NETL

the ENERGY lab

R&D FACTS

Oil and Gas

Materials Performance in High Pressure, High Temperature Ultra-Deep Drilling Environments

Background

Oil and natural gas fuel the American economy, accounting for more than 60 percent of the energy consumed in the United States today. Most forecasts indicate that they will continue to play a vital role in the U.S. energy portfolio for the next several decades. Increasingly, however, the domestic oil and gas industry must search for hydrocarbons in geologically challenging and operationally complex settings, including ultra-deep formations, both onshore and offshore. Innovative exploration and production technologies are needed to effectively and economically access these resources in an environmentally benign way.

In accordance with the Energy Policy Act of 2005, NETL is working with U.S. industry in a complementary research program to develop and demonstrate oil and natural gas drilling and production methodologies in ultra-deep formations. Among the issues addressed are the materials performance gaps that significantly limit the reliability and affordability of oil drilling, completion, and production architectures in these ultra-deep environments.

- NETL is providing expertise and cutting-edge testing capabilities to address the materials performance issues present in ultra-deep drilling environments. Relevant areas of expertise include:
- Mechanical stability at elevated temperatures and under variable stress states
- Corrosion and stress-corrosion interactions
- Microstructural stability under load and at temperature, and
- Life prediction based on environmental and loading history

These capabilities are critical to building a better understanding of the relationships among metallurgical factors, microstructure, and performance in order to develop or identify alloys for use in extreme environments. For example, NETL researchers have worked to develop a better understanding of how controlling alloy composition, heat-treating the material, and altering the surface micro- and macrostructure work synergistically to suppress cracking in a corrosive environment at elevated temperature and high pressure (Figure 1).

NETL is also investigating the fatigue behavior of advanced alloys for the next generation of ultra-deepwater risers (large-diameter pipe that extends from the wellbore to the surface). The new generation of risers must withstand increased tensile loads due to wave/current action in the Gulf of Mexico, for example, as well as internal pressures resulting from drilling into deep formations below the seabed at water depths greater than 10,000 feet. Further, the riser materials must be able to withstand the ultra-deep environment associated with the combination of seawater (chlorides), air (partial pressure oxygen content), and hydrogen sulfide (H_2S) that occurs in these reservoir fluids.

CONTACTS

George Guthrie
Focus Area Lead
Geological and Environmental Sciences
National Energy Technology Laboratory
626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940
412-386-6571
george.guthrie@netl.doe.gov

Jamie Brown
Division Director
Earth and Mineral Sciences Division
National Energy Technology Laboratory
3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880
304-285-5428
jamie.brown@netl.doe.gov

Jeffrey Hawk
Principal Investigator
Materials Performance Division
National Energy Technology Laboratory
3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880
541-918-4404
jeffrey.hawk@netl.doe.gov

PARTNERS

RUA: West Virginia University

This project is part of the DOE/NETL Complementary Research Program under Subtitle J, Section 999 of the Energy Policy Act of 2005.

U.S. DEPARTMENT OF ENERGY

Several suppliers of tubular materials have developed higher-strength tubular products that may enable the design of lightweight risers critical for deepwater applications. However, information is lacking on the fatigue performance (in particular the fatigue limit) of these new materials in typical ultra-deep environments. NETL will develop fatigue life curves at the appropriate stress conditions for these alloys in order to more appropriately address the fatigue design of the new generation of riser alloys.

In all aspects of drilling, completion, and production, corrosion-fatigue is an issue that crosscuts both onshore and offshore operations. However, there is very little information available on the corrosion fatigue performance of current and potentially new materials at elevated temperature and pressures on the ultra-deep well environment.

Goal and Objectives

Ultra-deep drilling environments pose significant challenges for the materials used in drilling. The service life of these materials is compromised by high temperatures (>500 °F), high pressures (>30,000 psi), corrosive substances, and complex states of stress resulting from a combination of extreme lengths and variability in loads of the drill string. In combination, these factors can result in more frequent replacement of materials and increased drilling costs.

Goal – To evaluate alloy capability for ultra-deep well environments (i.e., drilling, completion & production activities) by understanding environmental & mechanical factors that affect performance and influence effective life, thereby reducing, or eliminating, catastrophic events.

Objective 1 - To improve industry understanding of how the ultra-deep drilling environment affects the service life of materials

Objective 2 - To enable industry to develop cost-effective mitigation strategies to eliminate premature failure of critical components

Objective 3 – To develop new laboratory testing methodologies that utilize electrochemical techniques in simulated high-pressure, high-temperature (HPHT) environments (NETL Researchers)

Project Description

Materials failures are a concern associated with the high temperature, high pressure (HPHT) sour environments encountered in deep well drilling, completion and production operations. The pressure (> 30 ksi), temperature (> 500 °F) and corrosive substances (> 5 ppm H_2S) in the well environment can result in general corrosion, stress corrosion cracking (SCC), sulfide stress cracking (SSC), pitting corrosion, fatigue failures, and significant wear on components. Consequently, alloys utilized in these applications must have high yield strength, excellent fatigue capability, and excellent toughness with good to excellent corrosion resistance, and in drilling operation, very good wear resistance. It is critical to understand the relationships between metallurgical factors and microstructure which affect mechanical behavior in order to evaluate alloys for use in these extreme environments, especially in the presence of corrosive species that act to degrade material integrity.

Benefits

Performing laboratory tests in the conditions that simulate service environments are required to better understand mechanisms of potential catastrophic failures of the components in service. Therefore, the results of the various research projects in the Ultra-Deep Drilling (UDD) Program will serve as guidelines for materials testing, and materials selection and development for the oil and natural gas industry to operate safely and efficiently under UDD sour conditions. Also, the results can be used for identifying requirements for new materials with superior resistance to corrosion fatigue, especially where CO_2 and H_2S might complicate the corrosion process.

Results on fatigue testing of drill string alloys will provide the oil and gas industry information to guide the use of various alloys. In particular, the results of developmental drill pipe UD-165 in drilling after exposure to $CaCl_2$ containing completion fluids will be especially useful, as this is one of the highest strength steels available for use in UDD operations.

Accomplishments

During FY08, the focus of the project was to identify gaps in materials performance capabilities at HPHT conditions for onshore drilling applications, where drilling conditions are generally more severe than for offshore. For commercial materials, the research team identified sulfide stress cracking, corrosion fatigue, and stress corrosion cracking as potential materials issues.

The FY09 focus was to understand failures in HPHT environments and, in particular, fatigue failures initiated by corrosion, such as pitting. Research focused on understanding the effect of localized corrosion, such as pitting and crevice corrosion, on fatigue crack initiation in drill string alloys.

During FY10-FY11 the research focus shifted to understanding the mechanism of corrosion fatigue of high- and ultra-high strength, low alloy steels in simulated sour HPHT conditions. Specifically, the effect that environmental factors had on crack propagation kinetics became important to understand in fundamental terms. In FY12, the research activity has been expanded so that the role of hydrogen in this stress assisted cracking was investigated.

In FY13, the HPHT project will focus on several new activities. One such activity follows from work done at West Virginia University on the effect of hammer peening on corrosion and fatigue. Building upon this effort, new work will focus on the effect of Low Plasticity Burnishing (LPB) on the fatigue strength and corrosion behavior of high strength, low alloy steel and nickel-based tubular (e.g., oil grade 718) used in all deep well drilling activities. It is hoped that by targeting critical areas of tubular joints, or critical areas in the downhole assembly, that performance in sour environments can be improved.

Another area of research for FY13 will focus on catalytic properties of H_2S. As such, electrochemical corrosion investigations will be conducted on high- and ultra-high strength, low alloy steels in simulated sour service environments as functions of pH, temperature and H_2S concentration. The role of H_2S as a catalyst in each alloy's corrosion degradation process will be determined, and as such, effective means of corrosion control may be forthcoming, such as H_2S scavengers or corrosion coatings.