Fuel switching has become a popular technique for controlling stack emissions from pulverized coal boilers originally designed to burn high sulfur Eastern coals. Some Eastern and Mid-Western utilities that burn blends of Eastern bituminous and low sulfur subbituminous coals as a means of limiting SO₂ emissions have found that this also affects NOₓ emissions and overall unit efficiency. From an operational point of view, increasing the percentage of subbituminous in the blend increases the likelihood of severe boiler slagging, particularly in the convective pass. Recent studies by the Energy Research Center (ERC) show that these factors should be taken into consideration when optimizing combustion of a boiler firing a subbituminous - bituminous coal blend. The ERC effort in this area is being led by Drs. Carlos Romero and Nenad Sarunac, two of the Center’s research scientists.

According to Romero, “Lower rank fuels such as those from the Powder River Basin (PRB) produce lower NOₓ compared to the higher rank coals because of the higher reactivity of the PRB coal, lower fuel nitrogen content and greater percentage of fuel nitrogen in the volatile fraction.”

“As a consequence, with lower sulfur content and tendency to form less NOₓ than Eastern bituminous coals, SO₂ and NOₓ emissions decrease as percentage of PRB in the blend increases. However, for units that fire PRB/bituminous fuel blends, operating constraints such as mill capacity, coal pipe plugging, furnace slagging and convective pass. Inside this Issue: Changes in Coal Properties Removing Ammonia New Website

In meeting the reduced levels of NOₓ emissions, which are required under EPA regulations, many coal-fired units are being equipped with either selective non-catalytic reduction (SNCR) or selective catalytic reduction (SCR) technologies for NOₓ control. Both techniques make use of either ammonia- or urea-based reagents and, in both cases, some ammonia reaches the stack as part of the fly gas and some is adsorbed onto the fly ash. There is concern the presence of ammonia on the ash will adversely affect ash utilization. In response to this, researchers at the Energy Research Center (ERC) have developed a process for the removal of ammonia from fly ash at the power plant.

The Center’s research in this area is being carried out by Edward Levy, Center Director, and Brad Lawton and DeShau Huang, graduate students from Mechanical Engineering. The process they’ve developed makes use of a bubbling fluidized bed, operating at temperatures high enough to drive the ammonia from the ash.

According to Levy, “Fluidized beds are widely used in industry because of their excellent heat transfer, solids mixing and gas contacting characteristics. In a bubbling fluidized bed, the particles are supported by a gas distributor. At sufficiently high gas velocity, bubbles of gas are formed at the distributor and rise vertically through the particle bed, creating a turbulent-like motion and very good solids mixing.”

Levy adds, “With most fly ashes, it is difficult to achieve stable fluidization with
pass plugging can limit the maximum allowable proportion of PRB coal in the blend.”

“The increase in rate of furnace slagging and convective pass plugging rate caused by increasing the PRB content in the fuel blend is due to ash interactions and the formation of low melting temperature compounds in the furnace. It is widely known that a furnace designed for bituminous coal will be more prone to slagging when a PRB/bituminous blend is fired. Information on ash fusion temperature for the individual coals and for a blend are given in the enclosed table. The ash softening temperature cannot be simply calculated like the other coal properties. Ash fusion data from other power stations have shown that the ash softening temperature is approximately 2,400°F for a blend containing 60 percent PRB and 40 percent Eastern bituminous coals, which is approximately 350°F lower than for 100 percent Eastern coal. Flue gas temperature measurements taken by our group indicate that, typically, the furnace exit gas temperature (FEGT) increases as the percentage of PRB coal in the blend increases. This increase is in part due to the more reflective nature of the PRB ash that deposits on the waterwalls. The combination of higher FEGTs and ash with lower fusion temperatures increases the risk of plastic ash formation and slagging on the close-to-the-furnace heat transfer surfaces, such as superheater screen tubes and boiler arch.”

“Once the ash softening temperature is exceeded, ash particles become sticky and adhere more readily to the furnace waterwall, superheater and reheater tubes, resulting in lower steam temperatures, loss of performance, and high draft losses. To maintain unit performance and operability, sootblower activation frequency typically needs to be increased when firing PRB/bituminous fuel blends. In case the sootblowing capacity is insufficient to remove the deposits from superheater and reheater surfaces, bridging and plugging eventually occurs (typically in the reheater section, due to smaller tube-to-tube spacing).”

Sarunac adds, “For the reasons just cited by my colleague, Carlos Romero, firing of PRB/bituminous fuel blends represents a challenge to combustion optimization and low-NOx operation. The low-NOx boiler control settings should incorporate the effect of fuel properties on unit operation, emissions and performance. The optimized settings should also take into consideration that fuel blending can affect unit-specific constraints, such as the minimum excess O2 level, or maximum separated overfire air (SOFA) damper opening.”

“To provide the additional information needed to factor the coal properties into the combustion optimization process, we recommend instrumentation be added to measure gas temperatures. Optical pyrometers can be used to provide direct measurement of furnace exit gas temperature for pulverized-coal boiler applications. These probes provide average temperature measurements along the line of sight with typical dynamic response time of 60 sec, relative accuracy of ±30°F, and measurement range up to 3,000°F. Optical pyrometer capabilities can be used for upper furnace slagging variations, as well as waterwall cleanliness indication. Laboratory analysis of the mineral constituents in the coal ash is also very helpful in identifying coals which have the potential to cause problems.”

“We used these techniques in two of our recent combustion optimization studies. Both involved boilers which were originally designed to fire Eastern bituminous coals, but which were subsequently converted to bituminous -PRB blends. Both units are sensitive to slagging and plugging in the upper furnace and in the superheater and reheater sections.”

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active bubbling because of the fine size distribution of the fly ash particles. Our process makes use of acoustics to agitate the fly ash. A loud speaker, positioned at the top of the bed, creates high intensity sound waves, which disrupt the interparticle forces and help to promote active bubbling.”

The Center’s research on ammonia removal began in 1999 and the first phase of that work involved experiments on fly ash in a 6” diameter bed, fluidized with air. Electric resistor heaters submerged in the bed were used to heat the ash. As the ash temperature increased, samples of ash were removed periodically and these were subsequently analyzed for ammonium content. Three different ashes were tested with initial ammonium concentrations ranging from 500 to 1000 ppm. The test results showed that the ammonium content could be reduced to less than 10 percent of the initial level when the ash was heated to bed temperatures in the 650° to 750°F range. The 6” diameter bed is a small laboratory scale batch bed into which room temperature coal ash was loaded. The ash was then fluidized and heated until most of the ammonium was gone.

According to Lawton, “While the batch bed provides a good way of studying the ammonia removal process, it would not be a practical device for processing high volumes of ash in a power plant. Over the last year, we’ve been designing, building and testing a continuously operating bed for ash processing. This bed resembles a long, horizontal table. Dry ash is fed to the bed at one end and is heated as the ash flows along the surface of the distributor. Ammonia-free ash is removed at the far end of the bed. In the system we’ve built, the heating is accomplished using electric resistance heaters immersed in the bed. Before discharging from the bed, the ash is cooled by passing it over an air cooled heat exchanger. To provide the sound levels needed to achieve bubbling fluidization, loud speakers are positioned above the free surface of the bed.”

With help from other students, Lawton carried out a series of tests in this new bed using a fly ash with an initial ammonium level of 1100 ppm. The results showed that the bed could be operated stably with steady flow rates and temperatures. Ammonia removal efficiency was found to depend primarily on ash temperature. When the temperatures were in the 725°F range, in excess of 95 percent of the ammonia was driven from the ash. Although only 6” wide, the laboratory scale bed was able to process close to 300 lbm ash/hr.

Levy adds, “We’ve come a long way with our research on fine particle fluidization. When we began doing experiments with fly ash in a fluidized bed with acoustics, we had no idea what governs the sound pressure levels in the bed or how sound waves affect fluidization or heat transfer. But as a consequence of several Masters and Ph.D. studies, we feel we’ve developed a solid understanding of how to select acoustic frequencies, bed depths and gas velocities to achieve active bubbling. Our experiments and theoretical modeling on tube-to-bed heat transfer have given us the understanding needed to properly design a heat exchanger for use with fly ash particles.”

Levy continues, “Now that we’ve successfully demonstrated continuous removal of ammonia in a laboratory environment, we believe we are nearly ready to scale up the system for use in a power plant. But before doing so, we’d like to test other fly ashes in our laboratory to make certain we can handle them in our system. Once we’ve done this, we’ll feel comfortable about moving the hardware to a power plant and testing it in a small stream of ash from an ESP or ash silo.”

“At the same time, a design study is needed to scale up our laboratory-scale bed to commercial size. And, of course, both equipment and operating and maintenance costs need to be estimated.”

LEHIGH ENERGY UPDATE is a publication of the Energy Research Center at Lehigh University. Subscriptions upon request. Address inquiries to Edward K. Levy, Director, Energy Research Center, Lehigh University, Bethlehem, PA 18015 or by visiting our homepage at www.lehigh.edu/~inenr/inenr.htm. Ursula Levy, editor.
Sarunac concludes, “The other dimension of this problem is the effect of furnace sootblowing practice on combustion optimization. Boiler control settings, developed based on a relatively clean furnace, may not give satisfactory results if the furnace has a heavy slag layer. Slag deposits lead to a higher furnace gas temperature, which can increase NO\textsubscript{x} emissions. If the deposits also increase the FEGT above a safe level, uncontrolled slag buildup will occur unless the walls are cleaned. Load is reduced, economizer O\textsubscript{2} is increased or some other combination of boiler control settings are adjusted to compensate for the high FEGT. We believe the best solution to this problem is to optimize both combustion and sootblowing practice. To facilitate this, we are in the process of completing work on intelligent sootblowing software, which we believe will provide a very useful tool, particularly for utilities with severe slagging and fouling problems. We expect to field test that software on a utility boiler in the second half of 2002.”

Romero adds, “The second unit is also tangentially-fired, but with separate superheater and reheater furnaces. This boiler also has a low NO\textsubscript{x} firing system with two levels of SOFA ports for combustion staging. Here, too, the constraint on FEGT, which was 2100°F in this case, places limits on the NO\textsubscript{x} levels and heat rate values which can be achieved. Our studies on using combustion optimization techniques to reduce NO\textsubscript{x} showed that to avoid the severe boiler slagging that accompanies high levels of FEGT, we needed to develop combinations of boiler control settings which made it possible to meet the NO\textsubscript{x} goal, but which also resulted in acceptable FEGT values. Invariably, this caused the unit heat rate to increase the values above those we obtained when we ignored the FEGT constraint.”

“One of the boilers is a large tangentially-fired boiler with a divided furnace. This boiler has a low NO\textsubscript{x} firing system with separated overfire air. At full load conditions, with a fixed coal composition, the main parameters affecting NO\textsubscript{x}, heat rate and FEGT are economizer O\textsubscript{2} level, SOFA damper opening and burner and SOFA tilt angles.”

“Our testing on this boiler showed a strong effect of percent of PRB in the blend on NO\textsubscript{x} emissions, unit heat rate and furnace exit gas temperature. As a result, when we changed the coal blend, we found we needed to use a different combination of boiler control settings to meet the target NO\textsubscript{x} level and satisfy the plant’s 1950°F operating constraint on FEGT.”

RESEARCHERS’ PROFILES

- Dr. Carlos Romero is a Senior Research Scientist with a Ph.D. in Mechanical Engineering. He is a specialist in combustion kinetics and emissions control.
- Dr. Nenad Sarunac has a Ph.D. in Mechanical Engineering and is a Principal Research Scientist with the ERC. His research focuses on power plant heat rate improvement and emissions control.
- 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.
- Mr. K. Brad Lawton is a graduate student in Mechanical Engineering.

NEW WEBSITE
OPEN FOR BUSINESS

Over the last 6 months, Jodie Johnson, ERC publications coordinator, has been hard at work overseeing the development of the Center’s new website. The website features descriptions of a significant part of the Center’s research, particularly, those projects which deal with problems related to electric power generation and flue gas emissions control. Besides articles on research results, the website includes announcements of upcoming meetings and events, descriptions of new projects and detailed travel information on how to reach the Center and local hotel accommodations. A future section of the website will include biographical information on faculty and staff researchers.

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