The Latest on Damage Mechanisms in the Petrochemical Industry — How to Identify and Monitor Them Effectively

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Introduction

Efforts by the petrochemical industry to maintain or increase production levels using aging infrastructure, in a climate of increased scrutiny by regulators, have created a need to re-evaluate the methods of inspecting and maintaining fixed equipment assets. An understanding of the damage mechanisms that might affect various operating units within a petrochemical refinery or plant is key to maintaining the integrity and reliability of that fixed equipment, including pressure vessels, heat exchangers, and process piping.

As the petrochemical industry moves to update equipment maintenance programs, there is an opportunity to implement structural changes in monitoring and maintenance strategies. For example, refineries typically rely on fixed condition monitoring locations (CMLs) to assess the operational integrity of process piping within a unit. These CMLs are inspected at fixed intervals, determined by the class of the process fluid they contain. A systematic reorganization of inspection circuits to group process piping by damage mechanism, composition, operating parameters, and location can assist the unit inspectors to better understand whether a particular damage mechanism is active in that circuit, and to develop an inspection strategy.

On an even more fundamental level, understanding damage mechanisms guides material selection and fitness-for-service considerations. A comprehensive understanding of active damage mechanisms can also inform the selection of appropriate risk-based inspection strategies and assist plant engineers in establishing integrity operating windows (IOWs) that might alert the operator to an excursion or upward creep in the process pressure, temperature, or composition, such that a particular damage mechanism might become active or increase in level of severity.
Latest Findings

Toward these goals, the American Petroleum Institute (API) publication RP 571, *Damage Mechanisms Affecting Fixed Equipment in the Refining and Petrochemical Industries*, describes damage mechanisms that might affect fixed equipment in the refining industry. These mechanisms fall into broad categories including mechanical and metallurgical failure modes, uniform or localized loss of thickness, high-temperature corrosion, and environmental assisted cracking. The API guidance incorporates information from major incidents that have been reported by industry, to inform and develop the understanding of these individual damage mechanisms. Predictive curves are provided to assist refinery personnel in developing an inspection strategy for many of the listed damage mechanisms. However, API cautions that corrosion rates associated with specific damage mechanisms can vary greatly, depending on process composition, temperature, pressure, fluid velocity or turbulence, and metallurgy. Further complicating the assessment is the potential coupling of multiple damage modes. For example, as refineries process opportunity crudes with increasing TAN (total acid number), napthenic acid corrosion might become active in process piping that traditionally was susceptible only to sulfidation corrosion. The interaction between napthenic acid corrosion and sulfidation corrosion is not completely understood, and it is possible that the observed corrosion rate might be higher than the total predicted corrosion rate from both mechanisms.

API 571 is supplemented, on an individual damage mechanism basis, by additional technical reports, recommended practices, publications, and bulletins from API, as well as from the National Association of Corrosion Engineers (NACE) and the Welding Research Council (WRC). These supplementary documents are based primarily on industry experience and are updated as the fundamental understanding of the damage mechanism evolves. For example, since 2010, multiple refiners have reported high-temperature hydrogen attack (HTHA) damage in non-post-weld heat-treated carbon steel operating at conditions below the existing carbon steel Nelson Curve. HTHA is addressed by API RP 941, *Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants*. After evaluating these incidents, API issued an alert notifying the refining industry that HTHA may occur below the Nelson Curve in the heat-affected zone of carbon-steel welds that were not post-weld heat treated. The API 941 committee is in the process of issuing a new edition of RP 941 with an additional Nelson Curve for non-post-weld heat-treated carbon steel that is significantly below the current curve for carbon steel. Similarly, API RP 939-C supplements API RP 571 regarding sulfidation corrosion, which caused the loss of containment (LOC) and subsequent fire incidents at the BP Cherry Point refinery in Washington State (2012) and at the Chevron Refinery in Richmond, California (2012).

A practical method to address active damage mechanisms is to develop inspection plans that incorporate supplemental inspections of equipment that is experiencing corrosion. Establishing IOWs to set limits on process conditions can inform refinery personal when additional damage mechanisms become active. If established correctly, IOWs create a feedback loop with inspection planning, such that process variables that exceed specific operating limits create alerts, which can be addressed by updating inspection strategies.
For example, if an IOW is exceeded, the increased corrosion rate from the activated damage mechanism may affect remaining life calculations and can inform inspectors of the need for adjustments to the inspection plans to adequately monitor the mechanism.

Moving forward, one of the key questions the industry will face is how to accurately quantify and propagate uncertainties associated with each damage mechanism into their fixed-equipment asset management plans. Exponent has extensive experience in conducting failure analysis of LOC events, in evaluating damage mechanisms in the petrochemical and refining industries, and in assisting in the developing of fixed equipment inspection and management strategies. We encourage you to share your views with us. To that end, please do not hesitate to contact the authors of this article.
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