Corrosion Management

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- Insulation Inspector
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- Pipeline Coatings Inspector
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I trust you are keeping safe and healthy in these challenging times for us all. It has been very heartening to witness the way in which ICorr activities have transitioned almost seamlessly online. More than ever, our website, social media platforms and online meeting facilities are proving critical in bringing people together and facilitating the excellent networking, training and knowledge transfer activities that the Institute has to offer.

The future of ICorr rests with our younger members and I’m delighted to see the continued success of initiatives to support networking, training and career development of our students, apprentices and early career professionals. We have put younger members firmly at the heart of our membership development strategy and it is fantastic to see some of these activities already coming to fruition. I’ve mentioned some of these below but there is much more to come!

The Institute is proud to support the new Level 2 Industrial Coatings Applicator standard for apprentices, which has been developed in collaboration with Skills Training UK, BINDT and the Highways Agency. I was very pleased to hear that the first cohort of apprentices at Jack Tighe Ltd have successfully passed their End Point Assessment, which consisted of a series of practical tests and a professional discussion over a week in early August. The success of this initiative is down to a lot of hard work by a large number of people but I would particularly like to thank Martin Hillyard and John Whittaker of Jack Tighe Ltd for their strong support for the next generation of coating applicators. Hopefully this will be the first of many such cohorts!

Young ICorr is also continuing to flourish under the leadership of Caroline Allanach. Key to our strategy here is the intention to link Young ICorr activities with local Branch events to broaden the professional network of our early career corrosion engineers and scientists. Combined with the current need to hold Institute events online, this will also have the beneficial effect of revitalising some of our less active Branches. If you are interested in supporting these events in any way please get in touch with Caroline (Caroline.Allanach@gmail.com).

It was a pleasure to attend the 61st Corrosion Science Symposium, which was held online using the Institute’s Zoom Pro account in September. The quality of the talks by the students was very high and there were many interesting discussions, both verbally and via the chat function. I was also honoured to present the U.R. Evans Award (at least virtually) to Prof. Bob Cottis – hopefully there will be an opportunity to present him with the sword itself in the not too distant future!

As a professional society we are constantly striving to develop new ways to raise standards in corrosion protection across a range of sectors. Our training courses are an important part of this strategy and are internationally recognised for their quality and integrity. In the past few years we have been updating and expanding our portfolio of world class training courses. A notable addition that launched on 23 September is our new Level 3 Passive Fire Protection course, which has been developed in collaboration with PFNet and will set new standards for health and safety in this area.

Finally, I’m delighted to announce a new grade of Corporate Membership, with BP as our first Corporate Member. Our thanks are due to David Mobbs for developing this concept and making it a reality in discussions with BP. I would also like to extend my sincere thanks to BP for agreeing to act as a ‘guinea pig’ for this new grade of membership; their strong support for the Institute and its vital activities is greatly appreciated. Going forward we have exciting plans to roll out Corporate Membership to other larger companies, which will further raise the profile of corrosion protection as a major priority for asset owners.

Enjoy this issue of the magazine – I would also like to point you towards the excellent blogs on our website (www.icorr.org) and the interesting links they contain. Happy reading!

Gareth Hinds, Institute of Corrosion President

From the Editor

I hope everyone is well and that you managed to have a summer holiday (of sorts). This issue has the now regular “Ask the Expert” and “Fellow’s Corner” columns, together with three technical articles. There is the second part of the detailed article on cathodic protection of offshore renewable energy structures by Brian Wyatt, a look at contamination in gas pipelines in Kuwait, and the pros and cons of shop painting of bridge structural steel.

I hope these three technical articles and the new columns are of interest to you, and remember this is your magazine and I welcome suggestions for improvement, or new topics to be covered. You can also send me case studies, your industry news and new product information. I can be contacted at, brianpce@aol.com

Brian Goldie, Consulting Editor

Letter to the Editor

Sir,

Very interesting item about the restoration of SV Peking in the July/August issue of Corrosion Management. I think UK readers would be most interested in her history as Arethusa II, a Shaftesbury Homes training vessel at Greenhithe on Thames and then Upnor on the Medway, 1932-75 (www.childrenshomes.org.uk/STArethusa) with a 5 year Second World war gap as HMS Pekin in Royal Navy service as a floating barracks.

For information, her sister ship Passat when owned by the Erikson Line of Marieham, Finland participated in the last Great Grain Race of 1949 from Port Victoria (South Australia) to Penarth, Wales, and is now a hostel/venue and museum ship moored on the Baltic coast at Travemünde, Germany.

George W M Hobbs FICorr
Vice President of National Trust of South Australia
ICATS/CORREX

Apprenticeships

‘End Point Assessments’ for the first seven apprentices in our industry were carried out by Kevin Harold, ICorr, and John Moody, BINDT during August. The practical assessments and interviews were documented by David Mobbs, ICorr, to record this major event which would not have been achieved without the tenacity of the Jack Tighe organisation and in particular training manager John Whitaker and Chairman, Martin Hillyard in association with DN Colleges, Scunthorpe. The trail blazing began with senior ICorr members, David Horrocks and John Fletcher, together with Highways England.

The very nervous students all gained ‘distinction’ and are now time-served apprentices.

ABRACO (Brazilian Association of Corrosion)

ABRACO is the equivalent of ICorr in Brazil, and sometime ago discussions began with senior ABRACO members and Lucia Fullalove of ICorr, for them to offer ICATS in Brazil. This included a presentation in Brazil by Lucia about ICorr at an Industrial Coating Seminar (VI SBPA) organised by ABRACO in December last year (see below).

Mechanisms are being put in place even during Covid to bring ICATS to the South American market in the very near future.

Also, the newly published Petrobras Standard, N-2941 dated 07 / 2020: Personal Competence for Inspection Activities, recognises ICorr Coating inspector levels 2 and 3.

The ‘equivalence’ table for Industrial paint inspector showing equivalence among the schemes and certification levels, can be found under Section 6 – Specific Requirements, item 6.4 – Competence Requirements for industrial Paint Inspector personnel, which is reproduced bottom left.

This is a great recognition for ICorr, and it is hoped other ICorr certifications will be added to the list.

Training Courses

ICATS training has started to resume in the UK, with training centres opening their doors once more. The newest of which is IMechE in Sheffield, normally associated with Painting Inspector and NDT courses. IMechE have trained ICATS trainers and will be working with partner Hodge Clemco for the practical aspects.

Training has also resumed for many of our members including new trainers from Taziker Industrial, Bolton, NWL Group, Merseyside and Galco Steel Ltd, Ireland.

Visit the ICATS website
www.icats-training.org

<table>
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<tr>
<th>ABNT</th>
<th>NACE</th>
<th>British Gas BGAS/ER1</th>
<th>SSPC</th>
<th>FROSIO</th>
<th>ICORR</th>
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<tbody>
<tr>
<td>(ABNT NBR15218 Inspector Nível 1)</td>
<td>NACE Certified Coating Inspector – Level 2</td>
<td>Painting Inspector Grade 2</td>
<td>Protective Coating Inspector – Level 2</td>
<td>Frosio Inspector – Level 2</td>
<td>ICORR Level 2 Coating Inspector</td>
</tr>
</tbody>
</table>

| Inspectors Nivel 2 | NACE Certified Coating Inspector – Level 3 | Painting Inspector Grade 1 | Protective Coating Inspector – Level 3 | Frosio Inspector – Level 3 | ICORR Level 3 Coating Inspector |

Tabela 4 – Equivalência para Inspeção de Pintura Industrial Equivalência entre Esquemas e Níveis de Certificação.

Turn the page a few times and we are now on the verge of supplying ICATS to Brazil via our overseas training provider IMechE, together with a conversion course for ABRACO paint inspectors to ICorr Paint Inspectors.
Institute News

PMAC Group

PMAC was formed in 2000 offering Flow Assurance services and specialised products to the Oil and Gas industry worldwide, from exploration through to production and transportation of hydrocarbons. Utilising a unique blend of proprietary expertise and an established range of technologies PMAC draws on a combined knowledge of practical experience in chemistry, corrosion, inspection and electronic engineering, to provide clients with a unique design and manufacturing capability, complimented with a range of service capabilities. They offer a complete offshore CP survey and Gamma Flooded Member detection service to ensure the integrity of pipelines and structures. This service is based on proven technology with further developed hardware and software to meet industry and legislative requirements, and uses experienced engineers.

PMAC is a leading provider of a range of underwater inspection services, with many thousands of kms of pipeline, and several hundred structures, inspected using their unique system and offshore engineers, for most offshore operators in over 40 Countries and Territories.

With numerous skill sets under one roof, PMAC can offer multitasking CP & FMD(RPO) engineers and where appropriate 3.4u specialists in CP, helping reduce costs and accommodation requirements. All PMAC personnel are radiation protection officers/supervisors as well as holding minimum CSWIP Cathodic Protection level 2 and often Level 3.

For topsides, PMAC have designed and developed products for monitoring scale and wax in process pipework, and a number of corrosion related projects at Lloyd’s included RBI for the S-Chem (Saudi) Sulphate Reducing Plant, where the scope of work included corrosion matters for Bluewater’s FPSO. She was responsible for the delivery of RBI, pressure system inspection work scopes, fitness for service assessments, and technical reports outlining corrosion related issues, ensuring the constant update of risk-based assessments for all integrity related offshore facilities, and development of shutdown scenarios.

The following 3 year chapter in her life took her to Lloyd’s Register Aberdeen, working as a Corrosion Engineer on asset life extension assessments for SABIC petrochemical plant static equipment and piping, for sites at Teesside (UK), Mount Vernon (USA), Burville (USA) and Petrokemya North & South (KSA). Other overseas related projects at Lloyd’s included RBI for the S-Chem (Saudi) petrochemical refinery, and a corrosion study for the ZADCO Sulphate Reducing Plant, where the scope of work included static equipment and piping criticality assessment and generating inspection plan for all static equipment, piping and PSVs. As well as dealing with a number of UK offshore facilities, new
Institute News

experiences of pipeline corrosion management were gained, including cathodic protection reviews and developing corrosion control schemes. Most recently she joined the Aberdeen based IMRANDD Asset Integrity Management Firm, where she provides ongoing engineering support for Chrysaor’s offshore assets - Armada, Lomond and North Everest.

According to Mei Ling, her journey into the field of corrosion started with her fascination on what was known as the greatest technological prediction for half a century, Moore’s Law - cramming more transistors onto integrated circuit boards which lead to the age of computing and personal mobile devices. One of the challenges of keeping up with Moore’s Law was around the limitations with materials science, which decided her to study Materials Engineering at university. It was during this when they had a module on energy storage and battery systems that got her interested in the subject of electrochemistry. The process in a battery and corrosion of steel are chemically similar.

Mei Ling’s CV is typical of new corrosion engineers, in that experienced engineers in the branch are supporting her as she works toward Chartered status. In addition, Mei Ling is assisting Young ICorr nationally under chair, Caroline Allanach.

If you are a newly qualified engineer working the corrosion protection industry, then, just as with Mei Ling, your local branch can support you in your career development. A list of branch contacts can be found on the diary page of this magazine.

As usual, full details of future Aberdeen branch events can be found on the diary page of this magazine and on the ICorr Website, or by contacting, ICorrABZ@gmail.com. Copies of the majority of past branch presentations can be found at, https://www.icorr.org/aberdeen/, and a photo gallery for all Aberdeen events can also be found at, https://sites.google.com/site/icorrabz/event-gallery.

It should be noted that the planned ‘Industrial visit (Oceaneering), an Alternative/Interactive Industrial Event’, will now take place on 15th October 2020.

Midland Branch

The branch has the following two online talks planned. Tuesday 20th October, starting at 12.00 Social Media for Professional Growth - Tips and Best Practices, Presenter - Dr Dawid Hanak, Senior Lecturer, Cranfield University; and Friday 27th November, Introduction to Mental Health – (MHFA England, Mental Health Aware Taster), Presenter - Russell Mott Lead Auditor & Trainer ATAS UK. Official Building Mental Health in Construction (BMH) toolbox talk and promoting both chat and poll questions in Zoom, again starting at 12.00. In the interim, the following links maybe useful to members for support and help on mental health: https://www.samaritans.org/, https://www.mind.org.uk/, https://mhfaengland.org/, https://atas-uk.com/, and specifically for younger members, https://www.studentminds.org.uk/

Full details can be found on the events page of the ICorr website.
The latest article from ICorr Fellows who have made a significant contribution in the field of corrosion control is by Dr Sadegh Parvisi, Senior Principal Materials Engineer, McDermott, who describes the role of a Corrosion, Materials and Metallurgy Engineer. With some decades of professional engineering experience in engineering companies, operations and R&D, the author now shares this experience with fellow workers in ICorr.

The role of the Corrosion, Materials and Metallurgy Engineer in the integrity of Oil and Gas projects

This brief article is intended to highlight some strategic ideas to enhance the interaction of the Corrosion, Materials and Metallurgical (CMM) discipline with other fields, to improve the integrity of a project and enhance the reliability of the plants. It also aims to show the workflow, and identify the mechanism of interaction between all the disciplines engaged in the execution of a project.

Why CMM?

Today’s corrosion engineers cannot produce meaningful and reliable outputs without having a proper relevant knowledge of Materials and Metallurgy. For instance, for a corrosion engineer it is not sufficient to only know the electrochemical processes well, but it would also be necessary for him/her to have a clear idea of the difference between PVC and CPVC. The CMM engineer should also understand, for example, the role of molybdenum on pitting and crevice corrosion of stainless steels, and to assess that even if this is not an issue, it is still vital to be aware of the huge cost impact of selecting between SS304 and SS316 steels in a LNG project. Hence this being considered as a single discipline which is named CMM.

Why is this subject important?

Consistency between the engineering project specification documents has a significant effect in the integrity of a project. This consistency cannot be achieved unless a dynamic interaction is built between the engineering disciplines. Quite often, it has been experienced that the final version of the Piping and Instrumentation Diagram (P&ID) is not compatible with the material selection specification or report. Piping classes specifying the material of construction’s corrosion allowance divert from the as-built P&IDs etc. The root cause of these discrepancies lies in the lack of proper communication between relevant engineers, in particular in the CMM discipline.

Phases of Project

Any project can go through different phases before it reaches a ‘live’ production. For example:
- Conceptual
- FEED
- Detailed Engineering
- Procurement
- Fabrication & Inspection
- Installation
- Pre-commissioning
- Commissioning
- Trial Period
- Operation
- Maintenance
- Mothballing
- Extension/Revamping
- Conceptual
- Front End Engineering Design (FEED)

- Detailed Engineering
- Procurement
- Fabrication & Inspection
- Installation
- Pre-commissioning
- Commissioning
- Trial Period
- Operation
- Maintenance
- Mothballing
- Extension/Revamping

This article intends to briefly address some of the key activities in each phase.

Conceptual Phase
- The most fundamental phase in which preliminary materials selection and corrosion control, based on Statement of Requirement (SOR), and in line with process design parameters, are made
- Innovation, discussion meetings with reputed vendors
- Risk of employing new technologies should not be ignored
- Optimisation and cost savings to be looked at carefully
- Discussion and agreement with the client on any software to be utilised before it gets too late
- Site visit by CMM engineer can be very useful, if not crucial

FEED Phase
- The project statement of requirements should detail scope of work for this discipline.
- Optimisation process, i.e. risk analysis and economic analysis should be conducted

Detailed Engineering comprises
- FEED endorsement
- Endorsement correction, HAZOP, licensor, etc. Corrosion control check-ups, Approved changes
- Full definition of materials (e.g. exact grade of titanium, etc., for example)
- Basis of material selection to be consistent with FEED
- Materials requisition and any technical deviation
- Critical review of package material, request for compliance
- Setting and finalising materials selection, as built
- Material selection control manual

Procurement and Construction
- CMM to ensure compliance to specifications, and ensure that an exotic material choice is not necessarily fit for service.
Fellow's Corner

Validation of material selection
Corrosion control techniques

Pipeline

Process
- Heat & Mass balance
- Corrosion philosophy and materials selection reports
- Insulation specification

Mechanical
- Corrosion protection
- Material selection
- Datasheet review

Inspection
- Welding Specs
- Reviewing NDT procedures

Concession Request (CR) document
Upgrade requests from vendor should be assessed carefully
Participate in pre-production meeting
Materials selection change request during construction on CP, painting, storage, etc.
Issuing close-out report for as built condition
No compromise to be made if it could affect integrity

Pre-commissioning
The CMM engineers to be alert to some of the procedures in the manual, such as hydro testing, and that they are practiced carefully.

Summary
It is important to note that a continuous and integrated input and engagement of the CMM engineer and the other disciplines, and the table summarises the links between a process engineer and a piping engineer, as the main disciplines interacting with the CMM engineer in any oil and gas project, in order to have a robust and solid material selection philosophy. Similar tables can be produced to include other disciplines' scope of activities, for instance in applying a corrosion mitigation technique by ICCP, the interaction between CMM, pipeline, civil and electrical engineers should be clearly defined.

The Oil & Gas company should ensure active participation of the CMM engineer and appropriate interaction of them with other disciplines throughout the project.

It is recommended that
- The engineering director/company should ensure that there is a continuous active participation, and appropriate interaction, of the CMM engineer with other disciplines. It is also important that a proper organisational chart is developed before the start of the project, and the position and the work scope of the CMM engineer is defined for the project, without any budget constraints for this important discipline.
- The harmful misconceptions that “Nothing Can Be Done About Corrosion!” are avoided.
- There is increased awareness of the large cost of corrosion and potential savings that can be made.
- A sound Corrosion Management strategy should be set-up by changing policies, regulations, standards, management practices and attitudes, to increase corrosion mitigation savings.
- The education and training of staff in recognition of corrosion control should be improved.

Cable tray, JB material validation, CP (ICCP) coordination

The simple diagram shows the relationship between the CMM engineer and the other disciplines, and the table summarises the links between a process engineer and a piping engineer, as the main disciplines interacting with the CMM engineer in any oil and gas project, in order to have a robust and solid material selection philosophy. Similar tables can be produced to include other disciplines' scope of activities, for instance in applying a corrosion mitigation technique by ICCP, the interaction between CMM, pipeline, civil and electrical engineers should be clearly defined.

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There is increased awareness of the large cost of corrosion and potential savings that can be made.

A sound Corrosion Management strategy should be set-up by changing policies, regulations, standards, management practices and attitudes, to increase corrosion mitigation savings.

The education and training of staff in recognition of corrosion control should be improved.

Typical workflow for issuing a corrosion control material selection table/report.

- Vendors technical bid and Concession Request (CR) document
- Upgrade requests from vendor should be assessed carefully
- Participate in pre-production meeting
- Materials selection change request during construction on CP, painting, storage, etc.
- Issuing close-out report for as built condition
- No compromise to be made if it could affect integrity

Document Custodian To/from

<table>
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<tr>
<th>Process Design Basis</th>
<th>Process</th>
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<td>H&amp;M Balance</td>
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<td>Process</td>
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<td>Client</td>
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<tr>
<td>Final Issue</td>
<td>CMM</td>
<td>Client</td>
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The questions this issue relate to the maintenance and servicing of corrosion monitoring devices for pipelines and process pipework, and conflicts between coating specifications and the product data sheet requirements.

**Question:**

In a previous issue (editor, March/April 2020) the question of the selection of suitable equipment for effective corrosion erosion monitoring in process plants and pipelines operating across a wide range of temperatures and pressures, was discussed.

In order to be in contact with the process fluids to test them, devices such as coupons (normally of same material as the pipe), electrical resistance probes, bio probes, chemical injection quills, galvanic probes and other sampling equipment are inserted through proprietary access fittings, either flanged or welded connections.

Can you explain how these devices are maintained, and serviced, in a safe and cost-effective manner? What precautions should be taken before engaging a vendor to perform this work, and what preparations are required at the worksite? AB

**Answer:**

This type of monitoring equipment is manufactured in many countries by a wide range of vendors (in varying degrees of quality and equipment monitoring sensitivity), therefore carefully review, all associated QA documentation, materials of construction, test certification and installation procedures.

Great care should be taken in the selection and purchase of such intrusive equipment to check that it complies with all relevant standards such as NACE MR0175 requirements (Parts 1/2/3 – Cracking resistance of materials) and NACE MR0103 (specifically for sour service in refineries).

An intrusive monitoring, and associated servicing, system normally comprises of 5 main components – high pressure (HP) online retrieval tool, a HP double block and bleed service / safety valve, a mechanical or hydraulic access fitting system (permanently connected to outside of the pipe/pipeline or pressure vessel), the internal monitoring device holder (with seals for primary pressure isolation) and the device itself that is to be serviced, such as a test coupon. In addition, a heavy-duty cap provides secondary pressure sealing containment in normal operation, after the tool has been removed for service.

It should be noted that these monitoring devices form part of a pressurised system for process containment, and the regular corrosion risk assessment data obtained from them contributes to determining how frequently the remaining piping circuit (which can be of considerable length) requires to be monitored by full inspection and other NDT – non-destructive testing methods such as ultrasonic or radiography. The data from these devices (often now transmitted wirelessly), also influences other mitigation measures such as control of water content and chemical injection, with adjustments made to chemical dosing according to the corrosion rate measured on the test device, to within agreed targets / KPI’s – Key Performance Indicators. Further, these devices also monitor problematic contaminants such as bacteria (through sessile swabs taken at device retrieval) that can accumulate in the system, especially when the system is put out of service for any significant period of time without pre-treatment (e.g. biocide addition).

Removal of these in-service devices should only be undertaken by competent/trained personnel, due to the risks of injury and potential loss of process containment, if not performed in accordance with established practices for safe retrieval. All such measuring equipment would normally be pressure tested and checked as being in good condition prior to shipping to site, this being independently witnessed as compliant with agreed pressure test procedures. Every test fitting at the workplace will have its own unique ID (Tag No.) and set of risks, therefore as well as utilising the relevant fitting retrieval procedure (either for online or offline servicing) a task risk assessment must be performed to identify all hazards (and required mitigations), specific to the retrieval/service location. For example, the device may be located at height and require scaffold erection for the service team (normally 2 people), or the fitting maybe located to the underside of the pipework (6 o’clock position), in which case, there may be risks of fitting/thread blockages from internal debris or spillage of fluids at device removal (when environmental precautions will be required), especially if it has not been serviced regularly. It is also not recommended to perform the 1st service of any such equipment on a live / online basis.

Before the start of any work, it is necessary to consult with the facility’s owner/client who should have maintained an access fittings register (with the vendor’s assistance), of the operating and service history of each Corrosion Monitoring fitting installed on the facility. Generally speaking, a good and frequent service history will allow regular safe in-service/live retrieval and maintenance activities to be performed, and these previous operations will have already identified the risks and should such information not be forthcoming, or is lacking in detail, then only offline/non-live retrieval should be performed (with hand tools), by persons competent to do so.

It is strongly recommended that reference should be made to the new Energy Institute (EI) Guidelines 1st Edition, for the management of access fittings for pressurised systems, published in August 2020.1

This document covers the lifecycle from the design, application, registration and safe handling of the different types of fittings through to abandonment/removal. The types of degradation which can be expected are defined, as well as methods of monitoring and the maintenance required. For more general guidance on effective corrosion control and prevention, the EI Guidance for corrosion management in oil and gas production and processing, 2nd edition should also be consulted.2

Primary pressure retention/process containment is of the utmost importance to all operators for reasons of personnel safety and good control of environmental and business risks. ST

1) https://publishing.energynst.org/topics/asset-integrity/guidelines-for-the-management-of-access-fittings-for-pressurised-systems


**Question:**

How should a conflict between the requirements, such as for film thickness, in a product data sheet, and the specification, be resolved? JS

**Answer:**

The fast and easy answer is that the detailed requirements (specification) will always take priority over the general. With this I mean, the specification is specific or unique for a project or a certain application, and this would supersede the more general content of a Product Data Sheet (PDS).

A typical PDS in the paint industry consists of:
- Description and recommended use
- Recommendations on pre-treatment
- Guidelines on application, methods, thinning, mixing, film thickness, overcoating intervals etc.
- Physical data for the product, drying time, solid content, colour(s), Volatile Organic Compounds (VOC), specific gravity etc.

Some PDSs are more detailed than others ranging from one to up to ten pages. A well written PDS presents the framework for the product so that the optimum required product can be chosen and application process be decided upon.

The specification requirements should always be based within the parameters of the PDS framework. If there are deviations from this framework
this indicates that the requirements may not be met by the product as it will be used for something which it was not designed to be used for, risking a poor result or at the very least some difficulties in application.

In other words, the specification should always be built within the parameters, directly or indirectly, outlined in the PDS and that is normally how the majority of specifications are developed. But a few do stray outside the framework, some for sound reasons and some for less so.

When data for a PDS is processed it is an integral part of product development. Before a product is released from the R&D lab it will have passed stringent testing and trials to make sure that it meets the product profile, both with regard to performance as a coating and with regard to application properties. The resulting data including the tolerance is recorded into the PDS. Normally these data and tolerances are on what can be considered the conservative or careful side.

Developing or building specifications can be for both a broad range of applications or be more for specific or customised use. The latter is often dealt with by a specialist who can evaluate the solution needed, and design the specification accordingly. For this category it is not uncommon to see deviations from the guiding data in the PDS.

Looking more specifically at deviation from the recommended film thickness as mentioned in the question, how can that be a sound specification? If we assume that the specifier has good insight into the application conditions, (for example they may know that the spraying is undertaken in an automated installation and the control of overthickness is strong) then here there is room for extending the thickness range upwards as the tolerance does not need to be able to absorb the extra thickness that can be expected from manual application.

Similarly, if drying times are considered, the specifier will know if the ventilation is very efficient and there is strong temperature control, meaning matters such as over coating intervals and dry to handle times may be shorter than indicated in the PDS. This can also be applied in reverse of course, if the conditions are poor the times in the specification may be increased.

Simply put there may be good reasons for deviating, but they should always be defendable if challenged and they should be expected to be very close to the values stated in the PDS. Deviations wildly off should not be accepted as they, in principle, constitute a set of questionable data in either document.

As specifications are normally the result of serious work, they should have priority over the product data sheet.

Niels Lund Jensen (Subject Matter Expert, Hempel A/S)
Everyone responsible for specifying or supplying products for the maintenance of offshore Oil & Gas structures will be familiar with NORSOK Standard M-501. NORSOK standards were developed by the Norwegian petroleum industry in the 1990s to ensure that only the safest and most cost-effective critical engineering, manufacturing and maintenance products are utilised. Managed by Standards Norway they have since become the trusted certification, and operators world-wide now rely on the qualification when selecting materials.

There are many benefits for an organisation with products tested to NORSOK standards, which confirm a product’s performance, capabilities and their ability to meet operating requirements - critical when decisions are taken about material selection. However, passing the Standard M-501 test protocol involves a number of strict and lengthy procedures.

Corrocoat Plasmet ZF, a surface tolerant two-pack epoxy coating incorporating a rust inhibitor and passivator, with MIO and glass flake, was tested to NORSOK M-501 System 1 - use on carbon steel with a max operating temperature of <120°C. e.g. structural steel, equipment exteriors, vessels, pipework and valves including in tidal and splash zones, and System 3B - internal surfaces of carbon steel vessels - ballast water tanks/internal seawater filled compartments. As a requirement for a product to pass the protocol, all testing must be carried out by an independent registered inspection, verification, testing and certification company, and for this, Corrocoat selected Manchester based SGS.

Carbon steel test plates were abrasive blast cleaned to Sa 2½, with a surface profile of 84μm and then coated. The test protocol for System 1 requires a zinc rich epoxy primer, a minimum total dry film thickness of 340μm, and at least three coats, however Corrocoat wanted to test Plasmet ZF at their recommended application for this material - two coats with a total DFT of 250μm. This work was all carried out at their Leeds facility under the close supervision of an SGS NACE certified coating inspector. The sample plates were then transferred to SGS’s laboratories for the stringent 175-day long cyclic ageing, seawater immersion and cathodic disbondment testing in November 2019. The results of this test programme, carried out to ISO 12944-9, should give an accurate indication of the coating’s performance in arduous service conditions.

Seawater Immersion. Panels were scribed and subject to an exposure of 4200 hours in circulating aerated water. At the end of the test, corrosion from the scribe must be less than 8 microns as stipulated in ISO 2812-2 Standard.

Cyclical Ageing Test determines the resistance of a coating in a defined cycle of salt spray, dry condensation and UV light and variable temperatures. Scribed panels were subjected to 25 cycles each consisting of 72 hours of UV exposure, salt spray and low temperatures. At the end of this 175-day test programme the sample plates were then assessed against a number of criteria defined in ISO 12944-9, including indications of rust, corrosion creep, blistering, cracking, flaking, chalking and the adhesion of the coating to the substrate.

In addition, Cathodic Disbondment (CD) testing was carried out for System 3B. CD is an electro-chemical mechanism that can cause rapid and severe breakdown of a coating at a damage site. A 6mm hole was drilled
into the coating on the test panels which were then exposed for 4200 hours in a sea water solution, with an impressed current of 1.05 volts. To pass this test, disbondment radiating from the hole must be less than 20 microns as per ISO 15711.

According to the company, the coating performed extremely well, having good adhesion, low creep from the scribe and no rusting, blistering of flaking, meeting all the requirements. In the CD testing, all delamination was cohesive within the coating, and thus did not constitute a failure. However Plasmet ZF is non-compliant with M-501, as it is not as defined in the standard with respect to applied film thicknesses or number of coats, but clearly the coating passed the tests required at only 250 microns. The cathodic disbondment results were particularly impressive - inspectors at SGS commented that they couldn’t get the knife blade between the coating and the steel.

Graham Greenwood-Sole, Managing Director of specialist coatings manufacturer Corrocoat, stated that successfully passing Norsok M-501 test protocol for Systems 1 and 3B informs the market that Plasmet ZF meets a verified set of internationally recognised standards. The coating is manufactured to give good corrosion protection on rusted metals with minimum surface preparation, it may also be applied to UHP water-blasted grit-blasted surfaces as an inhibitive coating or primer. It is ideal for use on: rigs – super structure and sub structure; FPSO’s; Offshore wind turbine substructures (monopoles, jackets and floating structures) pipelines, structural steel, valves, vessels and blast tanks.

Vestas and Hempel enter into strategic partnership agreement

According Hempel they have formed a new strategic partnership with Vestas, a leader in sustainable energy solutions, to cooperate around innovative solutions for surface protection of wind turbines. The joint Vestas and Hempel ambition is to reduce surface treatment costs and support sustainable coating solutions. At the same time, Hempel will continue to assist Vestas in remaining competitive throughout the entire process of becoming CO2 neutral by 2030.

Vestas and Hempel will take the first step in the partnership at the Vestas wind tower manufacturing plant in Colorado, USA, where they will closely collaborate on bringing down costs and exploring new digital solutions to improve quality control and the CO2 footprint of the production of wind turbines. Initial calculations demonstrate that changing the processes surrounding the surface treatment application will potentially generate a 60 per cent reduction in CO2 emissions equal to 1,100 tonnes CO2 per year.

Study Looks at Concrete in Nuclear Plants

A new European Commission-supported project to advance the assessment of safety performance of critical concrete infrastructure in nuclear power plants began in September and runs until Aug. 31, 2024. According to Finland’s VTT Technical Research Centre, the project aims to clarify, enhance and unify methods of structural integrity assessment in support of long-term operation.

The project involves a consortium of 10 European companies and research partners, as well as one international partner, including CEA (France), CTU (Czech Republic), CVR (Czech Republic), EDF (France), ENERGORISK (Ukraine), ENGIE LAB (Belgium), IRSN (France), SCK•CEN (Belgium), ZAG (Slovenia) and the U.S.’s Oak Ridge National Laboratory.

The project named ACES, with a budget of €6 million, aims to have an impact on operations of Gen II and III nuclear power plants, as well as on the design of next-generation plants. It is intended to improve the understanding of ageing and deterioration of concrete, and will demonstrate and quantify inherent safety margins introduced by the conservative approaches used during design and defined by codes and standards employed throughout the life of the plant, according to VTT.

ACES hopes to give operators and regulators an improved understanding of the concrete, including:

- A critical review of aging management practice across EU NPP focusing on deterioration and aging mechanisms of reinforced concrete, linked to decision-based assessment criteria
- Improved understanding of corrosion phenomena focusing on embedded liners, predicting the occurrence of corrosion and developing an innovative inspection tool for early detection of corrosion
- Improved assessment of the effects of prolonged irradiation of the concrete biological shield using a holistic approach combining operating conditions, materials degradation and structural significance

Webinar, Corrosion Testing Innovation

The 3rd webinar in the Corrosion Testing in Extreme Environments series from LBBC Baskerville, will be held on 26 November 2020, at 13.00, and cover Corrosion Testing Innovation – The past, present and future.

Autoclave corrosion tests are a convenient way of laboratory simulation of many service environments by recreating the high temperatures and high pressures commonly occurring in industrial processes. However, there are numerous shortcomings, e.g. the conditions in the autoclave vary from real life because the fluid is not continually replenished, and the conditions are difficult to measure/monitor under the extreme conditions.

Discussions with the University of Leeds identified a specific opportunity to develop an innovative range of high pressure autoclave systems incorporating continuous, real-time monitoring of the corrosion process being investigated within the vessel. This will be of interest to a number of industries for lab investigations of corrosion of materials exposed to high temperatures and pressures.

In this webinar, Dr Danny Burkle and Dr Richard Barker will enlarge on their discussions from previous webinars and discuss the key challenges in harsh operating environments, current and future needs in tools, technologies and methods, and how new products can be developed to enable innovation and improve testing programmes.

The topics to be covered include, corrosion testing methods, limitations of current corrosion testing methods, and corrosion testing innovation: linking lab to field.

For more information contact, d.burkle@lbcbaskerville.co.uk or k.oliver@lbcc.co.uk, and to register, go to https://us02web.zoom.us/webinar/register/WN_fT6kwSR5-ljuAgbWVeK

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Review of the cathodic disbondment resistance of pipeline coatings

The main cause of coating degradation on pipelines with CP is cathodic disbondment. To provide useful guidance for selecting pipeline coating systems, cathodic disbondment test methods (categorised as standard test methods or modified test methods) that have been developed over the past two decades have been critically reviewed in this article.

In-situ techniques for assessing cathodic disbondment of coatings, especially those having promise for field applications, are also discussed. Finally, a brief discussion on the mitigation of cathodic disbondment and the associated corrosion is given. This review was published in Progress in Organic Coatings, Volume 146, September 2020.

Enhanced barrier properties of epoxy coatings

A new study describes the barrier properties of epoxy coating containing CaCO₃ microparticles modified with cerium nitrate.

In the study, the protective properties of epoxy coatings containing pH-sensitive calcium carbonate (CaCO₃) microparticles modified with cerium nitrate (Ce(NO₃)₃), applied to mild steel substrates, were investigated in 3.5 wt% NaCl solution, via electrochemical impedance spectroscopy (EIS) and salt spray testing. Scanning electron microscope (SEM), X-ray powder diffraction (XRD) and inductively coupled plasma (ICP) tests were performed to evaluate the characteristics of the synthesised CaCO₃ microparticles.

Results showed that the modification process changed the morphology of the particles and loaded them with Ce(III). EIS and salt spray tests showed that the incorporation of the modified CaCO₃ microparticles to epoxy coatings can enhance their corrosion protection.

The corrosion protection performance of the coating was affected by the amount of incorporated microparticles, in that increasing the amount of modified CaCO₃ microparticles led to higher corrosion protection. Increasing the Ce(III) ions content of the CaCO₃ microparticles led to similar behaviour.

The study was published in Progress in Organic Coatings, Volume 144, July 2020.

Effect of polymer hardness on the abrasive wear resistance of thick organic offshore coatings

The effects of polymer hardness on the abrasive wear resistance of organic coatings, designed for the corrosion protection of offshore wind power structures, have been investigated at varying applied forces.

The results of the tests revealed statistically significant effects of the polymer material’s Vickers hardness on the coating’s resistance against abrasive wear. With respect to the generic polymer type, the ranking of the abrasive wear resistance was estimated as epoxy > polysiloxane > polyurethane.

Thus, the most frequently applied top coat material (polyurethane) exhibited the lowest abrasive wear resistance and may therefore not be capable of protecting the underlying epoxy-based intermediate coats. Polysiloxane-based coatings could provide a longer protection against abrasive wear.

The dominant material removal modes for all polymers were micro-cutting and micro-fracturing, whereas the former mode is dominant at lower normal (right angle) forces, and the latter is dominant at these higher forces.

This study was published in Progress in Organic Coatings, Volume 146, September 2020.

STANDARDS UP-DATE

ISO

The following documents have obtained substantial support within the appropriate ISO technical committees during the past two months and have been submitted to the ISO member bodies for voting, or formal approval.

ISO/DIS 7539-9 Corrosion of metals and alloys — Stress corrosion testing — Part 9: Preparation and use of pre-cracked specimens for tests under rising load or rising displacement (revision of 2003 standard)

ISO/PRF 1460 Metallic coatings — Hot dip galvanized coatings on ferrous ISO member bodies for voting, or formal approval.

The following documents have obtained substantial support within the appropriate

ISO/DIS 7539-9 Corrosion of metals and alloys — Stress corrosion testing — Part 9: Preparation and use of pre-cracked specimens for tests under rising load or rising displacement (revision of 2003 standard)


ISO/DIS 18797-2 Petroleum, petrochemical and natural gas industries - External corrosion protection of risers by coatings and linings — Part 2: Maintenance and field repair coatings for riser pipes

ISO/FDIS 23449 Corrosion of metals and alloys — Multielectrode arrays for corrosion measurement

ISO/DIS 7539-9 Corrosion of metals and alloys — Stress corrosion testing — Part 9: Preparation and use of pre-cracked specimens for tests under rising load or rising displacement (revision of 2003 standard)

New international standards published during the past two months

ISO 23363:2020 Electrodeposited coatings and related finishes — Electroless Ni-P-ceramic composite coatings

CEN

Standards published within last two months.


This document specifies a field method for the assessment of the surface density of various water-soluble salts on steel surfaces, before and/or after surface preparation, by conductometric determination. The individual surface densities of the salt cannot be determined by this method, as it assesses only contaminants that form an electrolyte (ions) when in contact with water.

EN ISO 11463:2020 Corrosion of metals and alloys - Guidelines for the evaluation of pitting corrosion

This document gives guidelines for the selection of procedures that can be used in the identification and examination of corrosion pits and in the evaluation of pitting corrosion and pit growth rate.

The review was published in Progress in Organic Coatings, Volume 146, September 2020.
Cortec® Corporation has recently expanded its range of water-based anti-corrosion coatings by developing a new fast-dry version called EcoShield® 386 FD. This combines the worker and environmental advantages of a water-based coating with the performance of EcoShield® 386 micro corrosion inhibiting technology, in a topcoat that will force-dry in five to 10 minutes. According to the company, this is ideal for manufacturers of pipes, tubes, and other metal components without enough time to cool and dry the coated parts before continuing the production process.

It is a water-based acrylic one coat system that can be applied DTM at 37.5-75 μm dry film thickness to provide protection in harsh, outdoor, unsheltered applications. It contains 72 g/L of VOCs and is an excellent alternative to solvent-based and zinc-rich paints. It relies on a complex mixture of non-hazardous “nano” sized corrosion inhibitors to provide a more continuous layer of corrosion protection in micro cavities where traditional inhibitors may leave gaps due to their larger relative particle size, concluded the company.
Cathodic protection of offshore renewable energy infrastructure - part 2

B S Wyatt Corrosion Control Ltd, J Preston, Corrosion Control Affiliates Ltd, W R Jacob, The CP Consultancy Ltd.

Part 1 of this article appeared in the July/August issue of Corrosion Management, and described the background to the additional requirements needed to adequately protect near-shore installations, and ended with conclusions in respect of CP current density and water flow rate.

This article addresses other environmental effects on current density, anode positioning and potential distribution, protective coating performance, and summaries both parts of this detailed article.

CP Design Considerations

Effects of Temperature and other environmental parameters on current density

Hartt et al\(^1\) presented a comprehensive summary of the formation of calcareous deposits as cathodic protection current discharge increases the pH at the steel/sea water interface to about pH 10.5 to pH 11.5. The deposits are primarily insoluble calcium carbonate \(\text{CaCO}_3\) with varying amounts of magnesium hydroxide \(\text{Mg(OH)}_2\) and magnesium carbonate \(\text{MgCO}_3\). At higher current densities [and more negative steel/seawater potentials] the proportion of magnesium salts increases, and the quality of protection afforded by the calcareous film reduces.

Hartt et al\(^1\) also reworked data by Humble\(^2\) which indicated that low Mg content in the calcareous deposits [lower CP current densities] produced films that result in lower long-term current densities, see figure 1.

It has been widely established that in warmer waters it is easier to form effective calcareous deposits than in colder waters. It is also well established that the oxygen solubility increases significantly with decreasing temperature. Shell released the following data in their 1995 Design and Engineering Practice (DEP)\(^3\) as shown in figure 2.

Shell also published in their later DEP\(^4\) (but based on work by Rippon\(^5\)) multiple data sets from the worldwide offshore oil and gas assets of Shell companies (figure 3).

Figure 3 is the basis of the ‘Mean current density range for non buried bare steel pipelines in ISO 15589-1’ as its figure 2.

For many years in the North Sea, Shell have been known to use a significantly lower Mean current density than DNVGL-RP-B401, see figure 3. These applications are, of course, for offshore jackets, and not inshore wind farms. However, they present rigorously measured real Mean current densities in low velocity sea water. It should be noted that these structures are reported as being polarised to between -950 to -1000mV Ag/AgCl/sea water.

Hartt et al\(^1\) also reported on work by Rodrigo\(^7\) presented in figure 4.

DNVGL-RP-B401 guidance is that mean current density in tropical environments (>20 C) should be about 75% of the values in temperate environments (7-11 C). In addition, importantly, the effect of temperature on the electrical resistivity of seawater and thus on anode current output (see below) must be considered.
Klas in 1958 showed in the laboratory, using ‘simulated’ [artificial] seawater, that ‘full strength’ seawater permitted a more rapid decrease in CP current density with time [more rapid polarisation] than in diluted seawater. This would be expected due to easier formation of calcareous deposits. He also showed that long term CP current densities at -980mV [to a saturated calomel reference electrode, which is close to Ag/AgCl/sea water] were significantly lower than for steel polarised to either -780mV, -880mV or -1080mV. [supporting the real field data of Strommen in 1985 see figure 9 in part 1 of this article]. His work measured the reduction of current density with time of polarisation and showed that this was mirrored by an increase in the [calcareous deposit] film resistance with time (figure 5).

Effects of steel surface condition on current density

As described above, the extent and quality of polarisation films on the steel surface has a significant effect on the current density needed to achieve, and maintain, adequate cathodic protection. Klas is reported by Hart et al for the work in synthetic seawater on the influence of prior surface condition, whether lightly pre-corroded or heavily pre-corroded was small, and apparently inconsistent, in these experiments. See figure 6. However, work by Wilkins et al at Harwell indicated that pre-corroded steel surfaces in fresh seawater required significantly higher current densities to polarise to both -850mV and -1050mV Ag/AgCl/sea water than did grit blast cleaned steel (figure 7). After about 60 days, the maintenance current densities were of the same order, but there was a large degree of scatter in their data also. This study also compared variations between fresh seawater, ‘stored’ seawater [assumed to be ‘biologically dead’] and artificial seawater.

It should be noted that many offshore wind monopiles are bare steel and are generally delivered to site by a purpose designed vessel that pile drives them on location to design depth. It may be some months before CP is provided by way of anodes welded onto the Transition Piece [TP]. The bare steel surfaces receiving CP current will be pre-corroded and the work above infers that the initial current density requirements will be higher than for those structures or samples whose data were reviewed in part 1 of this article, which typically received CP from the first moments of seawater immersion.

*Note: The lower Polarisation Current Density curve is the minimum requirement. The upper curve is meant for sensitivity analysis. For Driving Voltages other than 0.25 Volts, multiply the polarisation current density values by 0.25/Damping Volts - 0.80 - (Anode Operating Potential).
Seawater resistivity

In addition to the temperature effects summarised above, the instantaneous current available from a galvanic anode is inversely proportional to the electrical resistivity of the seawater at the infrastructure site, which is a function of the local temperature and salinity. The selection of the correct value of resistivity is essential for ensuring sufficient protection current, particularly for initial polarisation of uncoated structures, and end-of-life current on coated structures. The highest anticipated resistivity (lowest temperature: lowest salinity) during the year must be used in CP designs.

Figure 8: Effect of seawater temperature and salinity on resistivity (DNVGL-RP-B401).

The variation in resistivity due to temperature and salinity is set out in Figure A-1 in DNVGL RP B401, reproduced in Figure 8.

Working on the basis of these data, an ill-conceived CP design might assume that it would be appropriate to use the average sea water temperature 10.4°C, together with a typical salinity of, say, 35%, to determine the calculated sea water electrical resistivity of 0.27 ohm m. This would produce a CP system that could deliver its designed CP current only in June to October. With the lowest monthly mean sea temperature being 5.9°C in March, a more appropriate design electrical resistivity would be 0.30 ohm m.

The electrical resistivity of the sea water is a fundamental determinant of the current that can be delivered by galvanic anodes. A 20% increase in resistivity will result in a 17% reduction in galvanic anode current. The CP system is required to be competent for the entire year and there are no demerits in having current capability in excess of requirements.

It may be noted that, when data are not available to calculate resistivity, DNVGL-RP-B401 advises that a sea water electrical resistivity of 0.30 ohm m should be used and that if lower values are used, they should be ‘based on actual measurements, taking into account any seasonal variations in temperature’. The latter requirement is often not followed.

Many Offshore Wind Farm (OWF) CP designs have used water electrical resistivities in the range of 0.25 to 0.27ohm m. This is considered to be inappropriate and risks inadequate CP performance during the periods when the water is coldest [typically December to April in UK sector of the southern North Sea]. These periods are also likely to be the high water velocity months with the highest current demand. In these months there may be considerable periods where the temperature is at or below 5°C. In these conditions the CP system will only be able to deliver ca 83% of the designed current output of the galvanic anodes, on the basis of resistivity alone. This will often be made worse by the factors discussed above and below.

However, many OWF operators neither deploy permanent steel/sea water potential data logging facilities, nor are they able to undertake diver or ROV surveys of CP system performance during winter months, and particularly not during winter storms. They are thus likely to be unaware of the real CP performance, and corrosion fatigue risk, during large periods of each year.

Anode interaction

Many OWF CP designs claim or document compliance with DNVGL-RP-B401 in respect of the minimum anode/structure stand-off distance [300mm] required to achieve the theoretical current output, but show anodes that are closely spaced, anode/anode. Many OWP monopile foundation designs use only Transition Piece (TP) mounted clustered anode arrays, which their CP designers argue that this is in compliance with RP-B401.

DNVGL-RP-B401 was not prepared with monopiles in mind and the advice within it in respect of anode/anode interference, which proposes a minimum spacing of 500mm, is widely considered to be inadequate. However, there are ‘clues’ in the RP which have been widely ignored by OWF CP designers, including guidance on considering closely spaced anodes as a single anode with the overall dimensions of the group [conservative] and a requirement for uniform anode distribution over the structure. The latter is evidently not met with anodes clustered on TPs, although typical spacing between anodes on a TP will be 1-2m.

It can be understood why designers assume that such spacing will be sufficient to avoid interaction effects that reduce the anode current outputs
as they follow the advice in RP B401, but experience, and boundary element mathematical modelling indicate that the advice is, significantly, incorrect.

Because of this, designers need to follow the guidance in DNVGL-RP-0416 which states that where there are reasons to assume a significant interaction between anodes, an analysis by a computer model should be carried out to determine a reduction factor for the anode current output. The reduction factor is to be applied as a factor on anode current output as calculated by anode resistance formulas for anodes with such interaction.

The mathematical modelling company CM-BEASY have published studies of the effects of clustering of anodes on the effective resistance of anode arrays. Typical results indicate the significance of mutual anode interaction on anode output, viz:

- Simply placing two stand-off anodes on opposite sides of a supporting tubular will produce ca 97% of the anticipated current output based on single anodes to remote earth using the standard [modified Dwight] formula
- 6 anodes spaced approximately 0.5 m apart end to end and on alternate sides of a tubular will produce ca. 81% of the anticipated current output
- 23 anodes spaced approximately 0.9m apart in a rectangular array will produce only 19.2% of the anticipated current output

Two examples from studies of rings of anodes on OWF TP serve to emphasise the importance of interactions between anodes. Figure 10 shows calculations for a double ring of anodes with 8 anodes per ring.

<table>
<thead>
<tr>
<th>Model</th>
<th>Details and Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model:</td>
<td>No. of anodes: 16</td>
</tr>
<tr>
<td></td>
<td>Anode size: 2200x200x200</td>
</tr>
<tr>
<td></td>
<td>Area protected [m²]: 280</td>
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<tr>
<td></td>
<td>Driving voltage [voltage]: 45mV due to polarisation</td>
</tr>
<tr>
<td>Results from Model:</td>
<td>Current: 6.1A</td>
</tr>
<tr>
<td></td>
<td>Resistances [ohm]: 0.057</td>
</tr>
<tr>
<td></td>
<td>16 anode 'ring': 0.007377</td>
</tr>
<tr>
<td>Current:</td>
<td>By 16 x Dwight: 9.88 Amps</td>
</tr>
<tr>
<td></td>
<td>By 'ring': 6.10 Amps</td>
</tr>
<tr>
<td>Modelled predicted current is 62.5% of that calculated following DNVGL process BUT ignoring interaction</td>
<td></td>
</tr>
</tbody>
</table>

Figure 10: Illustration of effect of anode interaction.

The model output above indicated that the total current output was only 62.5% of that calculated by the standard formula within DNVGL-RP-B401 if anode/anode and anode/cathode proximity interaction effects are ignored. This is often what happens, despite DNVGL advice to use modelling; this advice is subtle in RP-B401 and clear in RP-0416, but is still widely ignored.

In another CP design, using anodes only on the TP, with 51 vertically disposed anodes of ca. 2500mm x 200 x 200mm in 3 ‘rings’ with the rings 500mm vertically separated, modelling indicated that the current output will only be 17% of that calculated from individual anode resistance. Detail in the model showed the extreme non-uniformity in output between individual anodes.

- Currents from each ring were calculated as 26% top, 27% middle, 47% bottom
- The current from the highest output anode was calculated to be 3.4 times that with the lowest output; this would clearly result in non uniform life of anodes and a likelihood of the CP system not delivering its design life competently
- Calculated current density on the anode surfaces varied by a factor of 44, with very high values at the lower ends of the bottom anodes and the lowest on the middle row of anodes

It is clear from this experience, that modelling of any CP arrangement involving numbers of closely spaced anodes must be a mandatory part of the design process.

Field surveys on real offshore wind Monopiles (MPs) that had been previously modelled by Beasy with competent input parameters have delivered data that were very close to the predicted performance.

Potential distribution

For convenience and low cost of installation, it is usual to distribute external anodes on a monopile foundation as a circular array on the bottom of the transition piece. As discussed above, these closely grouped anodes have much less available current output than when they are widely spaced, and this can lead to lack of protection even if the [conventionally] calculated numbers of anodes are installed. In addition, distribution of current from anodes at a single level can be problematic for water depths greater than about 15m, leading to non-uniformity in the protection potentials achieved and, ultimately, loss of protection remote from anodes. These two factors are cumulative, but apart from by way of anode location, are not interdependent.

This illustrated in figure 11. In the left hand view, all the anodes calculated as being required for protection are placed as three rings on the TP. Under the conditions modelled, a large part of the MP surface is under-protected compared to the design potential criterion, which in this case, was -900mV in order to protect against microbial corrosion. The area close to the mud line is less negative than -800mV. Using the same number of anodes, under the same external conditions, moving a number of them to rings lower down on the MP (figure 11, right hand view) results in full protection over the whole of the MP surface, with a least negative potential of -940mV.

This serves to emphasise the value of modelling for these offshore installations where, for structural reasons, there are significant distances between the anode locations and steel surfaces requiring protection.

It is appreciated that solutions to CP designs with all the anodes ‘clustered’ on the TP offer developers low CAPEX solutions but they come with significant risks of very large OPEX expenditures in offshore retrofits, or reductions in asset life due to the lower parts of the MP needing to be assessed structurally for fatigue using ‘free corrosion’ S-N curves rather than ‘in seawater with CP’ S-N curves, as is clear in DNVGL-ST-0126.

Figure 11: Effect of anode distribution on protection potential.
**Electrical bonding**

Where anodes are mounted on the TP but intended to protect the MP surfaces below, it is essential to ensure an electrically conducting path of very low resistance between the two. While bolted and flanged interfaces may fulfill this requirement, a grouted interface will not. Bonds specifically designed for CP will be needed.

Conventionally, the electrical bonds between TP and MP have been designed only for electrical/lightning protection and have been assumed by those designing the CP systems to be also sufficiently adequate for CP purposes. In practice it is becoming evident that the bonds have been inadequate for both functions at the time of installation, and that they can deteriorate significantly and quickly in service.

In service, electrical bonds will have two quite different functions. For normal CP operation, the current passed will be typically up to 70A low voltage DC for a medium sized uncoated monopile. For lightning strike dissipation, the current may well be as high as 200kA. The design of the bonds, not only the conductor size but, importantly, the contact resistances at each end, are required to meet both sets of parameters, these include the very low volt drop across the bonds, preventing degradation of CP performance, and the calculations of temperature rise for specific energy characteristics for the predicted lightning.

It is essential, therefore, that bonding is rigorously designed to be competent for both electrical safety and CP function, and to be reliable throughout the design life. The design should estimate the total resistance of the bonds, including the contact resistances determined by their methods of connection (pin braze, bolted, crimped or other) and then ensure that the volt drop in the bonds, which will reduce the available anode/steel driving voltage, is properly addressed in the CP design. Typically, the voltage drop at peak CP current should be no more than 10mV. This criterion has not been met by most existing monopile CP designs.

Typically, bonds consisting of 750mm long 50mm² multi-strand copper cable, competently pin-brazed at each end can be installed to have a total resistance of 0.0005ohm. Multiple bonds are then installed to ensure a maximum of 10mV drop at the maximum anticipated CP current of both internal and external CP systems. Connection points need to be competently coated to ensure resistance to corrosion in the, often warm, humid marine atmosphere inside the MP.

Significant deterioration and failure of TP / MP cable continuity bonds has been detected in OWF developments.

**Internal CP considerations**

The focus of the previous section has been the provision of external CP to offshore energy infrastructure. Internal corrosion is also a major risk for offshore wind turbine foundations. Its effects could mean costly offshore retrofit work resulting in the loss of generation and the exposure of operatives to additional health and safety risks. Corrosion protection internally therefore is of vital importance in assuring the overall integrity of offshore foundations and minimising exposure to these risks.

The monopile has been the most commonly used type of foundation for offshore wind farms. These large diameter steel piles, which have normally been uncoated internally, are flooded with seawater when installed. Although nominally sealed from further ingress and egress of seawater, experience has shown that seals often become ineffective, leading to corrosion of the internal surfaces due to the replenishment of oxygen. Accordingly, the application of CP, in the form of galvanic [sacrificial] anodes, is being used as a remedy to address such a situation in the event of it occurring and, more commonly, as part of initial foundation designs.

The use of internal CP systems in monopiles is a relatively new development, for which again there is no relevant guidance in the currently published offshore cathodic protection standards. However, in addition to the ISO 24656 Standard for ‘Cathodic Protection of offshore wind structures’ (in preparation), EN 17243 was published in 2020 and presents some of the relevant requirements.

These Standards give guidance on the significantly reduced current densities required to achieve and maintain effective CP within quiescent sea water conditions. It appears likely, from some of the data outlined above, that current densities can be further reduced in conditions where oxygen depletion occurs, however rigorous trials of such an approach are not known to have been completed.

While the influence of Metocean environmental parameters is clearly reduced within flooded monopiles, many of the deficiencies in external OWF CP designs noted above may affect internal MP CP systems. In addition, evidence has emerged that there are other considerations associated with the application of CP in enclosed spaces if particular secondary effects are not considered.

Recent studies of galvanic anode CP in enclosed spaces have concluded, that:

- If no seawater replenishment takes place and aluminium anodes are used, an increase of acidity (lowering of pH) will increase the cathode currents required for protection of the steel, increase the self-consumption rate of anodes, and increase the rate of hydrogen evolution. It is possible that protection of the steel may not be maintained, and that microbiologically influenced corrosion (MIC) may proceed, with the production of HS and accelerated corrosion rates.

- By contrast, zinc anodes do not significantly alter the pH and will, therefore not have the adverse consequences described for aluminium anodes in non-replenished conditions. They will also evolve less hydrogen than aluminium anodes.

- If tidal seawater replenishment were achieved, the pH may be maintained at levels close to that in natural seawater, depending on the percentage seawater exchange on each tide, and aluminium anodes can be used. However, care in the design of the flushing system is important to mitigate against the stratification of the water column which could present problems of decreasing pH even if tidal replenishment is employed, in particular for those monopiles that are drilled and have deeper water columns below the sea bed.

- Whilst the greater anode capacity (amp hours per kg) of aluminium anodes makes them lighter and easier to install, and less costly, than zinc anodes, the latter are a more secure choice if there is no inadequate, or uncertain, replenishment of the sea water within monopile foundations.

The use of conventional stand-off or flush anodes is not applicable to internal CP systems. Instead, strings of cast anodes (zinc or aluminium depending on replenishment conditions) are used. They are typically connected to the TP above the ‘air tight’ deck, by copper cable ring main arrangements, thus there is an additional capacity required in the necessarily low electrical resistance bonds between the MP and TP, through which the internal CP current must flow. This aspect has been ignored in some designs. The design of galvanic anodes strings for foundation monopile internal applications requires steps that are not documented in existing standards. These include proper evaluation of anode/anode and anode/monopile resistance within the string, assessment of anode/anode and anode/cathode Mutual interaction and the calculation of attenuation down anode strings. The possible corrosion of the anode suspension system above the water level within the foundation also need to be assessed.

Poor installation practice, entanglement of anode strings with other strings, network or export cables, risers or construction aids, along with inadequate commissioning testing and polarised performance assessment can all occur.

**Coating performance**

The above discussions have, in general, been relevant to uncoated structures. However, coatings are often used in conjunction with CP, significantly improving current distribution and reducing the weight of CP anodes required for protection of a structure. No coating is perfect and all degrade with time, increasing the current required for protection. CP design codes offer advice on the change in coating breakdown with time to be allowed for, and the recommendations in RP-B401 are often followed.

Coating degradation is difficult to predict and therefore these coating breakdown factors are deliberately conservative and noted by DNVGL-RP-B401 as ‘rather coarse but conservative engineering judgements’; their Category III (the best) system is of 2 or more coats of epoxy, PU or vinyl to a nominal DFT of 350μm for which RP-B401 predicts a 32% coating breakdown [to bare metal] in 25 years. An unpublished draft revision of RP-B401 (which may change before publication) has a new Category IV which is essentially a Category III with enhanced quality assurance; this predicts 22% bare metal in
25 years. All of these values refer to immersion depths of 0-30m; at greater depths, or internally at any depth, the breakdown is predicted to be less.

With the recent developments in coating technology, correctly applied epoxy based coatings to optimally prepared surfaces suffer significantly less degradation than stated in the design codes. This has been confirmed in investigations by SINTEF and Statoil of coating degradation on four offshore installations after about 20 years, in which the authors estimated that the coating breakdown on two of the structures was 1-5%, on a third it was <5% and on a fourth was 5-10%. The fourth structure was a manifold carrying oil with a reservoir temperature of 98°C and at least part of the structure would have been operating at elevated temperatures.

Earlier laboratory work by SINTEF presented 4-year data on coating breakdown (determined as a ratio of CP current density for coated steel/CP current density for bare steel in the same exposure). Testing was in synthetic seawater, with the samples polarised to -1050mV. Multiple parallel samples were exposed and assessed. It is noted that polarisation to -1050mV would be at the most negative end of the anticipated polarisation range, and may have accelerated cathodic disbondment.

The data are reproduced in figure 12 below for four coatings designated in the paper as DNV Category III.

A 682μm polyester-polystyrene system performed somewhat worse than the epoxy systems, and a 668μm vinyl ester glass flake system performed worse than the DNVGL values.

The coating breakdown figures seen in this SINTEF study are generally <1% and are relatively constant for 4 years. This contrasts with 6.8% predicted by DNVGL after 5 years. The SINTEF data are consistent with unpublished data from an FPSO vessel off West Africa, which indicated a maximum coating breakdown on the hull of 3-4% after more than 10 years on station.

Less well documented, but supported by the publicly available photographs, Akzo Nobel claim <1% breakdown for their glass flake epoxy Interzone 1000 in the splash zone of the Conoco Hutton tension leg platform after some 30 years’ service.

Prudent use of lower coating breakdown estimates can provide substantial savings in the cost of CP systems, but their use is contingent on rigorous test data for the coating being used, together with optimum good practice in respect of coating system selection, surface preparation, application and independent inspection of all stages of the work.

Summary

Existing OWF CP designs

- Have failed to follow the advice in DNVGL-RP-B401 in more subtle respects, included, but not well detailed, in the RP, apparently due to inadequate understanding by the designers, who have often had no training or expertise in corrosion or CP
- Have failed to acknowledge and take account of water velocity in high water flow rate conditions. In these conditions the initial current densities in DNVGL-RP-B401 are significantly less than those required to adequately polarise bare structures
- Produce typical monopile CP designs, with anodes only on TPs, which, due to unconsidered anode/anode interaction, deliver typically between 35% and 50% of the design current documented as deliverable from the design. The design figures are calculated by the conventional [e.g. Dwight] formulae and driving voltage approach for individual anodes to remote earth. Even though the designers claim to have complied with DNVGL-RP-B401, they have ignored the requirements for uniform anode distribution over the structure and failed to assess anode/anode interaction as is clearly advised in DNVGL-RP-0416.
- Incorrectly apply water electrical resistivity data and its direct impact on current output. Typical designs deliver anode currents 10% below declared design values in cold months due to this alone
- Underestimate or ignore attenuation of current density and potential at increasing distance from anodes. For example, on an uncoated monopile, the potentials near the TP may be 300mV more negative than those at the seabed, the latter may not meet the design criterion. For a coated structure the design may work initially but may require retrofit of additional anodes once coating breakdown is significant. If an additional array or cage is incorporated at construction, either on the seabed or on the MP, ca. 75% of the immersed depth to sea bed, it will negate the very high retrofit cost
- Often underestimate, or ignore, the contact resistance and deterioration of bonds between TPs and MPs on monopiles

The deficiencies in design above are additive.
Some designs have been ‘lucky’, and have been adequate, despite not delivering CP currents in accordance with their design calculations. Fortunately, their locations have been in areas of low water flow rates, and the DNVGL-RP-B401 mean current densities are generous for low water flow rate conditions. It is likely that other CP schemes have not been so ‘lucky’ and actually do not perform adequately, this is known to be the case in some developments. These systems may not have their performance adequately assessed if they are only surveyed in calm weather.

**System performance assessment**

The detail and competence of CP surveys, which have not been defined in DNVGL-RP-B401 [and are poorly defined in many OWF project specifications] are often such that they are unable to properly measure the CP system performance. DNVGL-RP-0416 does give some guidance on CP surveys but it is not considered sufficiently rigorous and these surveys can generally only be undertaken during benign summer weather.

Inadequate performance that may impact on the fatigue life of the structure is unlikely to be detected by poorly conceived ‘dipping electrode’ CP surveys in calm summer weather.

Key factors are:

- Reference electrodes remote from the structure and measuring average anode/cathode potentials and not local steel/sea water potentials at points remote from anodes
- Surveys with structure connections on TPs not taking account of the volt drop in cable bonds between TPs and MPs. As an extreme example of the principle, if all the bonds have failed [and many have], all potentials will indicate the well protected TP with anodes welded to it, whilst the MP may be freely corroding
- Surveys with no documented calibration of reference electrodes or instrumentation, and thus no certainty of survey accuracy
- Surveys undertaken at slack water in summer months not being representative of possible (funder) protection during winter and early spring months when water temperatures are low, waves are high and water velocities may be high

**Design improvements required**

In order to ensure appropriate, and cost effective, CP design the following steps are necessary.

- Attention must be paid to all the available Metocean data, to assess maximum flow rates caused by tidal and wave effects, as a basis for selecting appropriate CP design current densities. Without such an assessment the CP designer cannot properly estimate the CP current densities. Those in the various present Standards and Codes, including DNVGL-RP-B401 are often inadequate in particularly high flow rate or storm prone areas that increases the inadequate Initial current density in RP-B401 by 50%, this may be inadequate for inshore tidal waters. Whilst DNVGL-RP-0416 represents of possible (under) protection during winter and early summer months.

- Metocean data should also be used to determine the appropriate seawater resistivity [a function of temperature and salinity] for the calculation of anode resistances and current outputs
- The effects of closely grouping anodes on their ability to provide the output current must be assessed by suitable mathematical modelling of final designs
- Likewise, modelling must be used to ensure that the required protection potential is reached on all wetted surfaces at all times during the operating life. Ignoring attenuation does not represent competent design
- Particular attention must be paid to the design of electrical bonds between parts of the structure that may not have assured electrical continuity between them. Bonds must have sufficiently low resistance and be designed to perform throughout the intended structure life

- Internal CP systems must be designed on a similar basis, but their design should take into account the possible development of acidity in enclosed spaces with limited seawater exchange, and address the particular attenuation of voltage and current within the anode cabling system and the resistive effects of the constrained electrolytes within the MPs
- Properly selected, applied and inspected coatings can greatly improve attenuation issues and reduce CP system weights and costs. The DNVGL-RP-B401 guidance on coating breakdown is appropriated nuanced but the ‘default’ figures are over pessimistic for well applied modern coatings. The CP design may advantageously take into account documented low coating breakdown factors, particularly for high build glass flame epoxies. DNVGL will accept properly documented, lower, coating breakdown factors
- For both external and internal CP systems it is essential to install competent monitoring systems and institute a rigorous programme of inspection and monitoring. The fixed monitoring will deliver representative CP performance data in all weather conditions, 365 days a year. Properly specified surveys can deliver simple, limited ‘proof of function’ data and detailed performance assessment and fault finding data over the whole structure. A combination of all three are required to deliver proof of the adequacy of CP applied to a multi-structure offshore wind development

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12. EN 17243 ‘Cathodic protection of internal surfaces of metallic tanks, structures, equipment, and piping containing seawater.’
17. Steinsmo, Unni; Bjordal, Marit; Knudsen, Ole Øystein; Sollem, Tone; ‘Coating quality in CP/Coating systems- Comparison of accelerated test and long time exposure,’ NACE 2000, Paper no. 00680.

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Contamination due to ‘black powder’ in gas streams has been a matter of great annoyance to operators.

The term ‘black powder’ is often used in the Oil & Gas Industry to refer to the material found in gas pipelines that consists of corrosion products (iron sulphides, iron carbonates, iron oxides, etc.) and several other contaminants. The physical form of the black powder can vary in different occasions, it can be wet or dry, black, tarnished, or grey. Its occurrence causes operational, maintenance, HSE, as well as integrity and reliability issues. It leads to various unwanted consequences like product contamination, production loss, economic loss, and sustainability concerns (e.g. due to flaring), for both the operators and the downstream customers. Various measures, that continue to evolve, are being adopted by the industry to handle the black powder challenge.

This article discusses the formation of black powder in gas pipelines, reviews the problems with its occurrence and the various strategies adopted to mitigate these issues, with reference to those undertaken by a Middle East Oil company. The objective of the article is to demonstrate the success of immediate / short-term measures taken to minimise the occurrence of black powder by revisiting the chemical injection dosages, frequent pigging operations and other methods, at one of the oilfield areas in Kuwait. It is hoped the article will create awareness and enrich the knowledge base regarding the occurrence of black powder in the Middle East region, and in the Oil & Gas industry in general.

Black Powder

Although iron sulphides are the prevalent constituent, no traces of them have been seen in some cases, and combinations of iron sulphides, iron carbonates and iron oxides have all been reported, and a large amount of literature is available on the formation mechanisms. [Ref 1]

It is documented that the black powder is formed because of chemical / microbial actions triggering internal corrosion of the pipeline.

Black powder forms throughout the process, through well bores, into gathering lines, in separation facilities, and along the gas transmission pipelines. It continues to build-up in the gas plants and refineries and reaches the end user storage facilities.

Iron from the pipeline material reacts with the various corrodents (S, O₂, CO₂ and H₂S) in the produced gas and condensate, leading to the formation of black powder. CO₂ and H₂S are the normal constituents of the gas, and in addition, sulphate reducing bacteria (SRB) also contributes to produce H₂S. Microbiologically induced corrosion (MIC) or microbial corrosion can take place due to acid producing bacteria (APB) or iron oxidizing bacteria (IOB), or simply promoted by microorganisms. The
black powder has been observed in gas streams. Problems associated with black powder

At the oilfield areas of KOC, black powder has been observed in gas streams. Issues include,

- Choking of instrument impulse lines (see sketch below)
- Contamination of feed
- Damage to equipment

All causing operational, maintenance as well as HSE issues, leading to financial loss, environmental impact etc.

In general, following issues can be considered:

- Black powder deposition inside the pipelines create flow restrictions, this requires additional energy leading to increased operational cost to transmit the given quantity of the gas / fluid. It could block the orifice of meters causing inaccuracy in measuring flowrates thus disturbing the downstream processes where dependency upon the accurate measurement of flow is important. It possibly reduces the performance of rotating machines such as compressor, turbines etc.

- The issue of choking of impulse lines of instruments due to black powder may affect control valves, PSVs, isolation valves etc., threatening the process control as well as process safety. An example, that is worth mentioning here is that the Middle East O&G fields are facing a critical issue over the maintenance of the ‘Isolation Valve’ of safety relief valves. Safety relief valves are critical components of any plant. Safety relief valves are usually installed with an upstream block valve to facilitate O&M of the safety relief valve. The adverse impact of black powder on the operation of isolation valves is affecting the very maintenance of the Safety Relief Valve.

- Frequent plugging of filters due to black powder requires extra maintenance and may lead to production loss, as well as flaring

- Black powder may contain pyrophoric materials, this requires extra precautions during operations, and maintenance. In this case its removal and disposal from pipelines / equipment requires extra safeguards

- The black powder presence in the gas streams will contaminate the export gas, thereby leading to cutting the feed supply to downstream customers

- It affects inline inspection (ILI), and pigging operations, involving extra cost and time

The presence of black powder not only leads to product contamination but also decreases effectiveness of the whole system by accelerating corrosion & erosion rates, as well as choking and flaring, safety & various hazards, and finally it culminates into financial losses to the industry.

**What is the solution. Is it difficult to find a solution to the black powder?**

Black powder occurrence is considered a complex phenomenon, as its occurrence, physical and chemical characteristics, vary widely. It has been reported that even in parallel lines, one line may show evidence of the problem while the other does not. Hence due its complexity and unpredictability, finding a lasting solution becomes a tedious and difficult task.

Pipelines and associated systems are designed taking into consideration both the solid and liquid portions in the gas, however black powder can still occur during operation as the design aspects usually do not consider its occurrence because of its unpredictability. When black powder is observed during operation, then e.g. a specific filter may frequently get clogged, or some constituent of the black powder may pass through the filter, leading to damage to various equipment such as exchangers, compressors etc.

**Strategies for managing the challenge of black powder**

Several strategies can be applied to manage the problem of black powder, these are, prevention, mitigation, and removal.

**Prevention**

From experience a way to fully eliminating the black powder problem once it starts, is not yet known. Therefore, it is better to prevent it from occurring in the first place. The usual plan would be to carry out some preventive programme over a defined period that could address the root cause of the black powder formation. This could involve several measures as follows:

- The quality of the gas to be transported should have the lowest concentration of the various constituents such as water, sulphur, hydrogen sulphide, oxygen, carbon dioxide, etc. that contribute to black powder formation through chemical and microbial actions. This can be achieved for example by, scrubbing (water removal), chemical dosing, and installation of acid gas recovery plants prior to distributing the gas to the network.

- Monitoring of the gas dew point should be considered while operating the pipeline as moisture along with acid gas components can trigger severe corrosion thus avoiding chemical / biological reactions. Providing an internal anti-corrosion coating reduces the occurrence of black powder to certain extent. NACE MR0175 Standard’s compliance should be ensured where \( \text{H}_2\text{S} \) gas suitability is required, while selecting the material of construction to prevent chemical and microbial action.

Special care should also be taken during construction, commissioning and throughout the entire service life to prevent contamination, presence of water (e.g. after hydrotesting), microbial growth, and corrosion. Precautions should be taken to ensure that any contamination is eliminated from the pipelines.
such as dirt, debris, construction wastes. Flushing, draining and drying operations of the pipeline system to be done when necessary to prevent corrosion. Moreover, the quality of water for testing / flushing should be appropriate.

Mitigation

Internal corrosion control is the key to mitigating the black powder problem. Moreover, it is also important to recognise that improper selection of mitigation measures may unintentionally worsen the corrosion viz the black powder problem (see below).

Removal

As described earlier, whether black powder material is attached to the internal wall, or deposited in the pipeline, or being carried away with the gas, various methods are used, either individually, or in combination, for its removal. 

- Mechanical Cleaning: Mechanical pigs are utilised to take out the black powder material which is attached to the wall and clean any deposits inside the pipeline system
- Chemical Cleaning: Pipeline cleaning by various chemicals
- Gas-Filter: Such as cartridge type filters are used to remove solid particles from the stream of gas
- Cyclonic Separators: Where two phases are separated through centrifugal forces of separation

Assessment of mitigation measures taken

Due to the complexity involved, the problematic features and worries, the general response of the Oil & Gas companies has been to implement a black powder management system combining prevention, mitigation, and removal strategies. Accordingly, when the occurrence of black powder, along with liquid carry-over, in sour gas streams at one of the Kuwait's oilfields was observed, the various short-term strategies already in hand, such as adjusting chemical injection dosage and frequency of pigging operations, were reviewed. Generally, the practice was to inject measured chemical doses over a period, then assess which dosage had the optimum effect. Similarly, for the pigging operation, the frequency of which was increased substantially to, say once every month.

The affected lines in the network were identified and classified in terms of amount of black powder produced, as ‘High’, ‘Medium’ and ‘Low’, as shown in Figure 1. Initially, the frequency of pigging for all the affected lines was the same, but after the review exercise those categorised as high, were specially monitored for the various factors mentioned above such as, water H₂S etc., compared to medium and low black powder producing lines.

- Careful monitoring of the quantities of black powder for each line of the network was carried out at selected time intervals after employing frequent pigging operations, as well as adjusting chemical doses
- Special attention was given to the stagnant lines and pigging was scheduled for these lines, as it had been observed that these were more vulnerable and had generated substantial quantities of black powder. The lines which had not been in operation for some time, were mothballed

Results

The outcomes of the measures taken after four months of the exercise are given in Table 1. The observations reported are those at the end of the study compared with those made after the end of the first month.

This table gives the results after four months of frequent pigging (every month) as well as close monitoring of the chemical dosing, and careful operation of dehydration units at the facilities. After four months, the quantities of black powder were significantly reduced, however the network lines have not been completely rid of the black powder. Therefore, more advance technologies need to be considered as long term measures for those pipelines (with their respective upstream facilities).

The reasons behind these further steps taken by the Operations team are:

- As there are two 16” & 12” HP lines initiating from same source, but the 12” is free of black powder whereas, the 16” is not, this phenomenon has to be investigated
- The 30” HP line still has black powder after the exercise, as this is vital line for operation, it has therefore been decided to increase the frequency of pigging further

Figure 1: Schematic diagram of classification of affected lines (shows percentage of black powder in each line, and diameter and length of line).
As there is another line available to deliver the Fuel Gas, the 10” FG line which is producing a substantial amount of black powder after the exercise, is therefore to be mothballed.

The short-term measures employed have significantly reduced the black powder formation and subsequently accelerated its removal from the gas lines. Furthermore, the faster black powder removal from the network lines reduces the adverse effect of black powder. The visual quantities of black powder significantly reduced with every cycle (every month) over a study period of four months.

Recommendations

Various recommendations for operational changes, based on the outcomes of the short-term measures taken, can be summarised as follows:

- **Dehydration units**
  Efficient operation along with controlling the dew point to avoid moisture in the stream which should help with the reduction in formation of iron oxides.

- **Monitor acid gases (H₂S, CO₂)**
  Reduction of H₂S and CO₂ should be undertaken. This would help with integrity management by reducing corrosion, and can be achieved by chemical injection of scavengers etc., adjusted according to the nature of the feed, or by using acid recovery units, together with strict monitoring.

- **Pipeline Safeguarding**
  Stagnant pipelines to be pigged and mothballing of unused lines should be carried out. This would help with MIC-related H₂S production, which in turn reduces FeS production.

Long-term solution

Various long-term solutions, such as using cartridge filters, cyclo-filters, and wringing separators, etc., should be assessed and employed to deal with the issue of black powder. Generally, the strategy to handle solid / liquid contamination in gas streams has been to use normal / conventional filters, but in the case of black powder, the filter may face problems of blockage if the mesh size is too small. Multi-cyclone scrubbers do not face the same problem of such blockages, and in cases where black powder occurs after some time in operation and the existing facilities have limited space, for example offshore, then multi-cyclone scrubbers usually require relatively less area for installation compared to other types of conventional scrubbers.

Table 1: Observation of network lines (after four months) *

<table>
<thead>
<tr>
<th>PL*</th>
<th>SIZE</th>
<th>FROM</th>
<th>TO</th>
<th>OBSERVATIONS</th>
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<tbody>
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<td>HP</td>
<td>12”</td>
<td>GC</td>
<td>TR</td>
<td>Clean</td>
</tr>
<tr>
<td>HP</td>
<td>14”</td>
<td>GC</td>
<td>MF</td>
<td>Small quantity of black sludge</td>
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<td>HP</td>
<td>16”</td>
<td>GC</td>
<td>TR</td>
<td>Black Powder Observed</td>
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<td>HP</td>
<td>30”</td>
<td>TR</td>
<td>AA (122 KM)</td>
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</tr>
<tr>
<td>HP</td>
<td>30”</td>
<td>BS</td>
<td>TR</td>
<td>Black Powder Observed</td>
</tr>
<tr>
<td>HP</td>
<td>16”</td>
<td>EPF</td>
<td>Point</td>
<td>Clean</td>
</tr>
<tr>
<td>HP</td>
<td>30”</td>
<td>BS</td>
<td>Point</td>
<td>Clean</td>
</tr>
<tr>
<td>HP</td>
<td>40”</td>
<td>Point</td>
<td>BG (114 KM)</td>
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<tr>
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<td>10”</td>
<td>TR</td>
<td>BS</td>
<td>Black Powder Observed</td>
</tr>
<tr>
<td>FG</td>
<td>4’’</td>
<td>GC</td>
<td>GC</td>
<td>Carry out pigging immediately</td>
</tr>
<tr>
<td>FG</td>
<td>4’’</td>
<td>Point</td>
<td>EPF</td>
<td>Non Piggable (not shown in figure)</td>
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<tr>
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<td>KD</td>
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<tr>
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<tr>
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<td>TR</td>
<td>AA</td>
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Table 2 Further steps taken after the 4-month exercise.

<table>
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<td>16”</td>
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<td>Investigate</td>
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<td>HP</td>
<td>30”</td>
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<td>AA</td>
<td>Increase Pigging Frequency</td>
</tr>
<tr>
<td>FG</td>
<td>10”</td>
<td>TR</td>
<td>BS</td>
<td>Mothball</td>
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</table>

References


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Total Shop Painting of New Bridge Steel – Pros and Cons

Ken Trimber, KTA-Tator Inc.

When all the coats of a paint system are applied to bridge steelwork in an enclosed shop, the quality of the preparation and painting is typically good. The steel is blast cleaned and painted in a controlled environment, minimising or eliminating the concerns with temperature, relative humidity, dew point, and inclement weather, that often plague work in the field. Access to all surfaces for cleaning, painting, and inspection is better than most field conditions, especially when the field work requires the use of lifts, rigging, and some degree of containment. The time between coats is often brief, and the potential for inter-coat contamination is greatly reduced. Field painting is then limited to painting connections and touching up shipping and erection damage, reducing the need for extensive rigging and lengthy inconvenience to the travelling public.

Given all the advantages of total shop painting with field touch up, why isn’t it done for every project? The reason isn’t related to the quality of the work produced in the shop; it’s related to the quality of the finished product together with aesthetics.

With shop-applied coating systems, extra care is required during shipping, handling, and erection to minimise damage to the coating. While coating systems do an excellent job protecting the steel from corrosion, the coatings cannot withstand the impact of one member being dropped against another, or resist damage when secured or lifted using chains, or when banged with hammers. The resulting damage requires touch up in the field. If the damage is limited, repair is straightforward. Only localised access is needed, the damaged coating is removed to sound material using hand scrapers or power tools, the existing coating edges feathered, and one or more coats applied to the damaged area. However, if the damage is widespread, more extensive rigging and surface preparation are required. And depending on the nature of the damage, it may be necessary to abrasive blast clean large areas rather than attempt to repair each spot on an individual basis, greatly increasing the time, effort, and cost to complete the project in the field.

The localised areas of touch up will also be visible, and affect aesthetics of the structure. It is essentially impossible to conduct localised touch up without each repair being visible, by virtue of difference in texture, gloss, and even shade of colour. Brush and roller repairs of spray-applied coatings stand out, and the border of a spray applied touch up is readily seen by virtue of a fine edge of overspray around each patch. While the touch up will commonly fade over a few years and be less visible, the only way to avoid seeing the repair areas is to apply a full finish coat to logical break points on the structure. Another complication that often occurs is when the concrete bridge deck is poured. While specifications require the complete removal of cement scum before it hardens, cleaning is often incomplete, leaving thin films of cement on webs and heavier deposits on flanges. The cement typically adheres so well that removing it by chipping, power tool cleaning or water jetting, often removes the coating as well, or impacts the aesthetics by reducing the gloss.

Another complication that often occurs is when the concrete bridge deck is poured. While specifications require the complete removal of cement scum before it hardens, cleaning is often incomplete, leaving thin films of cement on webs and heavier deposits on flanges. The cement typically adheres so well that removing it by chipping, power tool cleaning or water jetting, often removes the coating as well, or impacts the aesthetics by reducing the gloss.

Localised touch-up readily visible.

Hardened concrete on new coating system from deck pour.

continues on page 28
Repairs often require extensive surface preparation and repainting to repair the damage.

In summary, while shop-painting offers distinct advantages related to the quality of the initial application, the overall integrity and aesthetics of the final system can be compromised if extensive touch up is required, and cement scum is not thoroughly washed from the surface during pours.

One compromise is to apply all coats in the shop except for the outside fascia, which receives only the primer or the prime and intermediate, depending on maximum recoat times. The expectation is that touch up on the underside of the bridge can be performed without concern for aesthetics and some cement on the coating can be allowed to remain. Since the fascia would already be scheduled for one or two field coats, damage to the paint during handling or when removing cement scum is less concerning since there’s no finish coat to salvage. Instead all deficiencies will be corrected during cleaning and the application of the specified one or two full coats.

Attempts to remove cement scum by grinding create significant damage, in this case, to the steel, to the zinc primer, and to the white epoxy intermediate.

Current UK (Road) Bridge Coating System

The paint system approved for UK road bridges is detailed in “Manual of Contract Documents for Highway Works” (MCH), Series 1900 Specification for Highway Works Protection of Steelwork Against Corrosion, Volume 1 Table 19/2B, Requirements for Bridges, etc.

Currently the generic system is:
- Zinc phosphate high build quick drying epoxy (2-pack) blast primer
- Micaceous Iron Oxide (MIO) high build quick drying epoxy
- Polyurethane topcoat

with a total dry film thickness (dft) of 300 microns

Typically for new construction, the steel deck would be blast cleaned only. Reinforcement bars would be fitted and concrete poured, followed by primer, polyurethane waterproofing membrane and then the tarmac laid.
Key Facts

Corrosion Management
- Circulation of 1500 subscribers
- Published bimonthly – 6 issues a year
- 75% of subscribers UK Based
- Majority of readers employed at senior level as decision makers and specifiers in their field
- The main focus of each issue is a themed technical article

Don’t delay

We have a range of advertising opportunities in Corrosion Management Magazine. However because this is a technical journal, space is limited and is booked on a first come first served basis.

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Due to the ongoing restrictions, ICorr meetings are being held online. At the time of going to press, the following branch meetings are expected to be held.

### BRANCH DATES

**20th October 2020**

**Midland Branch**

12.00

“Social Media for Professional Growth-Tips and best practices”

Dr David Hanak, Senior lecturer, Cranfield University

**27th October 2020**

**Aberdeen Branch**

18.00 – 19.30

“Recent updates to HOIS-RP-103, and discussion of relevant parts to practicing Corrosion Engineers” Susan Osbeck, ESR, and Neil Wilson, ENGTEQ.

**12th November 2020**

**London Branch**

17.30

Young Engineers Programme – Case study presentations

**24th November 2020**

**Aberdeen Branch**

18.00 – 19.30

Joint meeting with IOM3/MIS

*Body armour: why, how and what (from)?*

Prof. Deborah Carr, Defence and security accelerator DASA Scotland

A provocative presentation to get you thinking “out of the box”.

**27th November 2020**

**Midland Branch**

12.00

“Introduction to Mental Health -MHFA England, Mental Health Awareness Taster”

Russell Mott, Lead auditor and trainer, ATAS UK

Official building mental health in construction (BMH) tool box Zoom talk.

### ADDITIONAL DIARY DATES

**9-13th November 2020**

Fundamentals of Corrosion for Engineers Course

Presenter: Jane Lomas

Corrosion House, Northampton

**17 – 18th November 2020**

NACE European Corrosion management virtual conference

**IMechE courses at the Sheffield Training Centre**

**26th October 2020**

Painting Inspector, Level 2

CP Buried, Level 1

**23rd November 2020**

Painting Inspector, Level 1

Insulation Inspector, Level 2

**30th November 2020**

CP Buried, Level 1

**7th December 2020**

CP Buried, Level 2

**14th December 2020**

Painting Inspector, Level 2

Online Corrodere courses plus online assessments with practical workshops and practical assessments completed via Zoom

**24 – 25th November 2020**

ICorr Coating Inspector Level 1 & 2, Workshop & Assessment

**26th November 2020**

ICorr Coating Inspector Level 3 Mandatory Workshop (online, interactive)

**27th November 2020**

ICorr Coating Inspector Level 3 Theoretical Assessment

**15 - 16th December 2020**

ICorr Coating Inspector Level 1 & 2, Workshop & Assessment

**17th December 2020**

ICorr Coating Inspector Level 3 Mandatory Workshop (online, interactive)

**18th December 2020**

ICorr Coating Inspector Level 3 Theoretical Assessments

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