6. MIC IN 3-PHASE PIPELINES

If the mitigation of MIC in oil pipelines with low water and seawater pipelines with 100% water proves difficult than the management of MIC in

3-phase- pipelines presents perhaps our greatest challenge.

MIC Prediction

Whilst the 3-phase system is more complicated than both the seawater and oil pipeline systems the application of the models previously mentioned does allow some screening of predicted corrosion rates due to the extremes of temperature , pH, flow velocity and total dissolved salts which can be encountered . Furthermore controls may be predominantly applied for other corrosive conditions such as CO2 and H2S due to their potential severity. The application of corrosion inhibitors and/or sulphide scavengers may have a secondary controlling effect on MIC.

Thus despite the completely it is probable that the potential for MIC in 3-phase pipelines may have be indirectly considered in more detail than for the other two pipeline systems previously discussed whilst the overall corrosion risk assessment is being performed.

Fluid Chemistry

The physicochemical environment in the water phase associated with 3-pipelines can vary significantly from field to field and even from well to well . In the worst case therefore each flow line will have to have a strategy developed specifically for that environment and this strategy will need to change as transported fluids change in water chemistry and solids content.

Once again water control is not generally an option and there will be parts of the line which will be almost continuously water wet. Furthermore the inorganic chemistry of produced water can vary significantly affecting the biology within the system and therefore varying the probability of MIC with location and time.

Biocide Treatment

The application of effective biocide treatments proves very difficult particularly where the situation is further complicated by the formation of inorganic scales (sulphate and carbonate or organic deposits and the continuous injection of potentially biostatic dependent on formulation and concentration , corrosion inhibitors . Determining the corrosion mechanism in such systems can also be very complicated and leads to frequent reporting of the cause of corrosion being MIC or Under Deposit Corrosion.

As mentioned previously MIC mitigation often becomes confused with other reasons for bacterial control. This can result in biocide being applied for no economic benefit Commonly repeated errors include:

- Treating the system with biocide despite acceptable corrosion rates being confirmed.
- Applying very occasional treatment (ie one every three months) as just in case control.
- Monitoring for bacteria but using an inappropriate media (wrong TDS) or incubation temperature.

Biological Condition of Source Water

In a 3-phase pipeline carrying fluids directly or indirectly from a producing wells the biology of the system is the most complex of the three pipeline systems discussed in the paper.

The water associated with oil production can be formation water aquifer water or mixture of these with injection water . Each water source will have its own original microbiological populations including bacteria and archaea (the term which combines these two different microbial life forms is Procaryotes). Which of these prokaryotes provide the source of sulphide producing organisms which might be predominant in MIC activity is an extremely complex problem to resolve. As a consequence many chose to ignore the complexity and continue to monitor for only sulphate – reducing bacteria (SRB) whereas strictly speaking if we hope to resolve MIC in 3-phase pipelines we should be studying sulphate reducing bacteria (SRB) and other prokaryotes capable of producing sulphide (or other corrosive environments) within the pipeline .

As the prokaryotes in the pipeline may be the result of microbiological activity within the oil reservoir it is often and possible to provide any control to their introduction into the system . This makes controlling their activity very difficult without to continuous treatment either into the well or directly downstream of the wellhead.

7.MIC MITIGATION MONITORING

Historically most attempts at MIC mitigation monitoring presented specifications for biocide efficacy determination based on limiting on limiting planktonic bacteria numbers to below set target limits . Whilst this strategy may be appropriate for bacterial control in a closed or batch process system it is not appropriate for continuous process systems as pipelines.

MIC Prediction

In order to prevent MIC it is essential to control sessile bacteria in biofilms together with other key parameters associated with MIC stimulation. However most corrosion management system do not have a philosophy of corrosion prevention but of corrosion mitigation . In order to mitigate MIC it is necessary to predict a corrosion rate against which any mitigation measures can be monitored . Currently there is a distinct lack of MIC prediction models. In part this is due to a reluctance within the industry to accept the introduction of qualitative MIC models despite the fact that discussion continues as to whether the commonly applied CO_2 corrosion prediction model are quantitative or qualitative.

As stated earlier the application of even a simple qualitative model for MIC is an essential first step in any MIC mitigation strategy .

Decision Trees

Decision trees are required to test the sensitively of model parameters exerting the greatest effect on MIC mitigation under different conditions. This will allow the greatest emphasis to be placed upon the most effective mitigation measure for that particular system . Within the decision tree it is important to include only those parameters that can be measured or predicted by modeling.

Implementation

Once the strategy has been developed from the model and decision trees this needs to be implemented . KPI `s are required to mange and measure the extent to which the strategy to being implemented . Typically KPI`s are required for application of controls biocide treatment , pig runs , removal, etc . as per any standard corrosion mitigation programmed.

Monitoring

It is key to a successful monitoring program is to monitor only those parameters where the data can be used either directly or indirectly to measure MIC mitigation. Pitting corrosion rates frequency of pitting etc, can be considered as direct analyses which could be used to measure MIC mitigation. Continuous on line measurement of temperature or pH and weekly counts on planktonic SRB is not uncommon but unless tied to an MIC prediction in some way this data serves to provide no useful purpose other than a comfort factor that something is being done.

Review and Learned for management

A continuous review of any management system is required to ensure that the effectiveness of the system is maintained . This must include a clear history of lessons learned and this is of particular relevance to MIC mitigation . This is no doubt that controls are being attempted and will continues to be applied with treatment regimes and strategies which have failed in similar systems at other locations. Particularly where this is the case with seawater pipelines where the transported fluids are very similar over a wide range of location a lessons learned database would help to fast track the strategy for MIC control in new projects.

It widely recognized that maintaining a new system in clean condition to mitigate MIC is far more easily managed than remediating a system already contaminated with biofilms and exhibiting MIC pitting corrosion. [16].

Due to the problems involved in remediating dirty systems novel approaches were undertaken resulting in the development of nitrate treatments which are now widely practiced by several operators for MIC and SRB control in water injection systems. As yet however the industry has not developed a set of guidelines aimed at preventing the need to implement remediation treatment within the projected life of a water handling facility.

8. CONCLUSION

▪ Improved control of the development of corrosive biofilms and mitigation of MIC can be achieved by the application of a manged MIC mitigation strategy . This is particularly the case if MIC management is practiced from start –up in new systems.

▪The strategy require a modeled prediction of MIC which pays due cognizance to microbial kinetics system design and those operational parameters which exert the greatest effect on pitting corrosion rates.

▪The strategy should be reviewed on an ongoing basis using properly interpreted data from a specifically designed routine monitoring programe.

▪ The monitoring program should include only those a biotic and biotic analyses which are practical and which are activity employed in measuring MIC mitigation and reports should demonstrate measurement by KPI`s.

▪ A remediation strategy will required very different treatments and controls in comparison to a mitigation strategy.

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