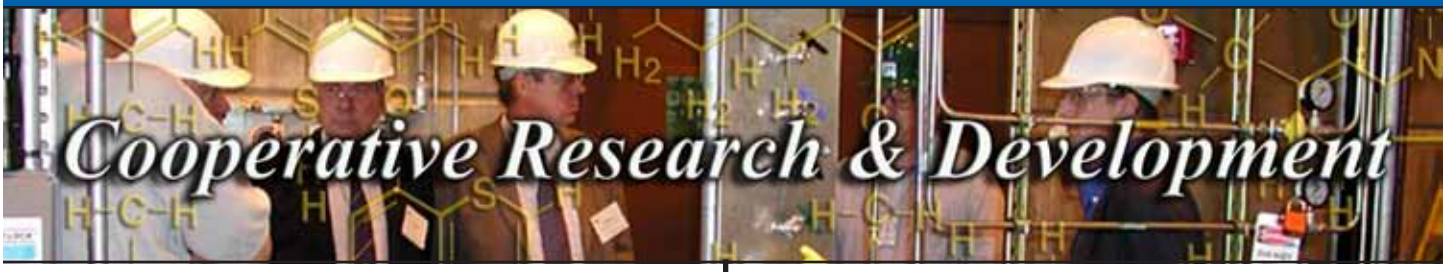
U.S. Department of Energy • Office of Fossil Energy
National Energy Technology Laboratory



Successes

Validation of Fireside Performance Indices Using PCQUEST

Advanced Research

To support coal and power systems development, NETL's Advanced Research Program conducts a range of pre-competitive research focused on breakthroughs in materials and processes, coal utilization science, sensors and controls, computational energy science, and bioprocessing—opening new avenues to gains in power plant efficiency, reliability, and environmental quality. NETL also sponsors cooperative educational initiatives in University Coal Research, Historically Black Colleges and Universities, and Other Minority Institutions.

Accomplishments

- ✓ **Process improvement**
- ✓ **Cost reduction**
- ✓ **Greater efficiency**
- ✓ **Environmental benefits**

Introduction

In the PCQUEST predictive computer model, the Energy & Environmental Research Center (EERC)—in collaboration with the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) and numerous industry partners—has developed a knowledge base of fundamental information on how ash deposits form inside coal-fired combustion boilers and how the composition of coal inorganics leads to ash deposition. This cooperative research and development (R&D) project was formulated as a continuation of the original PCQUEST software development effort. Its goal was to validate, improve, and provide commercial utility for the predictive indices contained in PCQUEST, so that utilities and coal companies could identify the best coals for their equipment to optimize power plant efficiency. The PCQUEST "fireside" (inside the boiler walls) indices were developed at the EERC through a series of fundamental research projects that involved advanced analysis methods, bench-scale combustion testing, and comparison with full-scale utility boiler experience.

This project involved a combination of developing predictive indices and validating them in field studies. The indices were designed to assist commercial sponsors in the resolution of specific coal quality and ash deposition issues. The project provided solutions to specific client needs. Additionally, the project:

- Broadened the PCQUEST-derived database of detailed analyses, particularly of U.S. coals;
- Provided bench- and full-scale information to validate fireside performance predictions; and
- Gave insight into the effects of coal inorganics, boiler operating conditions, and boiler environment on fouling and slagging behavior.

Commercial Need

Despite a century of experience with—and research on—the effects of coal properties and boiler conditions on problematic fireside fouling and slagging deposits, many utilities are still plagued with ash problems. The many ways in which the detrimental effects of ash manifest themselves in a boiler system include fireside ash deposition on heat-transfer surfaces, corrosion and erosion of boiler parts, poor slag flow, and production of fine particulates that are difficult to collect. These effects in turn result in impaired system performance and increased operating and maintenance costs.

The chemical and physical characteristics of the ash produced upon combustion are dependent on the inorganic composition of the coal and combustion conditions. These two critical factors—coal properties and combustion conditions—were united into predictive

Project Duration

Start Date
04/15/98

End Date
03/31/08

Cost

Total Project Value
$2,031,806

DOE/Non-DOE Share
$760,000 / $1,271,806

Industrial Partners

Energy & Environmental Research Center (EERC), Grand Forks, ND

ORYXE Energy International, Inc., Irvine, CA

Electric Power Research Institute, Palo Alto, CA

Florida Power & Light Company (FPL), Juno Beach, FL

Silbrico Corporation, Hodgkins, IL

Babcock Power Environmental Inc., Worcester, MA

Peat Technologies Corporation, Aitkin, MN

Minnesota Power Company, Duluth, MN

Minnesota Technology, Inc. (MTI), and Xcel Energy, Inc., Minneapolis, MN

AmerenUE, St. Louis, MO

Basin Electric Power Cooperative, Dakota Coal Company, and Montana–Dakota Utilities, Bismarck, ND

Microbeam Technologies, Inc., Grand Forks, ND

NRG Energy, Inc., Princeton, NJ

Sauder Woodworking Company, Archbold, OH

Dayton Power & Light Company, Dayton, OH

Airborne Clean Energy, Terrace Park, OH

PacifiCorp, Portland, OR

United States Steel Corporation, Pittsburgh, PA

TXU Utilities, Dallas, TX

TransAlta Centralia Generation, Centralia, WA

Dairyland Power Cooperative, La Crosse, WI

Alliant Energy Corporation, Madison, WI

TransAlta Utilities Corporation, Calgary, Alberta, Canada,

Isobord Enterprises, Inc., Elie, Manitoba, Canada

Marsulex Environmental Technologies, and Ontario Power Generation, Inc., Toronto, Ontario, Canada

models with advancement in the understanding of how coal ash deposits form and the improvement of diagnostic testing. Today, hundreds of coal companies, utilities, and energy developers can use information and predictive indices such as PCQUEST to save millions of dollars in outage, repair, and maintenance costs attributed to ash deposition and ash formation in utility boilers.

Shortcomings of Traditional Approaches

Traditional fouling and slagging predictive indices use simple expressions of ash content, base-to-acid (B/A) ratios, and other such coal parameters to derive rating factors for slagging and fouling deposits. These indices were fairly effective for the British and eastern U.S. coals for which they were initially derived, but with the expansion in the United States to lower-cost and usually lower-rank surface-minable coals, the traditional or current indices were less effective for predicting ash behavior. Traditional indices include the B/A ratio, slagging factor (Rs), and fouling factor (Rf). Western U.S. Powder River Basin (PRB) subbituminous coals, which saw dramatic increases in production in the late 20th century, do not adhere well to the predicted results of traditional indices. Central to the failure of these traditional indices for PRB coals is the lack of detail in characterizing PRB coal inorganics and understanding the nature of how those inorganics interact during combustion. The EERC-led PCQUEST project used great advances in analyzing coal and ash materials, coupled with an increased understanding of ash transformation, to devise a predictive model that provides a more reliable means for utilities to screen coal and coal blends for fireside performance in coal-fired boilers.

Technical Description

The project involved first quantifying organically associated elements in coal using chemical fractionation (CHF) and discrete minerals using computer-controlled scanning electron microscopy (CCSEM). The types of fly ash and ash deposits that form are temperature- and boiler zone-dependent. PCQUEST was built to predict the severity of furnace wall slagging, high- and low-temperature convective pass fouling, slag-tapping ability, tube erosion, and opacity for conventional pulverized or cyclone-fired coal combustion systems, as shown in Figure 1. The indices calculated by PCQUEST are based on the inorganic content of the coal as determined by CCSEM and CHF analyses, limited combustion conditions, and both theoretically and empirically derived relationships.

The PCQUEST program that drives the indices is not a comprehensive mechanistic engineering model; rather, it was developed using existing data and mechanistic information on ash formation during coal combustion. The software is relatively simple to use, with minimal computer processing time. A numerical system is used to rank the indices from 1 to 100 in terms of propensity for fouling. A range of 0–33 is considered a low magnitude, such as for expected fouling of bituminous coal; 34–66, an intermediate or medium magnitude; and 67–100, a high or severe magnitude, such as for sodium-rich lignite. This classification scheme applies to all of the indices except the coal grindability index, which is more closely related to the American Society for Testing and Materials (ASTM) International standard for grindability, whereby a higher number signifies a softer coal.

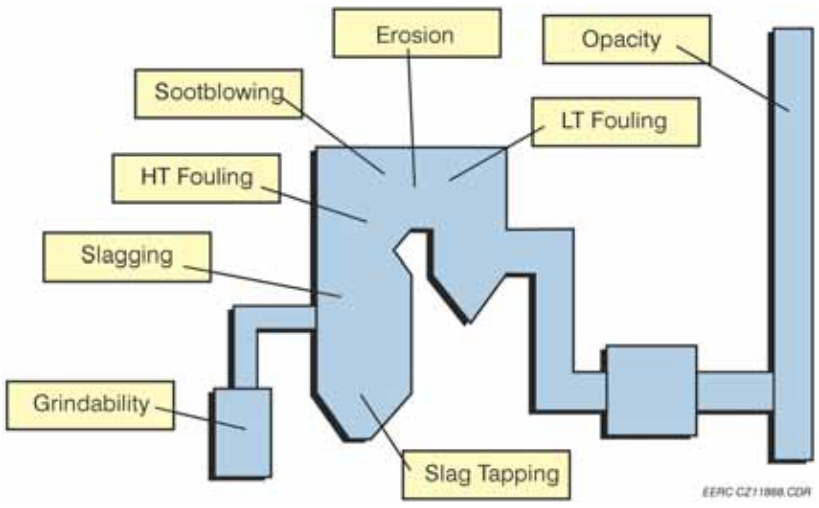


Figure 1 – PCQUEST indices are derived from coal combustion performance characteristics.

An example of expected high-temperature zone fouling for several coals is shown in Figure 2, with the predictions configured for a 400-MW (1365-MMBtu/hr) boiler. Coals A, B, C, D, and Black Thunder are all subbituminous PRB coals, while Illinois No. 6 is bituminous. As expected, the Beulah lignite, with its high organically-bound calcium and sodium contents, was predicted to have the highest fouling magnitude. All of the low-rank coals show higher values of fouling compared to the bituminous coal. PCQUEST shows considerable distinction in fouling severity for the five different PRB coals, a distinction that was not noticed using traditional indices, simple ash fusion, or B/A ratios.

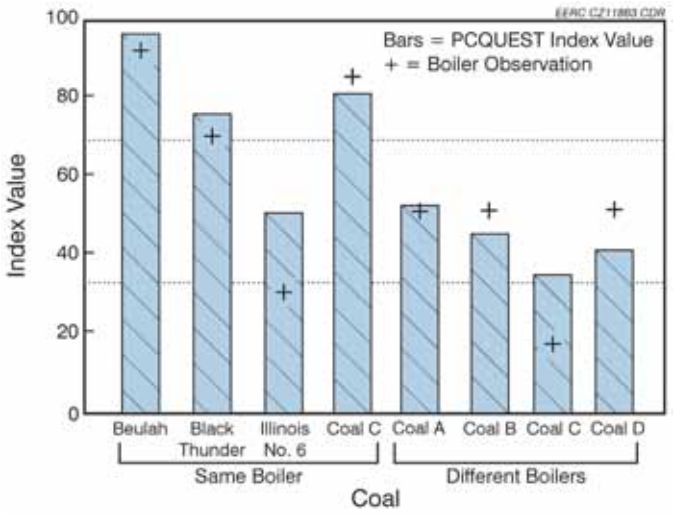


Figure 2 – High-temperature fouling index predictions and utility experience for several coals.

Commercial Opportunity

Real-world problems faced by several utilities, coal companies, and other industries have already been mitigated or solved using PCQUEST, saving these industries in some cases up to $350,000 annually for a 500-MW boiler.

The PCQUEST program and indices were used primarily to distinguish fouling and slagging performance attributes among many different PRB eastern subbituminous coals, some having similar compositions based on conventional analyses. Utilities and coal companies involved in this work were investigating new fuel buying strategies.

For several applications, actual boiler data and deposits were collected from boilers during full-scale operation to use as a comparison against predicted results. In-flight ash and probe deposits, and deposits collected from heat-transfer tubes, were commonly used. In other applications, lower-cost pilot-scale testing or equilibrium thermodynamic models were used to help verify the fouling and slagging predictions of PCQUEST. Most commonly, specific fouling and slagging problems were solved or at least made more manageable using a combination of PCQUEST predictive indices for better fuel blending and matching coals with high-temperature boiler environments. However, in one specific instance, PCQUEST helped a utility identify a particular coal type that was causing undue high-opacity excursions. In another case, a utility that had switched to several PRB coal types was experiencing slag tap freezing in a cyclone boiler and, with the aid of PCQUEST, adjusted to a proper blend with bituminous coal to solve the problem.

Benefits

The use and refinement of PCQUEST predictive models has a vital role in helping to optimize boiler operation, reduce maintenance costs, rationalize fuel selection and utilization, and reduce emissions of harmful pollutants. This research on ash behavior—along with related research on fuel switching and blending, fuel cleaning, use of additives, and changes in boiler design—has numerous benefits for the Nation and for power generating and consuming regions throughout the United States. A major benefit is to make possible the increased utilization of coal—the Nation's most abundant fossil energy resource. Research aimed at more effective, efficient, and environmentally acceptable power is of great benefit to regional coal-fired utilities responsible for technology selection and deployment, and to state agencies responsible for technology assessments and environmental quality.

"Today, hundreds of coal companies, utilities, and energy developers can use information and predictive indices such as PCQUEST to save millions of dollars in repair and maintenance costs attributed to ash deposition and ash formation in utility boilers."

States and Localities Impacted

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