

Subsurface Corrosion Spotlighted at Workshop

Corrosion remains a major challenge to maintaining the integrity of infrastructure in oil and gas fields, particularly at the subsurface. A recent SPE Applied Technology Workshop in Abu Dhabi, UAE called "Subsurface Corrosion Risks and Challenges" highlighted critical aspects of subsurface corrosion control, including selection of corrosion-protection methods, improving drilling practices to minimize corrosion, and assessing downhole corrosion-monitoring techniques.

The welcome address by Qasem al-Kayoumi of Zadco highlighted the importance of organizations working together to identify critical subsurface corrosion challenges, share and agree on best practices, and identify the best existing downhole corrosion-mitigation technologies. To understand the technical areas where additional focus is required, networks must be formed between the operators, well engineers, and service providers. Al-Kayoumi said that Zadco has gained valuable subsurface experience by creating a seamless co-operative relationship with other operators. Zadco has also sponsored projects for downhole corrosion-modeling programs.

Materials for Oil and Gas Production

The first technical session of the workshop highlighted materials used in oil and gas production. Keynote speaker Bijan Kermani of KeyTech opened by stating that hydrocarbons will continue to be the world's principal energy source in the foreseeable future. The expected growth in energy demand will spur increases in production, which will become more multiphase in nature and contain higher percentages of harsh components such as hydrogen sulfide (H_2S) and carbon dioxide (CO_2). These acid gases in high water-

cut production systems present major corrosion concerns.

Therefore, material selection must become more specific to mitigate corrosion, and the impact of corrosion with regards to health, safety, and the environment; capital expenditure; and operational expenditure must receive continued serious consideration. Kermani said that materials selection must be coupled with 'near-realistic' corrosion modeling and prediction for optimum integrity assurance.

Zadco's Obadah Al-Sawadi next discussed the principles of corrosion modeling and prediction as they relate to materials selection. He stated that any useful model should be able to accurately predict corrosion rates as operating conditions change and account for actual tubing conditions rather than predict the phenomena at only one set of design conditions. A successful modeling program should also clearly define target corrosion rates to assess whether carbon steel or a corrosion-resistant alloy (CRA) should be employed. Finally Al-Sawadi highlighted several continuing challenges for accurate modeling programs, including obtaining accurate field data, the large number of variables involved and their relevance, and changes in the operating regime.

The appropriate use of CRAs was presented by Hojin Choi of Saudi Aramco. Choi first summarized corrosion tendencies in sweet (low H_2S concentration) wells, stating that in vertical wells corrosion is typically experienced in the top subsurface section, while in horizontal wells flow-induced corrosion is a major concern. The main corrosion mechanism for the inner diameter of production tubing is flow-induced corrosion, while at the outer diameter (OD), galvanic and/or microbial corrosion are predominant. If the cementing operation is done correctly such that

the cement is completely intact, then the OD of casing should not corrode.

Choi described the criteria used to choose materials based on the corrosivity of the production fluid, stating that fluid media containing <100 ppm H_2S can be considered sweet, while media containing ≥ 100 ppm H_2S with a H_2S/CO_2 ratio of >0.4 can be considered highly sour. He stressed that the definition of sour based solely on H_2S concentration can be misleading and further review for a given asset is required.

Choi broadly summarized the suitable materials for construction as follows:

- Sweet service, vertical and horizontal wells: 13-Chrome
- Sour system, vertical: carbon steel
- Sour system, horizontal: alloy 28
- Mildly sour completions, both vertical and horizontal wells: alloy 28

Daniel Loulergue of S&L Consulting next reviewed the use of standards and life cycle cost (LCC) analysis in materials selection. He stated that corrosion should be viewed as a challenge, rather than a risk, that can be managed through the proper use of a materials-selection tool kit. This kit should incorporate standards from organizations such as the National Association of Corrosion Engineers and the International Organization for Standardization.

Loulergue stated that efficient use of these tool kits should result in fewer corrosion failures, which begs the questions of whether existing tools are inadequate, ignored, or both. He said that the industry has been unable thus far to construct mechanistic, theory-based models for corrosion prediction because of the large number of complicating variables present in real-world systems. A process that combines metal-loss measurement, corrosion mitigation, LCC analysis, and

risk assessment is expected to provide a more realistic approach.

Subsurface Corrosion Protection

The second session addressed practical methods for subsurface corrosion protection. Session keynote speaker Paul Hammond of Baker Petrolite explained that subsurface corrosion is caused by several factors including the presence of acid gases and bacteria, under-deposit attack, acid treatment of wells, erosion problems, and galvanic corrosion cells resulting from a mismatched selection of metallurgy.

To adequately safeguard a system, one needs to capture and manage system parameters such as pressure, temperature, fluid composition, and stability/compatibility of downhole materials at various locations. Hammond said that improved downhole access is important to capture this data, but remains challenging.

Depending on the system, several mitigation options are available, including the selection of carbon steel and chemical treatment, the use of clad steel or chrome steel, or implementing linings and coatings. Remaining challenges to subsurface corrosion protection include extending the operational envelop of carbon steel by corrosion inhibition, producing coatings that can withstand chemical attack and mechanical damage, and applying inhibitors reliably in unmanned/remote locations.

George Winning of Intertek/Capcis next reviewed the selection process for corrosion inhibitors. The inhibitor-selection process is affected by deployment decisions, such as annular treatment, squeezes, or batch treatment. Common corrosion inhibitor performance tests include screening/bubble tests, dynamic tests, high-shear stress testing, and high-pressure performance tests. Several extended tests are also available, including weld corrosion, corrosion under scale, extreme shear testing, and galvanic testing—particularly in clad or multiple metallurgy wells. Compatibility tests between corrosion inhibitors and other chemicals in the system should also be conducted.

Steve Wroe of CTS discussed cathodic protection (CP) of casing, first explaining that corrosion of the external sur-

face of the well casing occurs due to the occurrence of electrochemical cells all along the length of the casing. These cells arise due to differences in oxygen levels, different soil strata, temperature variations, and locations with poor cementing jobs. Casing corrosion from these parameters tends to be most severe near the ground surface and in aquifers containing corrosive waters.

In designing a CP system, one must know how much current should be applied to adequately protect the casing, which can be estimated by E-log tests, corrosion-protection evaluation tool logs, and computer modeling. Wroe said that E-log measurements are usually informative but sometimes limited since current density is plotted on a logarithmic scale, meaning that current must be recorded in a range of several orders of magnitude to yield a sensible curve. Drawbacks to CP include limits on protection depth and interference between wells and across isolating joints.

Gokul Radhakrishnan of Maxtube addressed the benefits of nonmetallic coatings on tubing and flowlines in waterflooding operations. These benefits include the ability to achieve targeted water-injection rates consistently and without interruption and delivering clean water free of corrosion by-products to eliminate plugging and souring effects. He recommended several material options based on application: stand alone glass-reinforced epoxy (GRE) for fresh water, GRE-lined carbon steel for downhole tubing, and fusion-bonded epoxy-lined or polyethylene-lined carbon steel flowlines.

At least one attendee expressed the opinion that although some remarkable progress has been made in applying nonmetallics, further R&D must be done to ensure that nonmetallic coatings will not transfer a corrosion problem to another location in the processing plant.

At the end of this session, presenters fielded questions from the audience. Hammond responded to a question on how to best handle elemental sulfur in a system. He said that although sulfur deposition is a major concern, there are chemical means to prevent this deposition. He said that sulfur deposi-

tion is most often the result of polysulfide decomposition, although another attendee pointed out that elemental sulfur may also be produced from oxygen ingress and reaction with H₂S. The corrosion rate of steel in the presence of wet elemental sulfur may reach 1,000 mil (thousandth of an inch) per year.

On the question of whether corrosion inhibitors can be used to protect casing, Winning said that a standard package is available that can be filled into the annulus to protect the internal casing wall.

Drilling Challenges to Corrosion

This session addressed corrosion's impact on drilling activities and stimulated discussion on establishing efficient mitigation procedures. Session keynote speaker Eddie Stevenson of Shell first asked if corrosion is inevitable when one considers that 75% of drillpipe losses are due to corrosion. He also asked if the industry fully understands where corrosion risks lie, and stated that as we move into deeper, hotter, and harsher drilling environments, we should have a clearer understanding of what is happening to our drilling metal downhole.

Saleh Al-Mutairi of Saudi Aramco then addressed some of his organization's experiences in protecting well materials during acidizing jobs. An appropriate acidizing job requires a comprehensive knowledge of the type of tubular, temperature, and contact time. Compatibility testing should be carried out prior to the acid job using representative metal coupons.

Aramco has a well-established acidizing procedure that ensures that mixing of acid is done properly, particularly taking into account the compatibility of the mixture. During the acid job, it is important to ensure that applicable quality-assurance and control policies are being followed. The system must be adequately protected during flowback, as the acidizing fluid can remove the passive film, but Al-Mutairi said that appropriate design and planning for this consequence is the only way to minimize corrosion problems.

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