RESERCH DEMONSTRATES BENEFITS OF DRYING WESTERN COAL

Over the last several decades, the US electric utility industry has come to rely, increasingly, on Powder River Basin coals (PRB) and lignite for electric power generation. This increase in the use of these fuels stems, in part, from their being relatively inexpensive and low in sulfur. However, both types of fuel are high in moisture—25 to 40% for lignite and 15 to 30% for PRB—and this results in significantly lower boiler efficiencies and higher unit heat rates than occur with higher rank coals. The high moisture content can also lead to problems in areas such as fuel handling, grinding, and fan capacity. Research being conducted on lignite drying by the Energy Research Center for Great River Energy Corporation (GRE) shows that the value of lignite can be significantly enhanced and the quantities of stack emissions substantially reduced by reducing the amount of moisture in the lignite feedstock. Similar benefits are expected for PRB coal, if it is dried before it is burned.

The Lehigh effort is headed up by Drs. Nenad Sarunac and Edward Levy; while Charles Bullinger and Mark Ness, who are with GRE’s Coal Creek Station, are in charge of the project for Great River. Coal Creek has two units with total gross generation exceeding 1,100 MW. The units fire lignite containing approximately 40 percent moisture and 12 percent ash. Both units at Coal Creek are equipped with low NOx firing systems and have wet scrubbers and evaporative cooling towers.

According to Levy, “It is widely recognized that there are performance and operational penalties associated with using high moisture fuel. Despite this, the practice of thermal drying of coal is not in widespread use because of the perception that the cost of the drying process outweighs the benefits. One of the approaches being considered by Great River Energy, which we believe solves that problem, involves use of thermal energy from the hot circulating water leaving the condenser to provide the heat for drying.

FABRICATING POWER PLANT COMPONENTS BY DIRECT LASER DEPOSITION

Many applications exist in the power industry which require the use of multiple materials in a single component. Dissimilar welds between carbon steel and stainless steel and protective coatings on the leading edge of turbine blades for enhanced erosion resistance represent just two of many possible examples. In these applications, the sharp change in interfacial microstructure and properties between the two distinct materials is often the source of premature failure. This interfacial failure problem can be avoided with components that employ a gradual, controlled variation in material composition, often referred to as Functionally Graded Materials (FGMs). Although techniques for producing functionally graded coatings are available, until recently no fabrication technique existed for manufacturing structural components using FGM concepts.

Under sponsorship from the National Science Foundation, Lehigh University has been developing a new FGM fabrication technique, known as Laser Engineered Net Shaping (LENS), for producing structural components. This effort is under the direction of Dr. John DuPont, of the Energy Research Center and the Department of Materials Science and Engineering.

DuPont explains, “Most conventional manufacturing processes used to fabricate components for the power industry, such as casting, welding and forging, have an adverse effect on the properties of the component. For instance, alloying elements that are added for strength and/or corrosion resistance in welds and castings are not uniformly distributed and may not be retained in solution.
As shown in the sketch, ambient air, heated to 110°F by the hot circulating water, is used to fluidize the coal in the coal dryer. Simultaneously, 120°F water from the condenser is circulated through tubes in the dryer to provide the bulk of thermal energy needed for drying. Besides improving unit performance and reducing stack emissions, this also reduces the flow rate of makeup water needed for the cooling tower which would be an important benefit for some stations.”

Sarunac adds, “With assistance from Dr. Hugo Caram, professor of Chemical Engineering, Dr. Levy and I performed theoretical analyses to estimate the impact on cooling water makeup flow of using hot circulating water to the cooling tower to heat the drying air and to estimate the magnitude of heat rate improvement and emissions reductions that would be achieved at Coal Creek Station by removing a portion of the fuel moisture. The results show that drying the coal from 40 to 25 percent moisture will result in reductions in makeup water flow rate from 5 to 7 percent, depending on the season. The analysis shows the heat rate will be reduced by about 5 percent due to a lower stack loss and reduced fan and mill power requirements. The CO₂ and SO₂ mass emissions will also be reduced by about 5 percent due to the lower unit heat rate.”

A coal test burn was conducted at Coal Creek Unit 2 in October 2001 to determine the effect on unit operations. Approximately 12,000 tons of lignite were dried for this test by an outdoor stockpile coal drying system. On average, the coal moisture was reduced by 6.1 percent, from 37.5 to 31.4 percent. Analysis of boiler efficiency and net unit heat rate showed that with coal drying, the improvement in boiler efficiency was approximately 2.6 percent, and the improvement in net unit heat rate was 2.7 to 2.8 percent. These results are in close agreement with theoretical predictions. The test data also showed the fuel flow rate was reduced by 10.8 percent and the flue gas flow rate was reduced by 4 percent. The combination of lower coal flow rate and better grindability combined to reduce mill power consumption by approximately 17 percent. Fan power was reduced by 3.8 percent due to lower air and flue gas flow rates. The average reduction in total auxiliary power was approximately 3.8 percent.

Great River Energy is now in the process of designing a fluidized bed lignite drying system for Coal Creek Station. To provide the data needed to design the system, Levy is heading up an experimental investigation into the effects of fluidizing velocity and bed design parameters on rate of in-bed heat transfer and rate of drying of lignite. These experiments, performed in the Center’s Fluidized Bed Laboratory, are being carried out by DeShau Huang, a Ph.D. student, and Eric Hahn and Chris Lightcap, Mechanical Engineering undergraduate students.

According to Levy, “There are several parameters which are critical to the design of the lignite dryers for Coal Creek. For example, the velocity of the fluidizing air affects things such as heat transfer, intensity of solids mixing, rate of drying, and the percentage of the lignite particles which are entrained from the bed and transported to cyclones for capture. Because of this, air velocity affects the overall bed dimensions, size of the in-bed heat exchanger and design of the downstream particle collection system. My team of students is performing experiments in a 6" diameter bed using crushed lignite obtained from Coal Creek Station. The data we are obtaining is being used to set the parameters for the full-scale prototype dryer being developed by Mark Ness and his design team from GRE.”

Sarunac adds, “We believe this drying concept has tremendous potential for the electric utility industry. Based on our theoretical studies of the impacts of drying on performance and emissions, and the results of the 2001 field test at Coal Creek, we have become convinced that this is a technology with huge potential benefits. The heat rate improvements we are seeing are quite substantial, and these result in significant reductions in emissions. Furthermore, results from our laboratory experiments on fluidized bed drying, and the results of GRE’s analysis of the economics of drying, show that it is definitely an economically attractive approach. Quite obviously, we will be very interested in the full scale drying data which will be generated by Coal Creek after the prototype fluidized bed dryer has been built and is placed into operation.”

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As a result, the mechanical properties and corrosion resistance will vary throughout the component in an uncontrolled manner, often leading to premature failure. Forging operations also produce anisotropic mechanical behavior in which the strength and toughness are inferior within a given direction. In addition, most conventional manufacturing processes are not capable of locally altering the composition and resultant microstructure at different locations within the part in order to tailor the properties for enhanced performance. For example, if a wear or corrosion resistant surface is needed, this must be accomplished through an additional processing step, and a sharp interface is produced between the coating and underlying substrate which is often susceptible to premature failure. Thus, development of a manufacturing process that can produce parts with uniform microstructures and graded properties could significantly improve component performance in power generation applications. This potential advantage has been the impetus behind development of Laser Engineered Net Shaping processes.

The LENS process employs a laser to create a molten pool on a substrate. Powder is injected into the liquid pool as the component under fabrication travels through a programmed path in the x-y plane to trace out the current layer shape. The travel path of the component is controlled by a CAD/CAM system. After completing a single layer, the laser focal point and powder feeder are incremented in the upward direction by an amount determined by the desired layer thickness. The component then traces out the new programmed path geometry and a new layer is added onto the previous layer. Adjacent layers are fused into a continuous shape by localized melting and rapid re-solidification with the laser. The substrate is removed when the final part is constructed. Because multiple powder feeders are used during the process, the composition of the part can be changed from location to location by simply controlling the relative feed rates of the individual powder feeders. Recent work has demonstrated this process is capable of producing components with complex shapes, graded layers of multiple materials for enhanced performance, and significant reduction in fabrication time. A wide range of alloys, cermets, and refractory metals can be deposited. In addition, the rapid solidification conditions associated with laser processing and use of powder filler metals can produce parts with uniform and refined microstructures for further property enhancements.

DuPont and his graduate students have demonstrated that the process can be used to fabricate high temperature alloys and components with multiple materials that were previously thought to be incompatible. As an example, they have produced a high temperature titanium-aluminide alloy that was fabricated with the LENS process. During fabrication, titanium carbide (TiC) particles were co-deposited along with the titanium aluminide alloy directly into the melt pool for enhanced strength and hardness. Tests conducted on this alloy showed that the hardness increased by a factor of two with the addition of the reinforcing particles.

Recent work has shown that the LENS process can also be used to fabricate parts containing dissimilar alloys. In a recent trial, a component was formed from iron and copper – two metals that are typically considered incompatible. With other fabrication processes such as casting and welding, the addition of copper onto steel would produce cracking at the interface due to the metallurgical incompatibility between the two elements. However, DuPont’s research has shown that LENS processing conditions can be identified to produce crack-free transitions between steel and copper. The localized deposition of copper onto tool steel is being considered in the tool and die industry in order to enhance the effective thermal conductivity of die materials.

DuPont adds, “Over the last two years, the Energy Research Center has acquired a LENS unit and is exploring the process for fabrication of a variety of components and multiple-material systems. We are interested in using this new technology to develop techniques to manufacture various parts for power generation applications. Candidate components include burner tips and turbine blades with graded coatings for improved corrosion and wear properties. Another intriguing possibility is the use of LENS technology to produce graded “dutchmen” for welding applications. These have carbon steel on one side and stainless steel on the other,
SOME RECENTLY INITIATED RESEARCH PROJECTS

Listed below are brief descriptions of some of the Center’s recently initiated research projects. For more information on any of these, please contact John Sale at (610) 758-4545.

- Field Implementation of the Intelligent Sootblower Advisor
- Development of an Early Warning Slagging Advisor
- Use of Artificial Intelligence Software Tools to Model Power Plant Cooling Water Discharge Temperature
- Flame Image Analysis for Combustion Control
- Improvements to Air Flow Measurements for Combustion and NO\textsubscript{x} Control
- Kinetics of Mercury Capture in Coal-Fired Boilers
- Combustion Optimization of Boilers Firing PRB Coal
- Kinetics of Drying Lignite in a Fluidized Bed
- Remaining Life Assessment of Circumferentially Cracked Weld Overlay Coatings
- Development of Low Cost Weld Overlay Coatings for Low NO\textsubscript{x} Waterwall Tubes

RESEARCHERS’ PROFILES

Dr. Edward Levy has a Ph.D. in Mechanical Engineering and is Professor of Mechanical Engineering and Mechanics and Director of the Energy Research Center.

Dr. Nenad Sarunac has a Ph.D. in Mechanical Engineering, is a Principal Research Scientist with the ERC, and is Associate Director of the Center. His research focuses on power plant heat rate improvement and emissions control.

Dr. John DuPont has a Ph.D. in Materials Science and Engineering and is an Assistant Professor of Materials Science and Engineering at Lehigh. His research interests include welding metallurgy and processes.

Mr. DeShau Huang is a Ph.D. student in Mechanical Engineering, whose research deals with heat transfer in fluidized beds. He is scheduled to complete his studies in Fall 2002.