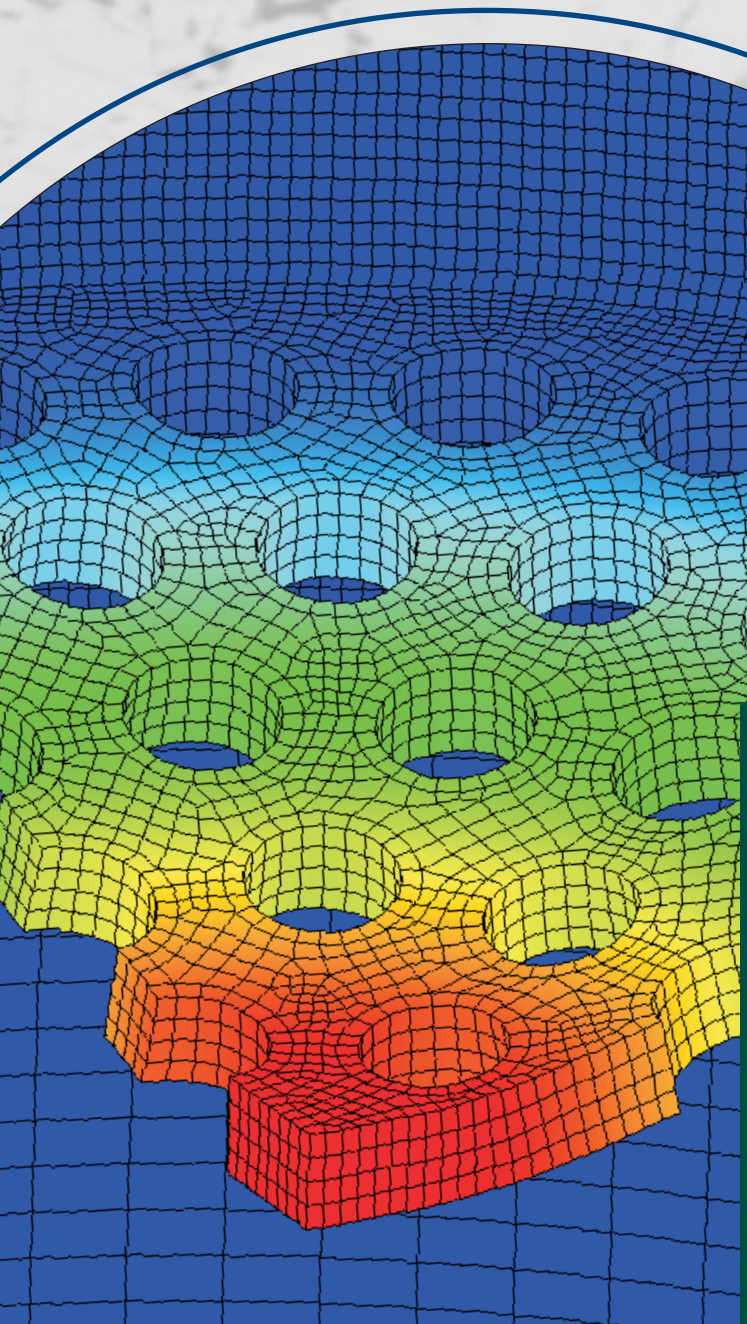
The Equity Engineering Group, Inc.

Advanced Methodologies for Remaining Life Assessments of Elevated Temperature Equipment



E^2G Leadership in Elevated Temperature Testing & Analysis:

- **Creep**
- **High Temperature Hydrogen Attack**
- **Metallurgical Embrittlement**
- **Advanced Stress Analysis**
- **Piping, Vessels & Other At-Risk Components**

E^2G: Focused on Optimizing Equipment Lifecycles at High Temperatures

High and normal operating temperatures, near or in the creep range, can degrade metallurgical properties and produce damage not seen at lower temperatures. The design codes for components in this temperature range only provide the basic requirements for the design, but actual component behavior is strongly dependent on the existing operating conditions and service environment.

Both under-utilization of equipment and equipment failure create high losses in production and revenue. The challenge for owner-users is to:

- Prevent unplanned shutdowns and failures
- Accurately predict remaining life
- Prevent unnecessary repairs and replacements
- Increase equipment availability and extend life
- Assess the mechanical and financial impact of operational changes

The Equity Engineering Group (E^2G) has in-depth experience in evaluating the suitability for continued operation of components operating in the Elevated Temperature range subject to a variety of damage mechanisms. Our membership and support of joint industry programs sponsored by the Materials Properties Council (MPC) Project Omega for creep damage evaluation and MolyHy for assessment of High Temperature Hydrogen Attack (HTHA) gives us special expertise in state-of-the-art technologies for equipment assessment.

E^2G's close working relationship with MPC, the worldwide authority for developing high temperature material models and properties, provides us access to extensive materials property information, and insight into innovative analytic methodologies. We can help you mitigate and manage the damage mechanisms that most often cause costly failure: creep, high temperature hydrogen attack, metallurgical embrittlment, and thermal stresses/fatigue.

MPC Project Omega: A Validated and Published Approach

E^2G is partnering with MPC to provide Omega testing and assessment services to non-sponsors of the joint industry program. We are also working with MPC on further improving and updating the materials properties for API 530.

MPC's Project Omega methodology can be used to accurately determine the remaining life of aging equipment not only by providing materials properties that are the best in the industry, but also through a procedure for conducting creep strain rate tests from the assessment day forward, thereby avoiding the need for a precise past pressure and temperature operating history. The methodology has been validated through experience and is published in API 579. Most of the major integrated oil companies are using this technology with great success.

One of its chief benefits is that the MPC Project Omega method is not a “black box” approach. The material models and properties utilized have received a rigorous peer review by the international community as well as industry committees involved in the development of Fitness-For-Service (FFS) standards.

API 579 suggests that a practitioner should be able to repeat the analysis from the documentation without consulting an individual originally involved in the FFS assessment. To accomplish this goal, E^2G has incorporated the MPC Project Omega method into our proprietary *VCE*Sage™ software. The assessment methodology includes all the required calculation steps, and material properties are clearly documented.

At the end of the day, owner-operators are responsible for what happens at the plant. If there's a reliability failure or event, will an FFS assessment based on a “black box” approach stand up to scrutiny by corporate management and jurisdiction?

Practical Advice for a Complicated Problem: A Phased Approach to Address Client Needs

E^2G's "phased" approach saves time and money by giving you the ability to stop applying technology as soon as the essential need is satisfied.

Phase 1 -- Preliminary calculations based on previous industry inspections and nominal operating conditions

Phase 2 -- More sophisticated stress analysis and better understanding of the materials involved; possibly some chemical analysis

Phase 3 -- Creep testing through one of the most respected labs in the country

Phase 4 -- Remaining life calculations

This working process assures that you won't get caught in a consulting quagmire of doing unnecessary work that yields marginal value. Our goal is to give you practical advice.

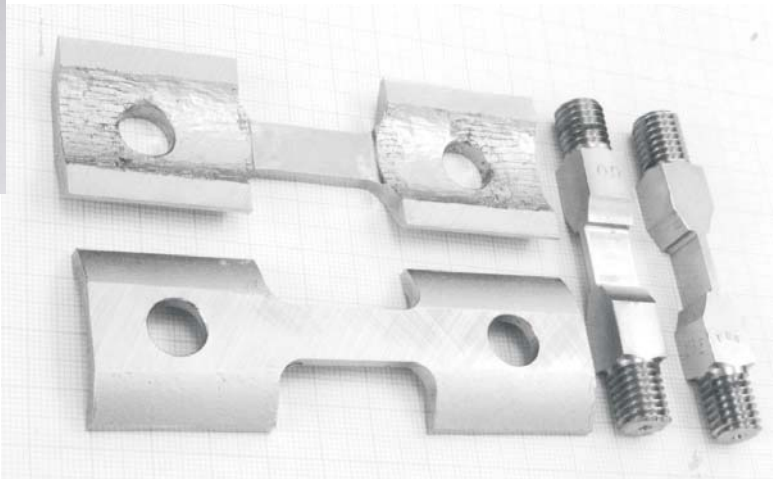
E^2G's engineers have all worked for major refineries and chemical companies, both in plants and central engineering groups. We understand the changing dynamics of a plant's operating environment and the pressures you face. Unlike most consultants, we will:

- Give you practical advice on how to run, repair, replace and do inspection monitoring of equipment
- Help you make practical decisions
- Give you all the numbers you need to make a decision
- Tell you exactly where the data comes from
- Go beyond analytic results to help you understand the numbers
- Provide the information you need to make financial decisions
- Help you order the right material in the planning stage

We know your concern is for safety, reliability and optimizing your plant's operating condition for profitability and not needlessly inspecting, replacing or shutting it down.

The Buckeye Sample

Creep Test Specimens



Expert Analysis: Put Our Experience to Work for You

E²G Principal Engineers David Osage and Gerrit Buchheim are internationally recognized high temperature experts:

- Drafted creep life assessment rules for Part 10 in API 579
- Authored Appendix F of API 579 published in 2000
- Active members of MPC Project Omega since its inception in 1984
- Created *VCE*Sage™ remaining life assessment module
- Active members of MPC MolyHy program

We pride ourselves on knowing the various ways in which high temperatures can impact your equipment and the interactions between mechanical, metallurgical, and environmental causes of high temperature damage mechanisms:

Creep

E²G uses the MPC Project Omega approach to identify vulnerable equipment long before inspectors can find advanced damage. We have applied this method to many fired heater tube assessments and have found that, in most cases, the predicted life is much longer than using standard industry guidelines such as API 530. The Omega method enables us to optimize heater throughput and tube life based on the accuracy of our assessments.

We use our proprietary *VCE*Sage™ software program to perform remaining life calculations. The heater tube creep module in our *VCE*Sage program contains both the API 530 and the API 579 Omega equations, materials data, and also considers tube wall thinning.

We have also applied the Omega approach and properties to other equipment operating in the creep regime with similar results (hot wall reactors, piping, valves, etc. See section "Beyond Heater Tubes")

High Temperature Hydrogen Attack

HTHA, particularly of C-0.5Mo steels, is a continuing industry challenge in high temperature/hydrogen environments. This issue is relevant now that many refineries are converting existing equipment as part of low sulfur fuels projects.

E²G engineers have been involved with API 941 for over 35 years, and we are members of the MPC JIP Moly-Hy, which has developed innovative technology to better characterize incipient damage and assistance with remaining life/FFS issues. We can help your facility identify potential HTHA issues with Risk-Based Inspection (RBI) methods, and then with inspection and assessment planning. We can also help you manage replacement versus maintenance decisions.

E²G's new Buckeye II Sampler™ cuts small samples without the need for weld repair. Samples are analyzed for methane content and voids.

E²G is the only engineering consulting company in the MPC Moly-Hy Joint Industry Program.

Metallurgical

There are number of changes that occur with certain alloys due to high temperature exposure:

- Sigma Phase Embrittlement of austenitic stainless steel
- Carbide Precipitation in many alloys
- 885°F(430°C) Embrittlement in ferritic stainless steel
- Temper Embrittlement of 2.25Cr alloys
- Reheat Cracking of 1.25Cr steels

These changes can be subtle, but can lead to big failures. Our materials experience can guide you as to when, where and how to look for these changes.

Beyond Heater Tubes: Help with Other At-Risk Components

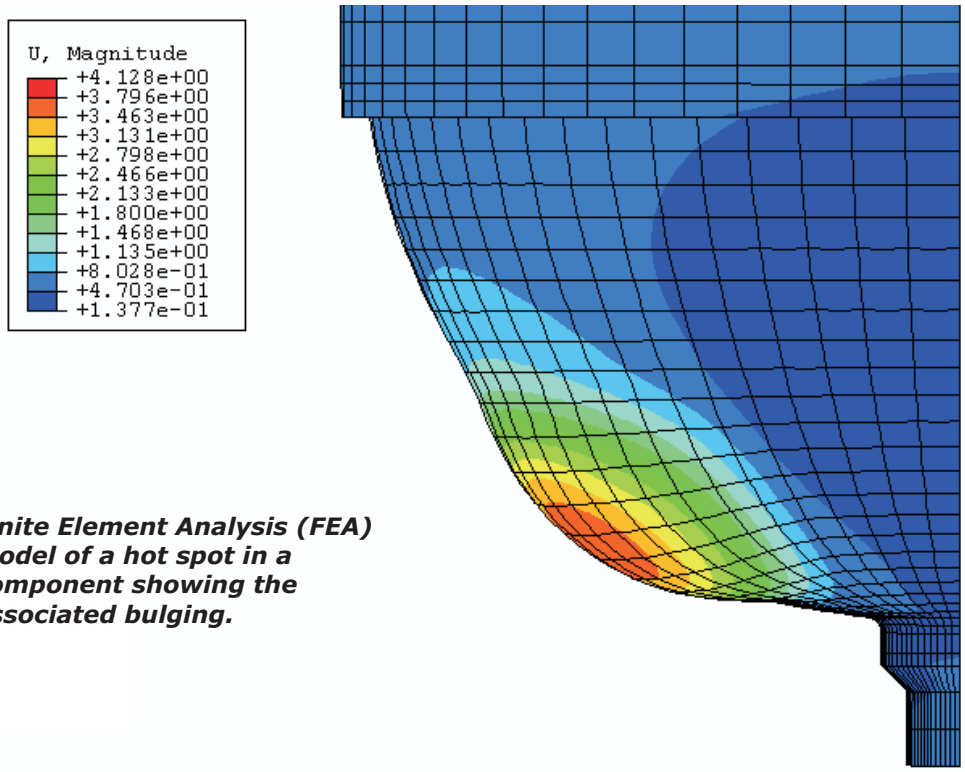
E²G has done hundreds of heater tube assessments, using *VCE*Sage™ software plus the API 530 design code for heaters and the API 579 FFS code. However, many components require more sophisticated analysis, including vessels, piping, and other heater components.

E²G performs finite element stress analysis to simulate temperature and structural response of complex components and loading conditions. We are one of the few firms to commonly employ advanced stress analysis techniques in conjunction with the MPC material models (that is, advanced non-linear inelastic stress analysis combined with an understanding of metallurgical properties) to simulate high temperature response and characterize creep damage.

This multifaceted approach can be beneficial in assessing high temperature damage in the following:

- Process heaters (coke heaters, cat reformers, steam/ammonia reformer heaters)
- Heater components (tube sheets, hangers, ducts, headers)
- Hot piping and valves
- FCCU reactor and regenerator components
- Reactor health/remaining life
- Thermal diffusion calculations for start-up and shutdown; safe envelopes
- PWHT simulations to advise on difficult applications
- Hot-tap analysis

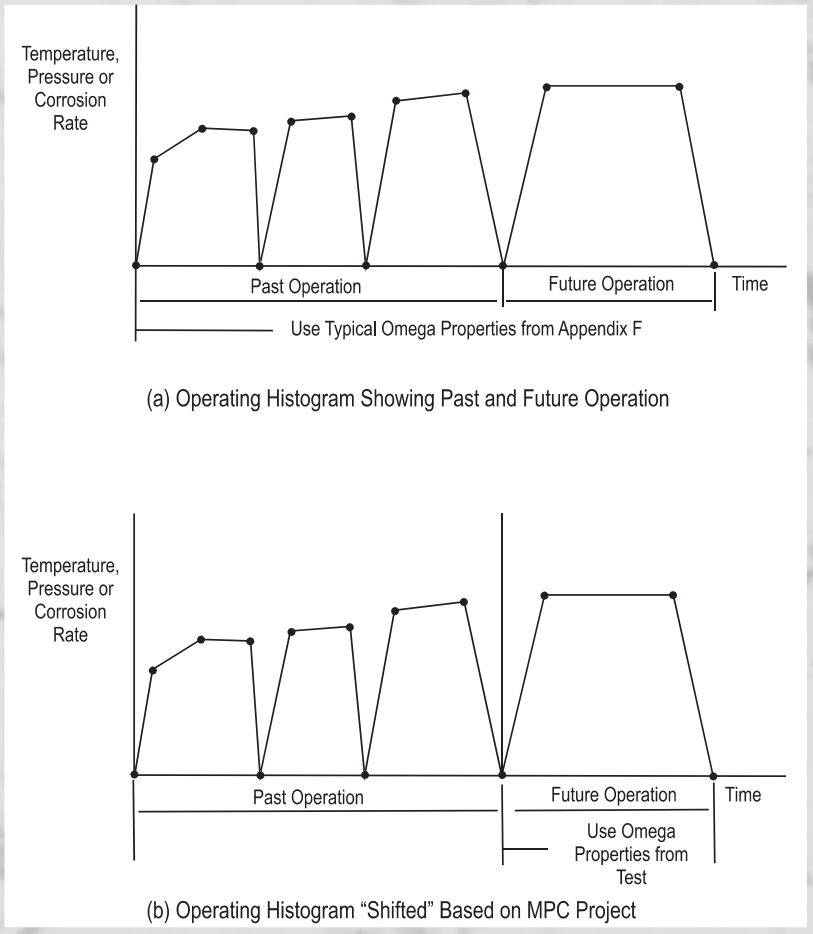
E²G performs these state-of-the-art assessments quickly, which helps you make informed decisions that impact the bottom line.



Finite Element Analysis (FEA) model of a hot spot in a component showing the associated bulging.

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

Shifting the Operating History
Based on MPC (Materials Properties Council)
Project Omega Testing *



* From API 579, which E²G authored

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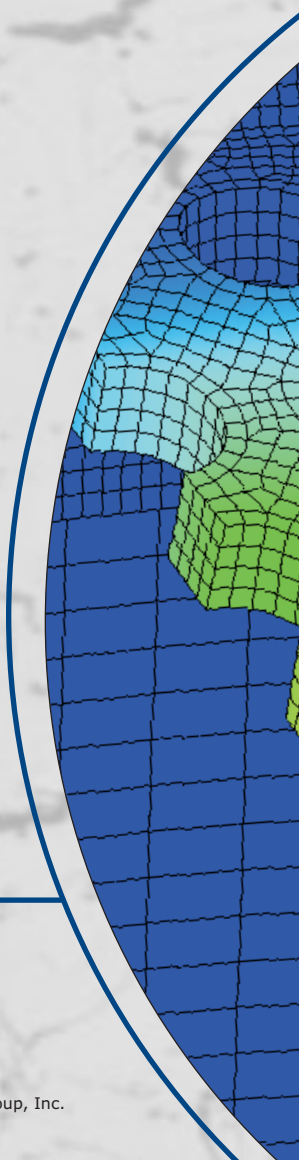

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