



Materials & Corrosion Technologies for Aging Infrastructure



E²G Leadership and Expertise in Materials & Corrosion Services:

- **Effects of Operations on Damage Mechanisms**
- **Specialized Corrosion Reviews**
- **Inspection, Repair & Damage Mitigation Guidelines**
- **Materials Selection**
- **Failure Investigations**
- **VCEDamage Mechanism Software**
- **RBI and FFS Assessments**

Owners Choose E²G Because Experience Counts

A key ingredient in both Risk-Based Inspection (RBI) and Fitness-For-Service (FFS) is an understanding of damage mechanisms, and the latest technology to address damage. The Equity Engineering Group (E²G) pioneered the development of RBI and FFS, and maintains a full-time staff of materials experts who are dedicated to the Materials & Corrosion field. We have the expertise and practical experience to help you develop the tools to increase the safety, reliability and, as a direct result, the profitability of your plant.

Years of experience

Our Materials & Corrosion engineers all have hands-on working experience with owner-users and industry service companies. With a combined 200+ years of experience, there aren't many corrosion problems we haven't encountered.

Practical advice

Because we have hands-on refinery experience, we understand the changing dynamics of a plant's operating environment and the pressures you face. We know that your concern is for safety, reliability, and optimizing your plant's operating conditions and not needlessly inspecting, replacing or shutting it down. Unlike most consultants, we'll help you make practical, experienced-based decisions.

Team approach

E²G's specialized experience in many fields enables us to apply a team approach to finding solutions to both your common and complex corrosion problems. Our Materials & Corrosion engineering expertise is complemented by RBI experts as well as mechanical engineering experts whose approach uses advanced techniques performed by stress analysis. We can help you better understand the relationship between process conditions and equipment damage, uncover vulnerable areas, and provide options to mitigate the risk.

Active industry leadership

E²G is active in API and NACE industry consensus group standards and recommended practice development. We were the principal developers of the landmark API RP 571, *Damage Mechanisms Affecting Fixed Equipment in the Refining Industry*, and we teach the official API 571 course on damage mechanisms. We've managed programs for API in the development of RBI (580/581) and FFS (579), and are rewriting ASME Section VIII, Division 2. We continue to put significant effort and funding into uncovering future materials technologies that will benefit our clients.



Vacuum Tower Eductor Corrosion

MPC membership

E²G's membership in the Materials Properties Council (MPC) gives us access to their state-of-the-art technology for evaluating materials behavior for long service times at high temperatures, as well as materials behavior in hydrogen service. It also gives us access to the pre-eminent repository of materials properties information in the world.

Cutting-edge client servicing

Because of our long-term involvement with these industry programs, E²G's Materials & Corrosion service provides the link between developing technologies and our clients' multifaceted materials, corrosion and inspection problems. We helped write the standards, so we know how to use these technologies to their full potential. And because we've worked in refinery environments, we know you need practical recommendations in a short time frame. Our goal is to keep your plant reliable and safe, yet not provide overly conservative recommendations that drive up your maintenance costs.

Corrosion Reviews Designed to Fit Your Needs

E²G offers various levels of corrosion reviews, either associated with RBI or FFS, or as stand-alone reviews. The levels increase in the complexity of detail and time required to perform them. Each has its own cost-benefit ratio, and E²G will help guide you in determining which type of review is most appropriate for your needs. While most oil companies and other vendors may have one or two knowledgeable experts who can perform these types of reviews, E²G has a team of experts who work together and review the final product on most projects.

Types of Corrosion Reviews

■ PFD level

- **Materials/corrosion reviews as part of RBI projects** - Selecting the applicable damage mechanisms, estimating corrosion rates and susceptibilities for SCC and other cracking mechanisms for fixed equipment and piping systems. Focuses on primary mechanisms and first order effects.
- **Materials Operating Envelopes (MOEs)** - Determining limits and boundaries of operating parameters, such as feed contaminants, temperatures, pH, water wash rates, stream velocities, etc. Defines corrosion control activities and focuses on stream sampling, analysis, corrosion probes and other monitoring activities. Includes parameters that can be controlled and those that cannot, but should be monitored for trending. MOEs are most effectively performed after RBI has been implemented - they may also be done during implementation. Another variant is key process reliability parameters.
- **Specialty items** - Focusing on HF acid alkylation (best practice operating and inspection guidelines and benchmarking), crude corrosivity screening for crudes and determining the correct alloy upgrades, monitoring requirements, etc.

■ P&ID and circuit level

- **More detailed materials, corrosion and inspection data reviews** - Determining ideal common corrosion circuit boundaries, and assigning damage mechanisms, corrosion rates and susceptibilities. These reviews are typically performed on a node-to-node basis similar to hazards analysis.
- **Advanced corrosion reviews looking for secondary effects** - Often performed in conjunction with a group of experienced process consultants that E²G has retained as part of the team to examine process opportunities.

■ Inspection Iso and TML level review

- **Review of each inspection Iso circuit** - Assessing the appropriateness of the selection of Thickness Monitoring Locations (TMLs), including numbers and locations, and the right types of inspection methods. Can help optimize the number of TMLs as well as statistically analyze the data.

Corrosion Reviews vary for each study and customer, but generally use databases, charts and tables to summarize information rather than extensive prose that gets filed away. As part of these Corrosion Reviews, E²G can overlay PFDs or other electronic drawings with damage mechanism information - materials, corrosion rates, susceptibilities and more - all in color coding. We can also customize our *VCEDamage Mechanisms*[™] software by including these drawings.

We started them (MOEs) because we had an incident that could have been prevented if an operating limit had been in place. So, we contracted with Equity to do MOEs for 12 units. We liked it so much, we've contracted an additional 10 units.

West Coast Refinery Maintenance Manager

E²G Assessments Improve Your Bottom Line

Evaluating Crudes - High technology & quick response adds value to a capital improvement plan

A refinery client planning major capital expenditures had to quickly decide between three major crude slates. E²G provided the expertise to decide which crude slate was optimal from a capital investment plus future corrosion-related maintenance and lost production cost point of view. E²G had already performed a Risk-Based Inspection study and a Materials Operating Envelope for the crude unit. Thus, data was immediately available to quickly evaluate the corrosivity of each crude type against the constraints of the metallurgy currently in place, as well as the upgrades that were planned. The client was provided with an analysis within two weeks that helped this major East Coast refinery formulate its final capital project plan.

Meanwhile, the same client wanted to assess the feasibility of temporarily running higher naphthenic acid crudes (opportunity crudes). E²G devised an additive injection scheme plus inspection and monitoring plan to detect accelerated corrosion. As a result of this "cold-eye review" of their plan, changes were suggested that would help the refinery safely achieve its goals to take advantage of higher margins while assuring reliable and safe operations.

HTHA - Advanced technology prevents 18 month shutdown

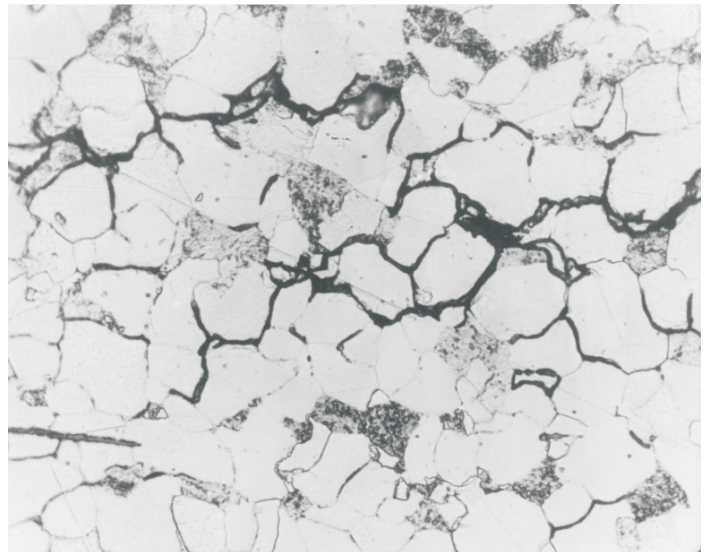
A client found significant HTHA damage with AUBT inspection during a shutdown of a clad C-0.5Mo reactor on a head, where cladding had disbanded and blistered. The client already had a new reactor on order, but the lead times for heavy wall reactors meant they needed to run for another 18 months.

Using the latest technology developed by MPC as part of the API 941 technical basis project and the MPC Moly-Hy Joint Industry Program, E²G was able to estimate the future progression of HTHA damage and predict where the damage would be, given a derate of the operating temperature. A subsequent inspection after six months confirmed that damage was continuing to progress through the wall, and that the resulting damage found was slightly greater than predicted, but within what was determined as safe. In this case, the client chose to refractory line the part of the vessel that was damaged to avoid having to run at derated conditions. However, the use of this advanced technology allowed them to operate the vessel where "conventional" practice would have resulted in a critical reactor being unavailable for 18 months at a huge lost opportunity cost.

E²G has also applied this technology on a proactive basis. This not only allows better predictions of expected damage, but also enables our clients to optimize inspections by focusing on the most critical equipment and advising on when sampling with the Buckeye II Sampler™ may be warranted.



Buckeye Sample



Micrograph Showing Decarb and Fissuring – HTHA

E²G Offers a Full Range of Materials & Corrosion Experience

E²G can help owner-users manage problems with corrosion, create safe operating environments and control risk. Here's what our experienced team of Materials & Corrosion engineers can do for your plant:

- Assess equipment damage, conduct failure analysis and repair programs
- Review and develop corrosion monitoring and/or management programs through our Materials Operating Envelope (MOE) approach
- Help you pinpoint damage mechanisms and potential areas of risk with our *VCEDamage* Mechanisms software
- Conduct materials, corrosion and inspection training courses for operations, maintenance, engineering and inspection personnel
- Develop specifications for heavy wall reactors, vessels and piping systems
- Select materials for grass roots, expansion, revamp and replacement projects
- Troubleshoot metallurgical and materials-related fabrication programs
- Develop proactive inspection programs
- Conduct reviews of inspection group performance
- Develop metallurgical/corrosion/materials safety and reliability programs

Owners Depend on Us for the Right Answers

For Aging Equipment

- Corrosion Reviews - various levels
- Assistance in understanding effects of crude slate changes
- Materials Operating Envelopes (MOEs)
- High Temperature Remaining Life Assessment - creep testing lab and HTHA sample analysis through MPC
- HF acid unit process and damage reviews
- Environmental cracking, including wet H₂S cracking advice for inspection
- Failure Analysis (forensic and root cause)
- Turnaround scope reduction reviews
- Welding training, supervision, and difficult repairs
- Inspection reviews and benchmarking evaluation for Mechanical Integrity compliance, and Best Practices for reliability (also software)
- Fire damage assessment
- Physical sample removal (Buckeye II Sampler™) and Metallurgical and Mechanical Testing



For New Equipment

- Materials suitability reviews
- Materials selection and specifications
- Fabricator qualification and non-process quality-control
- Damage mechanism identification and inspection planning

Equity Engineering is the recognized leader on aging infrastructure service and support for the oil refining and petrochemical industries. E²G experts help improve your plant's profitability by supplying state-of-the-art products and services that ensure equipment operational availability, control inspection costs and avoid costly shutdowns.

5.1.2.2 - Amine Stress Corrosion Cracking

Description of Damage

- Amine cracking is a common term applied to the cracking of steels under the combined action of tensile stress and corrosion in aqueous alkanolamine systems used to remove/absorb H₂S and/or CO₂ and their mixtures from various gas and liquid hydrocarbon streams.
- Amine cracking is a form of alkaline stress corrosion cracking.
- It is most often found at or adjacent to non-PWHT'd carbon steel weldments or in highly cold worked parts.
- Amine cracking should not be confused with several other types of SCC that can occur in amine environments which are further described in 5.1.2.3 and 5.1.2.5.

Affected Materials

- Carbon steel and low alloy steels.

VCEDamage Mechanisms™ software

With a technical basis in API RP 571 and WRC 489, this software tool is a quick reference guide for identifying the damage mechanisms that can cause costly equipment failure. The Solver Tab (above) enables you to navigate through units to identify potential damage mechanisms, which are then eliminated as choices are made on the pull-down lists. For a free demo version, visit the E²G website.

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