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I hope you are all enjoying the summer weather and trust that it will be possible for everyone to take a well-earned break at some point. The battle against corrosion never ends but it’s important that we all have the opportunity to recharge our batteries from time to time.

I was pleased to see such a great turn-out at the formal opening of the new Corrosion House on 6th June. The weather played its part, with a warm and sunny afternoon in Northampton allowing the attendees to gather in good spirits around the front door of the building for the official ribbon cutting ceremony. We were also delighted to recognise the tremendous contribution of two stalwarts of the Institute in the purchase of this, and the previous incarnation of Corrosion House, by naming the meeting room and the training room in their honour. To find out more you will need to read the report on the event in this issue!

One of the other highlights of the day was the formal signing of a new training provision agreement between ICorr and the Institution of Mechanical Engineers Argyll Ruane (IMechE AR). This has been over a year in the making and I would like to thank Sarah Vasey, David Mobbs, Brian Wyatt and John Fletcher for their unstinting efforts in bringing it to fruition. Revenue from training courses makes up a significant fraction of our income and we see the continued partnership with IMechE AR as key to achieving further growth in both existing and emerging markets.

On the subject of training, it was with regret that Council recently accepted the resignation of Chris Atkins as Chair of the Professional Development, Training and Certification (PDTC) committee. Over the past few years Chris has devoted a huge amount of time and effort to ensure that ICorr courses are fit-for-purpose and the correct governance is in place. I would like to put on record my sincere thanks for the great work he has done and extend a warm welcome to his successor, David Horrocks.

Our student numbers have exploded over the past couple of years, increasing to 213 at the last count. This is largely thanks to the efforts of former Young ICorr Chair Chris Bridge, who arranged visits to the Materials Science Department at the University of Oxford to sign up undergraduate students for free membership of the Institute. His successor Simon Bowcock is now rolling this out to other universities and we are looking for volunteers for these visits. If you can spare the time to visit your alma mater or local university to speak to students about the benefits of ICorr membership, please get in touch with him via the Northampton office.

The Institute continues to recognise excellence in corrosion science and engineering through our prestigious international awards and I am pleased to say that this year, for the first time, our two premier awards will be presented at the same event. This has come about due to a joint meeting between the 60th Corrosion Science Symposium and the annual Corrosion Engineering Division Working Day, which will be held in conjunction with Electrochem 2019 at the University of Strathclyde, on 26th-28th August. During the conference, Prof. Tetsuo Shoji will receive the 2019 U.R. Evans Award, while Dr Steve Paterson will be presented with the 2019 Paul McIntyre Award. I look forward to congratulating both of them in person for these significant achievements!

A resumé of their work is given later in this issue (editor).
From the Editor

I would also hope you are all enjoying the good weather, however as the President said, corrosion doesn’t stop. This is also the major maintenance painting season, but high temperatures and humidity are not the most suitable for blasting and painting activities, and I hope to cover this topic in the next issue of the magazine.

This month there are three articles on different topics in our industry. Brian Wyatt discusses the reliability of CP reference electrodes installed along a buried pipeline, and Bijan Kermani reviews the corrosion problems associated with the up-coming underground coal gasification process. Finally there is a case study highlighting a potential problem during hydrostatic pressure testing of a hydrocarbon storage tank.

Remember if you have any suggestions for future articles, or wish to submit a technical article, please contact me at brianpce@aol.com.

Brian Goldie, Consulting Editor

Opening of the new ICorr Building on 6th June 2019

It has been a long time since ICorr has had a permanent home of its own. After a long search for suitable premises in Northampton and 2 near misses, a suitable property was finally located by Trevor Osborne, who then supervised the purchase of 5 St Peter’s Gardens.

The new premises have been redesigned and fitted out to a high standard, to include modern office space for the office manager and staff, a conference room and a training floor with a flexible teaching layout, kitchen and breakout areas.

All the work involved in this process, from liaising with the local council, hiring an Architect and Contractors and overseeing the conversion work, has been personally handled by Trevor, without charging the Institute – a rare act of generosity in the modern world.

The office staff, Denise Aldous (Office Manager) ably assisted by Gwynneth and Sue, moved the office files, library and many ancillary items into the building and settled in the ground floor.

An ICATS training course has been successfully run in the new first floor training room and the presenter and attendees were impressed by the high standard of the facilities. The Trustees and the Council of the Institute have also held their first meeting in the bright meeting room on the second floor, and again were very pleased with the new facilities.

The official opening of the building took place on 6th June 2019 on a bright summer’s day, when the current President, Gareth Hinds, cut the ribbon with many ICorr members, Past Presidents and friends of the Institute in attendance.

Gwynneth, Sue and Denise with David Mobbs and Immediate Past President, Sarah Vasey.

Continues on page 6
Everyone then moved up to the meeting room, and Bill Cox explained that this was the second building that ICorr had owned. The first was organised by David Deacon, and the Trustees of ICorr thought it was fitting that the meeting room be named the Deacon room in recognition. Bill presented the name plate for the room to members of David Deacon’s family, who were present to accept the accolade.

The entire group then moved down to the first floor training room, where Sarah Vasey, the Immediate Past President, spoke about the long search to find the current home for ICorr and the enormous efforts made by Trevor Osborne to make it the reality we were all experiencing. In recognition of his selfless work, the Trustees had agreed that the training room would be named the Osborne room. Sarah then presented the name plate to a surprised and delighted Trevor.

The final ceremony of the day was the signing of a new agreement for training, between ICorr and IMechE. Chris Kirby was present for IMechE and Sarah and Gareth for ICorr.

Following the formal part of the proceedings, the guests continued to enjoy an excellent buffet, whilst Gareth gave a presentation on the bright future of the Institute, followed by time for people to meet up with old friends and enjoy the event.

At a time of perhaps greater than usual uncertainty about the future in the UK, the opening of the new building was a special occasion to recognise both the past and the new phase in the life of the Institute of Corrosion.

Jane Lomas
Corrosion Engineering Division (CED)

This year’s Paul McIntyre award is going to Steve Paterson, and he will be presented with this at the up-coming Electrochem 2019 Conference being held at Strathclyde University, Glasgow.

Steve Paterson obtained a B.Sc and Ph.D in metallurgy from Imperial College, London. His Ph.D thesis investigated the mechanical and microstructural properties of aluminium alloys during indirect extrusion. He joined Shell International, and over 34 years had an exciting journey in a variety of roles involving materials, corrosion, welding and integrity management. His experience covered the research, refining, chemical and oil & gas production sectors and he worked in the UK, Netherlands, Norway and Malaysia.

Since retiring from Shell in 2017, Steve has worked as an independent consultant and is currently a part-time lecturer at Robert Gordon University where he teaches materials & corrosion, and corrosion management. His involvement in academia includes his role as Chair of the Imperial College Materials Advisory Board, and he is an adviser to the Shell-Imperial AIMS centre which was set up to develop new insights into materials behaviour particularly surface interactions at the nano-scale. He also provides training in corrosion prediction and corrosion management for Shell, and he will soon start to deliver an industry course on Corrosion under Insulation.

He was a member of the Energy Institute Corrosion Management Committee from 2006 to 2014, including Chair, and during this time was directly involved in the development of the industry guideline publications for Corrosion Management and for External Corrosion Protection. His involvement with EEMUA (Engineering Equipment and Materials Users Association) since 2003 resulted in the continuing development of the subsea materials & corrosion control guidance publication (EEMUA 194 – now at Rev.4), and the delivery of the associated training course since its inception in 2008. He co-authored the EEMUA 218 publication for quality requirements for the manufacture and supply of duplex stainless steels, and subsequently provided input to the ISO 17781 standard for testing of duplex stainless steels.

During his time at Shell he was responsible for the development of graduate materials & corrosion engineers, and from 2006 to 2017 was involved in the mentoring of over 50 young engineers. He used this experience to help the Institute of Corrosion develop its C.Eng competence matrix in 2017.

He has been a regular attendee at Eurocorr conferences where he first met and got to know Paul McIntyre. From 2013 until 2017 Steve was the Chair of Working Party 13 of EFC for Oil & Gas and was responsible for their conference programme, which he tried to ensure was a good balance between academic and more practical papers. He has written 30+ technical papers or presentations and has been a regular contributor at conferences, seminars and industry meetings, including NACE, EFC (Eurocorr), SPE, Marine Corrosion Forum and Institute of Corrosion branch events. He maintains his interest in technology development through his position on the review panel for the Oil & Gas Innovation Centre (OGIC) in Aberdeen.

Visit the ICATS website
www.icats-training.org
As previously announced, this will be held on 26th-28th August 2019, as part of Electrochem 2019 at the University of Strathclyde (Prof. Sudipta Roy) and Glasgow (Dr Mark Symes).

Professor Tetsuo Shoji will receive the UR Evans award 2019 at this Symposium for his outstanding contributions in the broad aspects of corrosion science and engineering. His research field covers the Physics and Chemistry of Fracture, combining mechanics and chemistry that is necessary for the analysis of materials degradation and fracture mechanisms, as an extension of material strength and fracture mechanics. For example, one of the factors degrading the safety and reliability in structures and components is crack initiation and propagation under the influence of chemical environments, and its mechanistic understanding is of extreme importance. His work has been key in the development of better instrumentation and analysis, particularly in the:

- Development of a recrystallization-etch technique and a unique evaluation procedure for crack tip intense strain region, by which ductile fracture could be quantitatively analysed.
- The unique formulation of stress corrosion crack growth rate, based on a mechanistic understanding of crack growth under a mechano-chemical reaction at a crack tip. Thereby the first to establish a predictive capability of growth rate of stress corrosion cracking, taking into account both crack tip mechanics and chemistry, and;
- Establishment of a predictive model and a capable procedure for aging degradation evaluation of plant components in energy conversion systems such as fossil and nuclear power plants and plant life time prediction and management.

Also from his varied original work, he contributed to the setting up the Centre of Excellence for Physics and Chemistry of Fracture, focusing on mechano-chemical phenomena and its relevance to failure in the field of operating plants. He is one of the pioneering leaders in this research field and has published more than 500 journal papers covering atomic scale simulation of oxidation, hydrogen accelerated oxidation, mechanism-based alloy design, electrochemical materials characterization, mechanistic study of oxidation, non-destructive testing and evaluation and fracture mechanics and failure analysis.

Tetsuo Shoji served as a Professor of Tohoku University from 1986 until March 2018. He was honoured as a Professor Emeritus of Tohoku University in 2015. Currently, he is continuing his research work as a Senior Research Fellow of New Industry Creation Hatchery Center (NIChe) of Tohoku University. He is also a Distinguished Professor of the National Centre for Materials Service Safety, University of Science and Technology Beijing, USTB in China since 2013, and High-level Foreign Professor of Institute of Disaster Management and Reconstruction of Sichuan University since 2018.

Prof Shoji was a postdoctoral fellow working for Professor R.N. Parkins at the University of Newcastle upon Tyne, and a Visiting Professor at Massachusetts Institute of Technology. He was the principal investigator of various national and international programmes, such as the Centre of Excellence Programme on Physics and Chemistry of Fracture and Failure Prevention, the Co-Director both of CNRS LIA ELyT laboratory and the international Joint Laboratory of Tohoku University and USTB, and international cooperative research programme of PEACE and POLIM, working on mechanics and mechanisms of Environmentally Assisted Degradation such as SCC and Environmental Fatigue. He has received 20 national and nine international awards, including the NACE W.R. Whitney Award in 1998, the Lee Hsun Award in 2006, Chinese Academy of Science and the Great Medal from CEFRACOR, France in 2016. He was appointed by the Prime Minister as a Council Member of Science Council of Japan in 2011 for seven years and was elected as a Member of Science Council of Japan in 2018 for six years and also elected as a member of the Japan Engineering Academy.
Galloway Award 2018

The latest recipient is Mohamed Koronfel (Imperial College), for his work on “Understanding the reactivity of CoCrMo-implant wear particles”, published in Nature/Materials Degradation (doi:10.1038/s41529-018-0029-2)

The Galloway Award requires students to simply send a copy of a submitted or published paper from the previous 12 months, rather than a separate technical report. The student must be the primary author of the work and preferably first author.

CoCrMo alloys have been considered as an attractive material for orthopaedic implants due to their high wear and corrosion resistance. However, in practice, the release of millions of wear particles per patient annually led to high failure rates of CoCrMo Metal-on-Metal hip implants. These wear particles invoke an inflammatory response in the patient, where immune system cells (macrophages) are recruited to attack the wear particles. The inflammation comes with an associated severe pain that often leads to revision surgery and implant removal (failure). Due to the unexpectedly high failure rates, lawsuits were filed in both the UK and USA against the implants' manufacturers.

Furthermore, due to unknown long-term effect of these wear particles, clinical risks to patients may manifest even long after revision surgery. The macrophage cells, where wear particles were typically found in vivo, create a harsh acidic, oxidising environment which may lead to the release of potentially toxic and carcinogenic metal ions. A number of studies characterised the state of wear particles inside macrophages in periprosthetic tissue (accessible after implant removal during revision surgery). Although CoCrMo alloys are nominally an extremely stable material and contain very high levels of Cr (Co 60 % : Cr 30 % : Mo 7 %), the post-surgery wear particles were composed mainly of Cr and only trace amounts of Co. This high-level of Co dissolution is unexpected given the alloy’s stable Cr-rich passive film. Studies on periprosthetic tissue after implant failure provide little insight into the dissolution stages and exposure history imposed on wear particles in vivo. In order to understand the in vivo reactivity of wear particles, in situ monitoring of their chemical and physical changes in simulated biologically relevant conditions was carried out, using X-ray absorption spectroscopy and transmission X-ray microscopy at synchrotron-radiation facilities, which provide high chemical sensitivity and in situ measurement capabilities.

This work highlights the potential reaction mechanisms that would not have been evident from the required regulatory testing regimes. Additionally, the work demonstrates the potential of synchrotron-based approaches to provide dynamic chemical information on nanoscale systems under practical conditions.

Joe Nugent, 4th July 1927 to 26th June 2019

“Born on the 4th of July” – not many of us can claim that, and even fewer are buried on the same date, but that was Joe Nugent. Joe died on the 26th June, aged 91, having outlived beloved wife Patty by just a few months.

As a very green young lad back in the eighties, employed by Leights Paints to look after technical sales to the oil, gas and structural steel industries up in the North East, I was lucky to have come under the stewardship of Joe Nugent, irreverently known as Uncle Joe to us young pups at the sharp end.

Back then, Joe was manager in charge of Technical Service and based in Bolton, ably assisted by Rod Sandiford (another company uncle) and Bhiki Patel. As always with protective coating application on big projects, things could easily go wrong. Any delays caused massive pressure with the risk of liquidated damages, so if we local lads couldn’t find a solution, we used to send for the cavalry in the form of Joe and Technical Service from Bolton.

Joe had two great attributes. He not only unfailingly found out the root causes of exactly what had gone wrong, but he generated goodwill out of the disaster by providing a fast response along with practical solutions. This was always done with humour and positivity, so that Joe's arrival on site was something people welcomed. He took the heat out of a difficult situation and actually turned it into an advantage by finding solutions and providing great service, so we didn't lose customers.

When Joe and Rod were combined, they were unstoppable, with Rodney acting a bit like Dr Watson to Joe’s Holmes. I can honestly say I never saw them beaten, as they always found the technical reasons for failures as well as solutions. Sadly Rod, also another excellent technician, died a few years ago.

Joe gave me two invaluable pieces of advice, which I still teach my students when I’m lecturing today, as “Nugent’s Laws”. I remember these so well, as they are humorously true, and he always started with “Young Frost” as the precursor to any words of wisdom.

The first (this still applies for anyone in paint Technical Service):

“Always leave the car pointing out of the car park, Be ready for a quick getaway. I guarantee paint will make a fool out of you frequently during your career!”
The branch have secured continued commitments from all their existing 2018/2019 members and in addition have elected a new committee member, Mr. Jonathan Segynola (Corrosion Technical Authority of CNR).

At the AGM held on 28th May 2019, Stephen Tate and Nigel Owen, were elected Chair and Vice Chair respectively for the 2019/2020 session.

The successful May technical event was jointly organised between ICorr and NACE, and had 49 enthusiastic attendees from across industry and 3 very knowledgeable speakers.

Scott Maidman - Global Deployment Manager of Air Liquide, commenced proceedings with a detailed talk on the merits of Dry Ice Blast Cleaning, as an alternative method of surface preparation. This technique has been designed specifically for use in fabric maintenance in the Oil and Gas industry and similar applications, offering an alternative means of surface preparation and removal of coatings and corrosion. Further development of the equipment has allowed surface profiling through the addition of common abrasives to the dry ice flow. Its additional benefits include a reduced carbon footprint, less waste and post-blast clean up, when compared to other commonly used methods.

Graeme Kennedy - Manager Oil & Gas Downstream UK & Ireland for International Paint, continued with a complimentary talk on Cyclic Corrosion Testing on Surfaces that have been prepared by Dry Ice Blasting. International Paint collaborated with Dry Ice Global and NACE Aberdeen section to investigate the comparative performance of surface tolerant coatings systems when applied to corroded steel surfaces prepared by Dry Ice Blasting, with injected garnet abrasive. International Paint provided pre-rusted carbon steel panels which were blast cleaned and coated with two proprietary coatings systems and then allowed to cure prior to testing. These coated panels

Dick Frost (Leighs Paints’ past Managing Director: 2001-2010)

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Kennedy of International Paint, in an informative presentation entitled - Cyclic Corrosion Testing on Surfaces Prepared by Dry Ice Blasting.
Institute News

Continued from page 11

Out-going chair Dr Yunnan Gao presents Certificates of Appreciation to the event
Speakers - Simon Daly, Scott Maidman, and Graeme Kennedy.

were then exposed to ISO12944-9: 2018 (formerly ISO20340 Performance requirements for protective paint systems for offshore and related structures) cyclic corrosion testing, as used in NORSOK M501, Edition 6. The coated panels were all scribed to expose the metal surface and tested for 25 cycles /4200 hours /6 months of alternate UV/condensation, salt spray and freeze to -20°C. The presentation considered the performance of common surface tolerant coatings systems applied over this method of surface preparation, and assessed the corrosion creep from the scribe, and adhesion values, as an indication of performance in the field.

Simon Daly - Oil & Gas Segment Manager, Hempel A/S, rounded off a very informative evening with a final presentation entitled ‘Evaluating the Effect of Surface Preparation Standard on Zinc Rich Epoxy Primers’. The presentation focussed on work carried out over an 18 month period with a view to creating consistent reproducible test panels for use in the evaluation of protective coating systems for corrosive environments. Additionally he presented a draft evaluation methodology for combining coating’s application characteristics and long term performance. Simon explained that historically, zinc rich primers have been associated with use as a primary means of corrosion protection on offshore assets at the new construction stage. His presentation investigated the risks and benefits of adopting zinc rich epoxy technology for the far more demanding maintenance phase, by considering/comparing different zinc systems under a variety of sub optimal surface preparation conditions, and the impact upon performance, the effect of the number of coating layers and coating type on system tolerance to salt contamination, a suitable means of providing consistently prepared test panels to recognized standards, other than commonly applied SA 2.5, and a test methodology for ensuring consistent levels of salt contamination prior to application and evaluation of coating performance.

This most interesting series of presentations generated many questions and proposals for future testing programmes.

The branch have secured a continued agreement from the Robert Gordon University (RGU) for use of their main Lecture Theatre (N242), as its venue the 2019/2020 evening events free of charge, and an excellent programme has now been compiled, which will be featured on the Institute website and circulated to all branch sponsors and companion institutes.

Looking ahead, the branch will be hosting its annual full-day Corrosion Awareness (CAD) course on 27th August 2019, (via key sponsor Rosen UK, at the Palm Court hotel), comprising of a number of lectures / presentations focusing on microbiologically influenced corrosion (MIC) in pipeline systems. This year’s CAD programme will include talks by ROSEN specialists and other visiting speakers, on their MIC experiences from global operations covering - Sampling, Analysis, Monitoring of Pipelines for MIC damage, Chemical Mitigation / Cleaning Strategies and finally Inspection, Modelling and Monitoring approaches. Most certainly this event will provide a very comprehensive introduction, to this very significant and often troublesome area of Corrosion Control / Prevention.

Finally, It is with deep sadness that the Aberdeen committee have to report the loss of Alan Foxton, a past ICorr and TWI presenter, and Richard Woud, a valued and regular ICorr attendee, on the 9th and 10th July respectively. Our thoughts are with all their families, friends and colleagues.

As usual, full details of future branch events can be found on the diary page of the magazine and on the website, or by contacting: ICorrABZ@gmail.com

Midland Branch

Just to remind readers, on Thursday 26th Sept, the branch will be hosting a half day networking event for sustaining members, with a steam train ride, tour of the railway engine house and buffet lunch, at the Severn Valley Steam railway. The cost of attending for sustaining members is covered by the branch, please contact Bill Whittaker, bwhittaker@ cathodicengineering.co.uk, to reserve your place ASAP.

London Branch

The next meeting of the branch is a joint meeting with Society of Chemical Industry (SCI), being held at the SCI offices, 14/15 Belgrave Square, London, on 26 September at 17.30. The theme of the evening is “Offshore Energy and Telegraph Cables” and will be chaired by John O’Shea, Hon Life Fellow, ICorr.

Dr Fred Parrett, SCI London Group, will present the story of the first transatlantic telegraph cable, the story of how it happened and the personalities involved. The second presentation will be by Trevor Osborne, a Past President of ICorr, who will discuss the problems which occurred with the installation of offshore wind farm towers, and how, what should have been an easy transition from the early offshore oil and gas platforms, often was not.

Places are limited, so register your interest at http://bit.ly/Offshore_Energy, or email conferences@soci.org

The branch is still looking for a new home for the 19/20 evening meetings, and full details will be emailed to regular branch attendees, and posted on the Institute website once the venue is known.
Offshore Energy and Telegraph Cables
Thursday 26 September 2019, 17:30 for 18:00
SCI, 14/15 Belgrave Square, London, SW1X 8PS, UK

Organised by SCI’s London Group and the Institute of Corrosion – London Branch
The Evening Chair will be John T O’Shea, Hon ICorr Life Fellow

This evening event includes two presentations, followed by a networking reception at 19:30. Attendance to this event is free of charge, however places are limited. Please register today by visiting: [http://bit.ly/Offshore_Energy](http://bit.ly/Offshore_Energy)
The event is open to SCI, ICorr, IOM3, LMS, and TWI members and guests.

The Transatlantic Telegraph Cable
Dr Fred Parrett – SCI London Group Treasurer

The electric telegraph was first developed by Samuel F. B. Morse, in 1832, who soon developed Morse Code. Land based cables to use the telegraph soon followed, and within a decade, more than 20,000 miles of telegraph cable crisscrossed the USA and the UK. Trials of underwater cable were undertaken by Samuel Morse across New York Harbour in 1842 and Charles Wheatstone across Swansea Bay in 1844, and within a few years there were cables laid across the English Channel. The problems of laying a cable across the Atlantic was a greater challenge, not just the technical and logistical problems, but financing such a great undertaking. The presentation will cover the story of how it finally happened and the personalities involved.

From Oil and Gas to Windfarms – 50 years of Offshore Corrosion Control Experience
Trevor Osborne. Past President, Institute of Corrosion (ICorr)

For over 50 years corrosion engineers have dealt with offshore structures around the world. The recent decline in oil and gas markets, combined with a fresh upsurge towards renewable energy requirements, has led to interest in wind generation in the form of wind-farms. These consist of monopiles, transition pieces and substation fixed jackets which need to be protected to last their lifetime. The presentation will set out from early offshore structure design and construction for the oil and gas markets to the painful transition to wind energy. It considers the attendant problems that have occurred along the way and how what should have been an easy transformation, often times was not.

Book today! Free registration
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www.soci.org/events
Corrosion blamed for 2015 gas leak

A new independent report has revealed that microbial corrosion was the culprit behind a natural gas leak in South California, which released 109,000 metric tons of methane over a five-month period between 2015 and 2016. The root cause of the leak, which was in a 7-inch outer well casing, was corrosion due to groundwater microbes. According to the operator, the industry-leading safety enhancements and new regulations put in place after the leak, should prevent this type of incident from occurring again.

Industry News

John Fletcher receives Excellence and Achievement award from ASTM

John Fletcher, Standards Compliance Manager at Elcometer, has been presented with a Lifetime Excellence and Achievement Award from ASTM, in recognition of his services to the D01 Paint and Related Coatings, Materials and Applications committee.

A member of ASTM International since 2007, John was made Chairman for the D01 Committee in 2010, serving three consecutive two-year terms, after which he became Vice Chairman. He was then nominated as a Director on the ASTM International Board for a three year term, which finishes in December 2019. During his time at ASTM, John was also Chairman of D01 Sub-committee D01.23: Physical Properties of Applied Paint Films for 10 years, and a member of Committee E06 on Performance of Buildings.

John said that he was honoured to receive this award and that he had really enjoyed working with ASTM and will miss his regular meetings with D01 members, many of whom he would call friends. He joined ASTM after a lengthy period of preparing ballot responses for Elcometer's founder Ian Sellars, so was well steeped in the ASTM methodology before he started attending committee meetings.

John aims to continue to contribute electronically to committee work when he retires, but took this opportunity to thank his employer, Elcometer Limited, and the team at Elcometer Inc. and Elcometer Limited for their considerable support in his work with ASTM, and also like thank his fellow D01 members for their help and guidance as a D01 Committee Officer and to the staff of ASTM. John began working at Elcometer in 1982 and was responsible for their compliance with ISO 9001, Quality Management Systems and ISO 14001, Environmental Management Systems. He is a Fellow of the Institute of Corrosion, as well as being a former President and Trustee, a Chartered Scientist, and also a member of both SSPC and NACE.

STANDARDS NEWS

ISO

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

ISO 21809-3:2016/DAmd 1 Petroleum and natural gas industries — External coatings for buried or submerged pipelines used in pipeline transportation systems — Part 3: Field joint coatings — Amendment 1: Introduction of mesh-backed coating systems

ISO/FDIS 2808 Paints and varnishes — Determination of film thickness (Revision of 2007 standard)


ISO/DIS 11463 Corrosion of metals and alloys — Evaluation of pitting corrosion

ISO/FDIS 12944-5 Paints and varnishes — Corrosion protection of steel structures by protective paint systems — Part 5: Protective paint systems (Revision of 2018 standard)

ISO/FDIS 16900-1 Respiratory protective devices — Methods of test and test equipment — Part 1: Determination of inward leakage (Revision of 2014 standard)

ISO/FDIS 17872 Paints and varnishes — Guidelines for the introduction of scribe marks through coatings on metallic panels for corrosion testing (Revision of 2007 standard)
ISO/FDIS 21968 Non-magnetic metallic coatings on metallic and non-metallic basis materials — Measurement of coating thickness – Phase sensitive eddy-current method

New international standards published during the last two months.

ISO 9514 Paints and varnishes — Determination of the pot life of multicomponent coating systems — Preparation and conditioning of samples and guidelines for testing

ISO 11124-5 Preparation of steel substrates before application of paints and related products — Specifications for metallic blast-cleaning abrasives — Part 5: Cut steel wire


ISO 15540 Non-destructive testing — Eddy current testing — General principles

ISO 19345-1 Petroleum and natural gas industry — Pipeline transportation systems — Pipeline integrity management specification — Part 1: Full-life cycle integrity management for onshore pipeline

ISO 19345-2 Petroleum and natural gas industry — Pipeline transportation systems — Pipeline integrity management specification — Part 2: Full-life cycle integrity management for offshore pipeline

ISO 21809-11 Petroleum and natural gas industries — External coatings for buried or submerged pipelines used in pipeline transportation systems — Part 11: Coatings for in-field application, coating repairs and rehabilitation

Australia

Standards Australia (Sydney) has issued a new version of “Application Specifications for Coating Systems—Single-Coat Inorganic (Ethyl) Zinc Silicate—Solvent-Borne (AS 4848.1).” This is identical to the previous version of the standard (AS 2312), and includes three coating systems:

IZS1 — 75 microns for most atmospheric applications;
IZS4 — 125 microns for severe atmospheres; and
HR3 — 50 microns for high-temperature applications.

Previous errors and omissions have been corrected and the new standard information also includes all necessary

Innovative Products

New digital tool to help ship owners improve dry docking efficiency

AkzoNobel has introduced an ingenious new digital tool, DryDoQ Insights, to allow owners and operators of shipping fleets to better control their dry docking costs.

According to the company, the tool closely predicts the condition of a vessel’s underwater hull without the need for visual inspection. Using data analytics, it has a unique capacity to build a complete picture of the corrosion and fouling on the surface - helping to improve maintenance planning and increase efficiency. The new tool makes its predictions based on proprietary data enriched with multiple external data sources. It highlights specific areas for consideration, taking into account the specific vessel type, trading pattern and previous dry-docking events.

The technology has been launched as a minimal viable product to one of the world’s largest fleet operators, who will carry out testing and provide continuous feedback so that further developments and improvements can be made. The system will be simultaneously available to the wider market, concluded the company.

Spiralling demand prompts new stock facility for unique paint system

A unique one-coat system, Galvacoat, for painting galvanized steelwork is being made more widely available following significant growth in demand, according to Wedge Group Galvanizing Ltd., through a new stock-holding facility.

Galvacoat is a two-part polyurethane system specifically designed to deliver highly durable adhesion on galvanized steel – and has key advantages over alternative applications, according to Mark Endsleigh, Commercial Support manager, in that there is no need for any pre-treatment, and it can be used on site. It is compliant with all British Standard GT0 tests for adhesion on galvanized steel, can be applied by brush, roller or spray equipment and retains its original colour to within five per cent over 20 years, concluded the company.

Coating Consultancy appoints new Director

Corrtech Ltd, South Shields, has announced the appointment of Lee Wilson as Director of Technical Services. Lee is recognised as key figure within the corrosion control industry as well as being the author of the Paint Inspectors Field Guide. Lee is a Fellow of the UK institute of Corrosion, an ICorr level 3 Inspector, a NACE Corrosion specialist, and is NACE CIP Level 3 certified.

Lee commented that it was a great pleasure to join Corrtech, a rapidly expanding consultancy and becoming well established as specialists within corrosion control and corrosion mitigation projects, and is forward to the future with the Company.

Corrtech Ltd is a specialist painting and coating consultancy firm operating in the oil and gas, marine and renewable energy sectors, offering a wide range of services, and is currently working with IMechE and ICorr in delivering overseas training of the ICorr course syllabus.

For all the latest news, events and debates join us on LinkedIn
CORROSION EDUCATION: Theory and practice from the classroom to the field via on-line learning

Robert Lindsay, Stuart Lyon, Nicholas Stevens, Zee Shabbir, Corrosion & Protection Centre, Department of Materials, The University of Manchester, UK
Daniela Zander, Chair of Corrosion and Corrosion Protection, RWTH Aachen, Germany

A variety of educational approaches is required to deliver these different levels of corrosion knowledge and expertise. At the higher end, Universities are well-placed to act as corrosion education providers. Academics can teach the fundamentals of corrosion science (e.g. aqueous electrochemistry and materials engineering), as well as lead students in corrosion-based research activities; for an optimum student experience the latter is often best undertaken in collaboration with an industrial partner. There are a number of postgraduate corrosion programmes across the world, including the original (still going strong after more than 50 years), the MSc in Corrosion Control Engineering from the Corrosion and Protection Centre at the University of Manchester.

At undergraduate level, there is significantly less provision, with many engineering and materials science courses covering corrosion only briefly. While it is understandable that the fascinating properties of 2D-materials, or the power of jet engines, turn the heads of students at the age of 18, it is the responsibility of corrosion professionals to draw them into the equally rewarding field of minimizing the use of scarce resources, protecting the environment and extending asset lifetimes by the application of corrosion science, engineering and technology. If high-quality students are not enthused by the multi-disciplines of corrosion and the associated fundamental materials challenges (solve environmental cracking anyone?) at an early stage in their education, it will be a struggle to attract them afterwards. Significant exceptions include the established Corrosion Engineering program at the University of Akron, USA and the “Corrosion Engineering pathway” within the Materials Science and Engineering programme at the University of Manchester, UK.

Concerning more practical corrosion education, professional corrosion societies (e.g. Institute of Corrosion, NACE International, and European Federation of Corrosion, through its Working Party on Corrosion Education) play an important role both locally and globally. Not only do they focus on key practical topics, such as coating inspection and cathodic protection, importantly, they provide a certification route as a guarantee of technical and professional competence at various levels. Moreover, after sufficient experience gained on the job, there is a route for non-graduates to achieve professional accreditation and degree-level equivalence. Such formal accreditation ensures that standards are upheld and the workforce is skilled, both of which are key to avoiding early corrosion failures, maintaining company reputations, and minimising the overall costs of corrosion.

The corrosion education outlined above is largely targeted at individuals with an active technical interest, or a professional need, to understand corrosion. Moreover, the delivery mode is primarily classroom based, although online corrosion courses are now on the rise. One element that has not been covered so far are introductory courses, which can be useful for continuing professional development (CPD), as well as for inspiring newcomers into the corrosion profession. Residential short courses can satisfy these target audiences however, there is an activation barrier to registration and, in the current employment climate, limited time and money are also considerations. One way to address these issues, and to generate awareness of corrosion at all levels from school students, through the general public and technicians, to professionals, is to provide free point-of-access provision online through a “Massive Open Online Course” (MOOC). The Corrosion and Protection Centre at Manchester is putting the finishing touches to Protecting the World: Introducing Corrosion Science and Engineering, which goes live in September on the Coursera platform.
Results of an investigation into significant inaccuracies with Permanent Buried Reference Electrodes

Brian S Wyatt, Corrosion Control, UK

As part of an extensive upgrading of a cathodic protection system for an approximately 90km buried oil pipeline in the UK, some 50 permanent Cu/CuSO\(_4\) (sat) permanent reference electrodes were installed along the pipeline, by limited dig, water jetting techniques. The pipeline is subject to stray dc current interaction from a mainline electrified railway system, and also has some threat of ac corrosion from high voltage overhead transmission systems which parallel, and cross the pipeline.

Bare steel Coupons (1cm\(^2\)) were installed adjacent to each of these permanent reference electrodes, for both instant OFF or IR Free dc potential and dc and ac current density measurements. Both electrodes and coupons were installed adjacent to, and at pipe invert level (level with bottom of pipe). Due to the limited dig installation, the large, familiar, ceramic porous pot Cu/CuSO\(_4\) (sat) reference electrodes could not be accommodated.

In order to provide more rigour and flexibility in the testing regime, uPVC pipes were also installed at each location to enable portable electrodes or coupons to be introduced to pipe invert level between the fixed electrodes and coupons. Thus, approximately 15m to one side of the pipeline, were installed in a line with approximately 500mm between each item, a reference electrode, an open ended uPVC pipe and a coupon.

The permanent Cu/CuSO\(_4\) reference electrodes were from a reputable manufacturer and stated as having been developed for direct burial and had a micro porous tubular body and a solid matrix electrolyte preventing leaching of sulphates from the electrode; they had a claimed life of 25 years and stability of +/-5mV.

Within only a few months after installation, these electrodes were producing unexpected pipe/soil/electrode potential data. A full survey was undertaken to compare their electrode potentials with those of clean, calibrated, portable Cu/CuSO\(_4\) (sat) reference electrodes introduced down the uPVC tubes (within 500mm of the permanent electrodes at the same distance from the pipe and at the same depth as the permanent electrode). Many electrodes were presenting potentials >30mV from their theoretical potential, and some >100mV. Within months the greatest error was >200mV. At the last full assessment after some 16 weeks, the following errors (Table 1) were determined by measurement between the permanent electrodes and a clean calibrated Cu/CuSO\(_4\) portable electrode placed proximately to the permanent electrode:
Institute News

works for the CP systems and to pragmatically select accurate priorities were to progress with the extensive improvement time to retrieve any electrodes and examine them in detail. The porous tube electrodes, but it had not been possible at the locations that at some locations the sub surface water flows might be located below the water table in clay or silty clay; some were in drier chalk and marl soils. There was a suspicion that at some locations the sub surface water flows might be.

In North America (USA & Canada):

Corrpro Inc.
Electrochemical Devices Inc.
GMC Electrical Inc.
M C Miller Co. Inc.

In the UK:
Anglia Cathodic Protection Services Ltd (ACAPS)
Cathodic Protection Company Ltd
Corrpro Companies Europe Ltd
Silvion Ltd

Table 1: Errors of Permanent Electrodes, Measurements after 16 Weeks
All electrodes of common type Cu/CuSO4 (sat). “solid electrolyte”

<table>
<thead>
<tr>
<th>Location</th>
<th>Electrode Error mV</th>
<th>Location</th>
<th>Electrode Error mV</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP1</td>
<td>-29</td>
<td>TP50</td>
<td>-49</td>
</tr>
<tr>
<td>TP2</td>
<td>-67</td>
<td>TP53</td>
<td>-60</td>
</tr>
<tr>
<td>TP4</td>
<td>-63</td>
<td>TP6A</td>
<td>+29</td>
</tr>
<tr>
<td>TP6</td>
<td>-1</td>
<td>TP61</td>
<td>-61</td>
</tr>
<tr>
<td>TP7</td>
<td>-14</td>
<td>TP62</td>
<td>-52</td>
</tr>
<tr>
<td>TP9</td>
<td>-187</td>
<td>TP64</td>
<td>-53</td>
</tr>
<tr>
<td>TP10</td>
<td>-47</td>
<td>TP67</td>
<td>-39</td>
</tr>
<tr>
<td>TP12</td>
<td>-199</td>
<td>TP68</td>
<td>-41</td>
</tr>
<tr>
<td>TP12A</td>
<td>-153</td>
<td>TP70</td>
<td>-39</td>
</tr>
<tr>
<td>TP15</td>
<td>-6</td>
<td>TP72</td>
<td>-55</td>
</tr>
<tr>
<td>TP17</td>
<td>-66</td>
<td>TP73</td>
<td>+129</td>
</tr>
<tr>
<td>TP18</td>
<td>-224</td>
<td>TP74</td>
<td>-102</td>
</tr>
<tr>
<td>TP20</td>
<td>-84</td>
<td>TP76</td>
<td>-110</td>
</tr>
<tr>
<td>TP22</td>
<td>-78</td>
<td>TP78</td>
<td>-113</td>
</tr>
<tr>
<td>TP26</td>
<td>-67</td>
<td>TP81A</td>
<td>-46</td>
</tr>
<tr>
<td>TP28</td>
<td>-53</td>
<td>TP83</td>
<td>-57</td>
</tr>
<tr>
<td>TP30</td>
<td>-66</td>
<td>TP85B</td>
<td>-62</td>
</tr>
<tr>
<td>TP31</td>
<td>-20</td>
<td>TP89</td>
<td>-38</td>
</tr>
<tr>
<td>TP33</td>
<td>-66</td>
<td>TP92</td>
<td>-39</td>
</tr>
<tr>
<td>TP34</td>
<td>-195</td>
<td>TP94</td>
<td>-59</td>
</tr>
<tr>
<td>TP36</td>
<td>MISSED</td>
<td>TP97</td>
<td>-164</td>
</tr>
<tr>
<td>TP38</td>
<td>-51</td>
<td>TP101</td>
<td>-187</td>
</tr>
<tr>
<td>TP40</td>
<td>-126</td>
<td>TP102</td>
<td>-171</td>
</tr>
<tr>
<td>TP41</td>
<td>-51</td>
<td>TP104</td>
<td>-69</td>
</tr>
<tr>
<td>TP43</td>
<td>-22</td>
<td>TP106</td>
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<tr>
<td>TP45</td>
<td>-111</td>
<td>TP109</td>
<td>-97</td>
</tr>
<tr>
<td>TP45A</td>
<td>-13</td>
<td>TP111</td>
<td>-202</td>
</tr>
<tr>
<td>TP48</td>
<td>-191</td>
<td>TP113</td>
<td>-47</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TP115</td>
<td>-17</td>
</tr>
</tbody>
</table>

It is clear that these permanent electrodes cannot be classed as “reference electrodes”. It would be reasonable to expect competent reference electrodes to be accurate to +/- 5mV before installation and say +/- 10mV after installation.

The ground conditions along the pipeline were not prone to known contaminants, such as chlorides, that are known to contaminate Cu/CuSO4 reference electrodes. Most electrodes were located below the water table in clay or silty clay; some were in drier chalk and marl soils. There was a suspicion that at some locations the sub surface water flows might be sufficient to encourage accelerated electrolyte loss from within the porous tube electrodes, but it had not been possible at the time to retrieve any electrodes and examine them in detail. The priorities were to progress with the extensive improvement works for the CP systems and to pragmatically select accurate and reliable electrodes for the balance of the works.

The Trials

A programme was instigated to procure what, by reputation, were anticipated to be high quality reference electrodes from reputable manufacturers from the UK and USA, to assess their build quality and to install them at a single location on the same pipeline in a test site that replicated the previous installations. Reference electrodes were procured from:

- Anglia Cathodic Protection Services Ltd (ACAPS)
- Cathodic Protection Company Ltd
- Corrpro Companies Europe Ltd
- Silvion Ltd

In North America (USA & Canada):

- Corrpro Inc.
- Electrochemical Devices Inc.
- GMC Electrical Inc.
- M C Miller Co. Inc.

In total, 12 permanent reference electrodes of different types, and from different manufacturers, were tested. This included “old fashioned” ceramic porous pot electrodes with a high volume of Cu/CuSO4 electrolyte and quite large copper electrode area, to claimed “high technology” Cu/CuSO4 electrodes with ion exchange membranes, some claiming suitability for use in high chloride soils, and the full range of simple to complex designs in between. One Ag/AgCl/0.5M KCl electrode claimed to be designed for soil usage was also trialed.

All electrodes were installed at a single site, in the same manner to that which had been employed in the original enhancement programme, using a water jetting technique to produce a hole of the required dimensions to insert the electrode. The optimum hole size for installation at all the sites intended was only 80mm diameter, but at the test site there was a good local water supply and larger holes were produced for the larger diameter electrode assemblies. Electrodes were backfilled initially in a gyspum/bentonite backfill intended to keep them securely moist and in good contact with the soils; this approach had been taken during the initial deployment. It is known that some claim that such backfilling can cause small errors in junction potential, however it was assessed that any such errors were small compared with risks of electrodes drying out or having poor contact with the soil. The holes were then “hand tamped” full with compacted soil removed from the hole.

Later this test site was supplemented to allow field gradient measurements to be made proximate to the electrodes, to ensure that the apparent changes in electrode potential that were being measured were not influenced by the sometimes fluctuating field gradients. This was confirmed; the field gradient across a 1m distance, in the same direction as the 500mm spacing between the permanent and portable electrodes, was typically less than 5mV and the peak value measured was 10.4mV.

For the 12 electrodes tested, data obtained at 28 weeks after installation showed, that from the 8 manufacturers, one was in error by +190mV. The least accurate electrode was not from the originally selected manufacturer whose electrodes showed errors of approximately -200mv to +130mV as in Table 1 above. The electrode of the same type as originally deployed along the pipeline was in error by >60mV at the test site.

The 2 simple “old fashioned” porous pot electrodes were amongst the best performing electrodes, with one showing a maximum error of +25mV and the other +21mV. Both of these however would have presented dimensional problems for the optimum method of installation.

Only 5 of the 12 electrodes were accurate to +/- 20mV of their theoretical potential (which was assessed to include a maximum of 10mV soil potential gradient “error”).

The Ag/AgCl/0.5M KCl electrode which was included in the testing (converted to Cu/CuSO4 by a debateable 40mV conversion factor) was accurate throughout the trials to within 14mV (which was assessed to include a maximum of 10mV soil potential gradient “error”).

In parallel to the field testing, all of the electrodes which could not be viewed during construction were sectioned in order to visually assess the construction quality. The intention of this visual assessment was to attempt to make subjective assessments of the cable to electrode connection and its insulation from the
The simple porous pots were both assessed as reasonably well constructed and both performed relatively well.

The claimed high technology units from two manufacturers were assessed as reasonably well constructed; of these one performed particularly poorly and two performed reasonably well. One performed extremely well, better than its more expensive, claimed superior, sibling from the same manufacturer.

Three units of claimed high technology were assessed as particularly poorly constructed but all performed reasonably well; this may indicate that the subjective quality assessments from the sectioning of the cells were not as rigorous or appropriate as they were thought to be when the assessment was undertaken.

The full data sets, anonymised, are presented in Table 1.

Conclusions

The accuracy, or lack of accuracy, of permanent reference electrodes from a reputable manufacturer was only detected by the field provisions of unusually rigorous (at least in UK practice) testing provisions, which allowed “calibration” of these with calibrated electrodes, at the same depth, within 500mm of the permanent electrodes. The errors were very significant and continued after some 12 months of deployment. Many of “high quality” “premium producer” electrodes performed poorly in the subsequent field tests intended to select accurate and stable electrodes for future works. The errors were very significant in electrodes from several manufacturers.

The only Ag/AgCl/0.5M KCl electrode in the trial was selected for the ongoing installations on the basis of the good performance, small diameter, which suited the preferred “limited dig” water jetting installation procedure and would also be suitable for the small proportion of test sites where chlorides are high.

Acknowledgement

Thanks are expressed to the Client for permission to publish this work, with the intention of bringing to the attention of others in the pipeline cathodic protection community what are considered important errors arising from the use of poorly selected reference electrodes. I thank them also for them being prepared to undertake trials, at their cost, in order to quickly determine what electrodes would be best for future works. I also thank my colleagues who have assisted and provided technical support and guidance throughout all aspects of this complex project and undertaken much of the data collection for this small element of the overall work to improve the cathodic protection performance of these assets.

This work later informed the CEOCOR Commission 2 Working Group E in the preparation of their Pre-Standard ‘Reference electrodes for monitoring cathodic protection on buried pipelines’. This is available via the CEOCOR web site at https://ceocor.lu/biblio2

Reference Electrode Stability

![Figure 1: Permanent Reference Electrode Potential vs Calibrated Portable Electrode (500mm spacing at same depth) at same site. Weeks are not linear: “Week 16” is actually after 28 weeks of trial. The Ag/AgCl/0.5M KCl electrode is corrected to Cu/CuSO4 equivalent by 40mV. It is series 10.](image)

Visit the ICATS website
www.icats-training.org
As of today, new construction and revamping works for storage tanks follow the best trends in light of the current governing standards, recommend practices and relevant specifications etc. Even in the presence of these guidelines, degradation can still occur in storage tanks due to their configuration, design, construction and testing works. All these areas need to address the potential risks and appropriate mitigation plans. This article unveils the various failure events during hydrostatic testing of a storage tank that triggered MIC (microbiologically influenced corrosion) leading to pits with various morphologies, in spite of adequate corrosion inhibition.

Tanks and spheres are considered as an effective means for the storage of liquid chemicals, liquefied gases and slurries etc. The relatively fragile design (due to thin walls and high loadings), process parameters (flow rate in/out, fluid loads etc.) and height of the storage tanks, make them a unique entity in the processing facility. Also, they are more vulnerable to material damage mechanisms that are rarely encountered with other process equipment and piping. A key feature of a storage tank is the containment of high volume of fluids inside a relatively lower thickness enclosure than that for pressure vessels, piping and pipelines. Unlike pressure vessels, the majority of construction and repair works (such as welding, heat treatment, pressure testing, surface preparation and painting etc.) for storage tanks are performed at site instead of the controlled atmosphere of fabrication shops. These features (lower thickness, higher volume containment, site works etc.) also make storage tanks vulnerable to certain additional damage mechanisms due to wind loads, seismic impacts, neighbourhood factors etc.

In the last few decades, there have been numerous reported incidents of storage tank failures due to wind induced buckling [1]. There have also been several failures during the construction due to vacuum buckling caused by fast drainage rate after hydrostatic pressure testing. In order to combat this vacuum-induced buckling damage, operators have well established pressure testing, commissioning, operating procedures and technologies in place. Wind-induced buckling risks have been addressed in the governing standards, by taking into consideration wind loads and deploying wind girders on the shell plates of storage tanks.

Despite following best practices, failures can still occur during construction, testing, and even operational phases, due to corrosion and mechanical degradation which may lead to loss of containment. These failures can be triggered by non-conformances during design, construction, commissioning as well as during operation, e.g. by operating beyond IOW (Integrity operating windows).

The following case study discusses a failure caused by un-anticipated tilting of the concrete ring wall foundation of a storage tank during hydrostatic pressure testing phase due to settlement. This settlement in turn damaged the roof and bottom portions, causing a stoppage on the subsequent testing and commissioning activities. The delays with handling of the hydrostatic test water triggered MIC (due to stagnant water) and pitting at various locations inside storage tank.
Case History

A newly constructed A516 carbon steel API 620 (American Petroleum Institute) storage tank (height: 20 m, diameter: 16 m) for hexa-hydrocarbon product storage was released for hydrostatic pressure testing after construction. The tank was filled with water to check any settlement effects in the tank as well as the concrete foundation. After just a few hours of water filling, settlement effects were observed in the foundation, as well as the shell of the storage tank, leading to tilting of the ring wall foundation as well as the tank itself. Investigating the hydro test water, the settlement of the tank was found to be less severe, as the foundation had almost moved back to its original position. However, the considerable settlement under filled tank loads was still a concern. Various options were proposed such as to modify the foundation, by jack-up the entire tank followed by inspection, repair of foundation and bottom plates. Another option was to chip-off the concrete from the ring wall’s external surface in order to expose the re-bars, which would allow attachment of more reinforcing bars in order to circumferentially extend the civil foundations. Eventually, it was decided to extend the ring wall foundation around the whole circumference to mitigate against the chance of the foundation tilting again under filled tank load, as shown in Figure 1.

However, the project’s completion timeline was demanding the fast track repair of the foundation as well as the storage tank. Pitting on the bottom plate was inspected and repaired using weld build up and flush grinding. While pits on shell plates observed during inspection were declared as acceptable since they were within the tolerance provided by the governing standard [2]. After completion of mechanical and civil repair works, hydrostatic pressure testing was again carried out where no signs of settlement (beyond the tolerance limits in the standard) were observed. The hydrostatic test water was again drained to allow for surface preparation during which, considerable moisture was observed in and around the pits on the shell portions.

The moisture removal (drying) from these pits delayed the surface preparation as the grit blasting personnel had to sweep blast the surfaces multiple times, to remove this moisture. After the delays due to the settlement damage and surface preparation reworks, the storage tank was eventually declared as ready for coating with the specified system (epoxy primer, glass flake vinyl ester topcoat), and subsequent pre-commissioning works.

Results & Discussions

After several engineering reviews during the post-failure investigations, it was concluded that the uplift load of the tank (under the impact of water) caused considerable settlement of the ring wall foundation. Neglecting this load triggered the foundation settlement and caused tilting of the tank thereby posing secondary risks of material deterioration (corrosion and pitting) due to MIC. Corrosion inhibitor (sodium meta-bisulphite) had already been added to the hydrostatic test water in the quantities as prescribed by relevant project specifications. However the water had remained in the storage tank for more than a month due to the on-going failure investigations and engineering reviews. Evidently, storage of water inside the tank for an extended time triggered MIC, due to sulphate reducing bacteria (SRB) growth, which in turn caused both pitting and uniform corrosion, even in the presence of corrosion inhibitor [2].

After drainage of the test water, and before the repair of the foundation, the bottom plates, annular plates, shell plates were checked for thickness, while all weld seams were visually examined followed by dye penetrant testing. It was worth noting that the morphology and number of pits due to MIC on the bottom plate was different from those on the shell plate segments. These variations were attributed to the gravity effect which can result in deeper, step-wise pits at the bottom compared to the shallow and irregular pits on the shell portions [3]. The shallow pits also led to the track type cavities on the shell that can potentially retain moisture from hydro-test water as shown in Figure 2. It was also observed that pits on the bottom plate were scattered, with uniform depth, resulting in the remaining plate thickness being within the tolerance limit as per the standard’s criteria 4.4.7.4 [2]. The repair of these scattered pits, located away from the critical zone (more than 22cm from shell-bottom plate welds), was performed using a weld-build up and flush grinding.

The sum of diameters of all the pits in the various 8” segments of shell was found to be less than 2”. Also, the plate thicknesses on shell segments (excluding depth of pitting and the corrosion allowance) were found to be higher than the minimum required thickness as given in the governing standard. Hence, the shells were declared as mechanically acceptable in line with the standard’s criteria [3]. However, service conditions mandated blast cleaning of internal surfaces in line with NACE 1/SSPC – SP5 (Sa3) criteria. The entrapped moisture within the irregular cavities was not removed even during surface preparation (by blasting), which in turn prolonged the surface preparation process, and which could even jeopardize the integrity of subsequent coatings (by localised delamination) if not fully removed. Paint DFT measurements were carried out after the topcoat was fully cured, in accordance with SSPC – PA2, and found to be within the specified thickness (750-1000 um). Furthermore, considering the vulnerability of A516 carbon steel towards corrosion, a high voltage holiday detection test was performed.
Conclusions

In this case, where the initial damage triggered other failures (mechanical, corrosion), the presence of an optimized inspection and repair approach, which takes into account the possibility of MIC, and also incorporates frequent SRB testing, water analyses (for colour, odour) as well as a close watch on the time the stagnant water remains in the system, would have been advantageous. All these measures could have been adopted concurrently with on-going investigations. Some operators also recommend frequent analysis of samples of stored water at various intervals (during hydro-testing phase) to check for SRB (sulfate reducing bacteria) content, colour, odour and dissolved oxygen etc. [4].

Recommendations

Although pits on the shell plates were found to be mechanically acceptable due to their scattered location and shallow depth, they could be more vulnerable to crevice corrosion and subsequent coating delamination, as they can potentially retain moisture. Hydrostatic test water should not be allowed to remain in a system, or reused after more than a month, as has been specified by some operators. Though least discussed here, consideration of uplift loads is crucial towards the integrity of foundations and subsequent settlement effects. The development of MIC combating plans, incorporating SRB testing, water condition measurements (physical appearance, smell) is inevitable in such situations, and must incorporate even qualitative levels of the primary, secondary and residual risks [5, 6].

Reference literature


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Underground coal gasification: overview of corrosion/materials challenges

Bijan Kermani, KeyTech, UK

Corrosion and materials challenges facing the underground coal gasification (UCG) process are amongst the new topics in need of further scrutiny. In these systems, media corrosivity and diversity of conditions imposed on materials are excessive and require careful considerations to allow materials optimisation while offering economy and fitness for service.

Background

With the growing global energy demand and declining mineable coal reserves, alternative sources of energy are being increasingly sought. Amongst potential options and of growing interest are coal to liquid and underground coal gasification (UCG). The latter is considered a resurging technology that could provide a solution to the challenges. This has become an attractive option for energy generation in many countries with pilot plants in more than 60 locations. The process exploits the coal resources in-situ without the need for conventional mining operations, stockpiling, reclaiming or transportation\(^1,5\). While an UCG system can complement an energy mix strategy, there are byproducts including CO\(_2\) that do not contribute to carbon free energy and there is a need to combine the system with carbon capture storage (CCS). Approached in the right way and at the right scale, UCG–CCS stands to offer a solution to energy provision in areas rich in coal resources\(^6\). The UCG system is said to be able to recover ‘stranded’ coal seams and exploit deposits that are uneconomic to mine\(^5,6\).

UCG is an industrial process accessing the coal and recovering the product when transformed into a gas. The practice differs from surface-based gasification, in that the coal is not mined, rather the underground coal seams serve as the reactor vessel. There are several ways by which the UCG technology has been developed\(^6\). One way, dealt with in this article, is by drilling two or more adjacent boreholes into the coal seam (Figure 1). Oxidizing agents (air, O\(_2\) and steam) are injected down one borehole (injection wells) into a gasification chamber where the combustion reactions convert the coal into a gas. (Gasification involves subjecting carbonaceous materials to high temperatures, in the controlled presence of oxygen with only limited combustion to provide thermal energy to sustain the reaction). The UCG product gas (a type of synthetic gas) is then extracted and brought to the surface through another borehole (extraction wells). The connectivity between the injection and producer wells is made by special linking techniques\(^6\). In practice, a grid of wells is used which enables the location and direction of combustion to be closely controlled. The extracted gas is then cleaned of CO, CO\(_2\) and other byproducts and used as a fuel for heating, power generation, or the manufacturing of key liquid fuels, such as diesel, methanol or feedstock for various chemical products (i.e., hydrogen and ammonia)\(^4\).

The conditions in the UCG process are harsh and highly corrosive affecting the integrity of many materials which require careful attention in their choice and corrosion control measures, to allow safe and trouble free operations.

This article gives an overview of a number of elements in relation to UCG well completion, including, types of corrosion threat, typical well configurations, a corrosivity assessment for the use of carbon and low alloy steels (CLASs), and finally, gives a brief summary of suitable tubing materials. It is certainly not exhaustive and only attempts to set the scene for furthering future more focused studies.

Well Configurations

The two principal types of well shown in Figure 1 are as follows:

- **Injection Wells**
- **Extraction Wells**
- **Partial Combustion of Coal Seam**
- **Ground Level**
- **Water Table**
- **Overburden**
- **Coal Seam**
- **Synthetic Gas facility (eg power plant)**
- **CO\(_2\) Sequestration Facilities**
- **Injection Air/Steam**
- **Recovered Gasses**
- **Drain Water**
- **Rock fractures**
- **Injection Wells**

Figure 1. A schematic overview of UCG system.
Injection Wells: Air/Steam Injection

This type of well is intended to transport, and introduce oxidizing gases into the gasification chamber to convert the coal into a gas. It also allows the introduction of an ignition device, attached to coiled tubing, used to burn through the borehole liner and initiate the gasification process. The products of gasification flow to the extraction wells.

In injection wells, corrosion of CLASs can be excessive in the presence of steam and air unless the steam conditions are above the dew point/critical temperature where free water does not form.

Extraction Wells

UCG product gas is extracted in form of a synthetic gas. In these wells, drain water is also extracted from the coal seam and water may be injected for cooling purpose circulated back to the surface.

In extraction wells, again depending on the composition of the extracted gas and also depending on injected cooling water/drain water quality, CLASs may prove inadequate.

Operating Conditions

The operating conditions in UCG wells can be extreme with temperatures of combustion reaching 1400°C with more than 50 bar CO₂ and 10 bar H₂S in the Extraction Wells (EWs)⁶. In the Injection Wells (IWs), dissolved O₂ can be as high as 1ppm, and even the use of untreated surface water, depending on logistics, has been reported¹⁵. The ignition is typically achieved by coiled tubing following which the tubing is withdrawn for its protection. While such extreme temperatures only represent the combustion areas, the temperature diminishes to much lower values by the time it reaches EWs. Combustion temperatures can also be controlled by O₂/H₂O injection to lower the values. However, such temperature ranges are not a reflection of materials requirement, as the material may be exposed to such elevated conditions only temporarily at the gas extraction sites.

The product gases are primarily methane, hydrogen, CO, CO₂ and potentially H₂S, with varying ratios depending upon formation pressure, depth of coal seam and oxidant balance⁶.

System Corrosivity

The corrosion process generally falls into two broad categories of wet (aqueous) and dry. The latter occurs mainly in the combustion sites and the former in both IWs and EWs, and the subject dealt with here. Knowledge of corrosion processes involved in handling UCG process fluids and gasses is of paramount importance in the materials optimisation strategy to enable an economic and fit for service choice. Factors affecting such strategy include operating conditions, associated water chemistry and produced gasses, in combination with other production parameters.

Worth noting is that the knowledge of corrosion and materials for UCG wells is limited, as operating conditions are project specific depending on the combustion type. These conditions are neither universal nor holistic. With the advent of additional project specific data, a more tailor-made strategy can be developed to include pertinent information. Having said that, apart from the combustion gases, some of the operating parameters in EWs can be broadly analogous to those in upstream hydrocarbon production⁷. Nevertheless, it should be noted that materials which work well in petroleum wells, may not be suitable for all UCG wells.

In any methodical approach to materials optimisation, there are several elements that need careful consideration including evaluation of potential metal loss corrosion and environmental cracking⁸. The first step is to establish feasibility of CLAS as the most attractive material option and its fitness for service. This involves carrying out system corrosivity assessments through predicting CLAS metal loss corrosion patterns. However, there is no field proven corrosion prediction model specifically in relation to UCG systems that takes account of all operating scenarios. Therefore, the UCG industry has adopted petroleum industry corrosion modelling for CO₂ corrosion⁹ for and for O₂ corrosion¹⁰ taking account of relevant correction factors. These models are limited in terms of partial pressure of acid gases and operating temperatures prevailing in the EWs, and O₂ content in the IWs. The presence of residual O₂ in the EWs poses an additional challenge in that its effect on CO₂ corrosion is not complementary and rather unknown. In addition, there is no conclusive corrosion prediction model that takes account of H₂S on CO₂ corrosion fully applicable to UCG systems. Nevertheless, when applicable these models have been, and can be, used to provide an indication of potential corrosion.

### Table 1

<table>
<thead>
<tr>
<th>String</th>
<th>Corrosion Threats</th>
<th>Corrosion Risk</th>
<th>Materials Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface/Intermediate Casing</td>
<td>Potentially None; exposed to formation and/or treated packer fluids or cement</td>
<td>None; exposed to treated packer fluid</td>
<td>Low</td>
</tr>
<tr>
<td>Production casing</td>
<td>Potentially None; exposed to treated packer fluids</td>
<td>None; treated packer fluid</td>
<td>Low</td>
</tr>
<tr>
<td>Production casing/tubing</td>
<td>High Temperature Corrosion and/or CO₂/HS Corrosion; exposed to hot extracted gas</td>
<td>CO₂/HS corrosion; extracted gas</td>
<td>Low to High; subject to production conditions</td>
</tr>
<tr>
<td>Slotted Liner</td>
<td>Potentially None; exposed to treated packer fluid</td>
<td>O₂ Corrosion; potentially untreated water</td>
<td>Low to High; subject to water quality</td>
</tr>
<tr>
<td>Drain Water tubing/Water Cooling Tubing</td>
<td>Potentially None; exposed to treated packer fluid</td>
<td>O₂ Corrosion; potentially untreated water</td>
<td>Low to High; subject to water quality</td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>String</th>
<th>Corrosion Threats</th>
<th>Corrosion Risk</th>
<th>Materials Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface/Intermediate Casing</td>
<td>Potentially None; exposed to formation and/or treated packer fluids or cement</td>
<td>None; exposed to treated packer fluid</td>
<td>Low</td>
</tr>
<tr>
<td>Production casing</td>
<td>Potentially None; exposed to treated packer fluid</td>
<td>O₂ Corrosion; potentially untreated water/steam/O₂</td>
<td>Low to High; subject to injected steam/water quality &amp; O₂ content</td>
</tr>
<tr>
<td>Production casing/liner</td>
<td>High Temperature Corrosion/Oxidation; coal Seam</td>
<td>High Temperature Corrosion/Oxidation; O₂ corrosion</td>
<td>Low to High; subject to ignition temperature</td>
</tr>
<tr>
<td>Slotted Liner (in combustion site when used)</td>
<td>Potentially None; exposed to treated packer fluids</td>
<td>Potentially None; exposed to non-corrosive media</td>
<td>Low</td>
</tr>
<tr>
<td>Coiled Tubing for ignition (when used)</td>
<td>Potentially None; exposed to treated packer fluids</td>
<td>Potentially None; exposed to non-corrosive media</td>
<td>Low</td>
</tr>
</tbody>
</table>

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In carrying out this first step of feasibility for the use of CLAS, it should be noted that:

i. In the presence of high levels of chloride in the EWs, and under the in-situ pH and prevailing conditions, formation of a protective layer is likely, and the influence of H₂S in reducing CO₂ corrosion may be feasible.

ii. While a maximum temperature as high as 1400°C has been reported, this is believed to represent the combustion zones and not totally a reflection of the requirement for the materials to withstand such conditions permanently. However, the material may be exposed to such elevated conditions temporarily at the gas extraction sites. A major corrosion threat close to the EWs and also in the combustion zones, is that of high temperature oxidation in the presence of other corrosive agents, and a point of consideration in materials optimisation.

iii. There is normally no oxygen contamination during extraction, although, its presence, or the presence of oxidizing agents, may influence production tubing option for the EWs.

iv. Other considerations for EWs include the presence of elemental sulphur and organic acids both of which need to be considered in any system corrosivity assessment.

The second major step of corrosivity assessment in materials optimisation is that in relation to the resistant to corrosion cracking in the presence of H₂S. This applies to all components of both well types if the prevailing conditions are beyond the limits of ISO 15156, wherein there is a requirement for sour service grades steel.

**Completion Materials Options**

Well construction materials including casing, tubing and cement, need to be capable of enduring the elevated temperatures, pressures and system corrosivity caused by the injected fluids and extracted gases. The likelihood of potential corrosion threats are outlined in Tables 1 and 2 for EWs and IWs, respectively, and briefly are as follows:

Extraction Wells; Principal types of aqueous corrosion threat include CO₂ and H₂S corrosion, and when exposed to elevated temperature conditions, high temperature corrosion. The associated water cooling tubing may be exposed to water containing O₂ and drain water tubing may contain H₂S, CO₂ and O₂ in which case this combination of respective corrosion threats require careful consideration.

Injection Wells; O₂ corrosion is the primary corrosion threat, and where applicable high temperature oxidation (dry corrosion) for both well types may also be a threat.

Apart from the above, selection of a cement appropriate for the process conditions (pressure, temperature and type of gas, particularly CO₂) and also gas tight couplings, are subjects to be addressed at the design stage.

Bearing in mind potential high partial pressures of H₂S and CO₂ in the EWs, the operating temperatures and high corrosion rate of CLAs, the choice of fluid flow-wetted parts may be limited to corrosion resistant alloys (CRAs). Typical material choices are summarised in Table 1.

The operating conditions can be very corrosive and a demonstration of unsuitability of CLAS for the application in fluid flow-wetted parts of drain water/water cooling tubing in the EWs, and air/steam tubing in the IWs. Typical material choices for IWs are summarised in Table 2.

All proposed materials in Tables 1 and 2 are tentative and subject to confirmation of grade, media and conditions and also whole life costing.

It should be noted that unless fully covered by a uniform layer of cement, external casings may undergo corrosion by the geological formation, in which case cathodic protection of surface casing may prove beneficial. Other threat types including dry corrosion, erosion and microbial corrosion may be likely, although not addressed here, and again topics needing consideration.

**Summary and Conclusions**

The following conclusions can be drawn based on this brief overview:

- UCG is potentially an important coal technology of the future, and a substitute for deep mining coal for power generation to complement energy mix if combined with CCS systems.
- UCG operations consist of a series of IWs and EWs drilled into a coal seam. The operating conditions for both wells are highly complex exposing the tubing to different types of corrosive media on both the outside and inside, hence affecting the choice of tubing metallurgy.
- Leaving aside dry corrosion, CO₂ and H₂S corrosion in the EWs and O₂ corrosion in the IWs are the principal types of corrosion threat potentially experienced in UCG systems. High temperature corrosion/oxidation is also a threat in combustion areas. In addition, for the EWs, solid erosion is a likely possibility.
- Corrosion mitigation and materials optimisation are challenges facing UCG systems as economy and fitness for service play significant roles. The operating conditions in the majority of EWs, and water quality in IWs are highly corrosive which render CLAS unsuitable. There is, therefore, a need to consider the use of alternative materials including CRAs.
- While not addressed here, in combustion zones, the use of heat- and corrosion-resistant alloy is necessary depending on operating conditions and duration of exposure.

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2. Z Mavuso, Underground coal gasification can provide solutions to energy challenges, Engineering News, 2017
8. B Kermani and A Morshed, The original article was published in Corrosion, Volume 59, p 659-683, 2003
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BRANCH DATES

27th August 2019
Aberdeen Branch, Corrosion Awareness Day
Venue: Palm Court Hotel

3rd September 2019
Aberdeen Branch, Industrial Visit
Venue: NCIMB laboratories, Bucksburn, Aberdeen, AB21 9YA

24th September 2019
Aberdeen Branch, joint meeting with TWI
Venue: Robert Gordon University
Stress Crack Corrosion
Speakers: Daniel Sandana and Neil Gallon, Rosen UK

26th September 2019
London Branch, joint meeting with SCI
18.00 - 21.00
Venue: SCI HQ, 14 Belgrave Square, London, SW1X 8PS
Offshore Energy and Telegraph Cables
Trevor Osborne (ICorr) and Fred Parrett (SCI)

10th October 2019
London Branch
Venue: to be confirmed

29th October 2019
Aberdeen Branch
Venue: Robert Gordon University
Growing ICorr membership, and Reservoir Management
Gareth Hinds (ICorr President) and Matt Streets (Rawwater)

31st October 2019
Midland Branch
Technical afternoon and ICorr AGM
Details to follow

26th November 2019
Aberdeen Branch, joint meeting with IOM3
Venue: Robert Gordon University
Application of Bismuth Based Alloys to Address Oilfield Challenges
Paul Carragher (BiSN), Lance Underwood (BiSN) and Angus MacLeod (BP)

ADDITIONAL DIARY DATES

19th August 2019
Cathodic Protection Buried (ISO 15257) – Level 2 Technician
IMechE Argyll Ruane, Sheffield

2nd September 2019
Cathodic Protection Concrete (ISO 15257) – Level 2 Technician
IMechE Argyll Ruane, Sheffield

9th September 2019
Cathodic Protection Buried (ISO 15257) – Level 2 Technician
IMechE Argyll Ruane, Sheffield

9th – 13th September 2019
EUROCORR 2019
Seville, Spain
Contact: http://www.eurocorr.org

23rd September 2019
Cathodic Protection Buried (ISO 15257) – Level 3 Technician
IMechE Argyll Ruane, Sheffield

28th October 2019
Cathodic Protection Buried (ISO 15257) – Level 2 Technician
IMechE Argyll Ruane, Sheffield

11th November 2019
Cathodic Protection Buried (ISO 15257) – Level 3 Technician
IMechE Argyll Ruane, Sheffield

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