Being able to achieve balanced coal and air flows to individual burners in a pulverized coal boiler is important for obtaining efficient combustion and low emissions. Up to now, control of the pipe-to-pipe distribution of coal has been difficult to achieve in pulverizers having multiple coal pipes connected directly to the discharge turret at the top of the pulverizer. However, research carried out by the Energy Research Center has resulted in a new technology for balancing coal flow among the outlet pipes of pulverizers of this type.

Supported by government and industry, the research involved evaluation of possible coal flow balancing approaches using computer simulations, followed by testing of the most promising approaches in a laboratory-scale pulverizer model. The pulverizer team, consisted of Harun Bilirgen, Aly Elshabasy and Edward Levy and was led by Dr. Bilirgen.

Bilirgen explains, “From our previous research on control of coal flow distributions from two and three-way splitter junctions in coal pipe systems, we knew that there can be substantial benefits from achieving balanced coal pipe flows. Coal flow balancing tests which we performed at one unit showed that coal flow maldistributions resulted in higher fly ash unburned carbon and unstable combustion with large excursions in carbon monoxide (CO) emissions. Eliminating the coal flow imbalances in that boiler resulted in higher boiler efficiency, improved heat rate, lower NO₃ and CO emissions, and reduced ammonia injection rate for the SCR system.

Furnace and convective pass slagging and fouling cause severe operating problems and increase maintenance costs at many boilers. Selective use of sootblowers can help control ash and slag buildup, however, the boiler operators are typically given very little guidance regarding which sootblowers to activate and on what schedule. Results from recent field installations show that IntelliCLEAN, an intelligent sootblowing software program developed by the Energy Research Center, is quite effective at optimizing sootblowing.

IntelliCLEAN, which was developed by a project team led by Dr. Nenad Sarunac of the Energy Research Center, uses a knowledge-based expert system, data from sootblower characterization tests, live boiler process data, and information on the cleanliness status of boiler heat transfer sections to make decisions on sootblower activation. The software creates an optimal sootblowing sequence that can adapt to changes in fuel properties and sootblower maintenance condition. It can also adapt to changes in firing system operation which might affect slagging and fouling patterns. The software determines which sootblower groups to activate in order to satisfy the optimization goals and operating constraints.

Sarunac explains, “We’ve recently completed installation and testing of IntelliCLEAN at two large coal fired units. While both units needed to improve their sootblowing practice, the reasons for implementing IntelliCLEAN were radically different from one station to the next.

(a) Sketch of pressurized vertical spindle mill.  (b) Flow patterns in upper half of mill with four outlet pipes.

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Based on that successful outcome, we initiated a research project on coal flow balancing from pressurized vertical spindle mills. With funding from DOE, the Babcock and Wilcox Company and the Pennsylvania Infrastructure Technology Alliance, we performed computer simulations of the flow patterns in the top half of a pulverizer with four outlet pipes. The computer results revealed the regions of high and low coal concentration. This information was used to develop a new approach to coal flow control which uses flow control elements strategically positioned in the pulverizer to change the distribution of coal flow in the outlet pipes.

We then performed lab scale tests in a one-seventh scale model pulverizer. These tests provided data on the effectiveness of flow control elements located at various places in the pulverizer in adjusting the coal flow distribution.

Elshabasy continues, “The laboratory tests were carried out in the Center’s Coal Flow Laboratory, using a scale model of a pressurized vertical spindle mill. I modified the mill internals by adding flow control elements at strategic locations. These flow control elements were easily adjusted from outside the model while coal was flowing through the system. Each of the four outlet pipes connected to the top of the pulverizer model was connected to a cyclone which separated the coal from the conveying air. By accurately measuring the weight of coal which accumulated in containers at the bottoms of the cyclones, I was able to determine the coal flow rate in each coal pipe. With this approach, I was able to adjust a flow control element and immediately determine the effects on the coal flow rates in the four outlet pipes.

The original pipe-to-pipe coal flow imbalance was 16 percent. My laboratory test program showed that by adjusting the coal flow control elements, it was possible to reduce the imbalance to +/- 2 percent. The tests showed there was no measurable effect of coal flow balancing on the outlet distribution of the primary air flows. This is quite important because being able to independently control coal and primary air flows greatly simplifies the process of balancing air to fuel ratio.

A third finding from my tests is that the coal flow distribution was insensitive to the coal feed rate through the mill. This indicates the coal flow balance will not change as mill coal loading varies.

Finally, the coal flow control mechanisms were designed to produce negligible pressure drop. My measurements showed the pressure drop through the mill increased by less than one inch H₂O due to the presence of the flow control elements.”

Bilirgen adds, “We feel we have a technique for coal flow control which will achieve very good results in pressurized vertical spindle mills. The next step in this process is to demonstrate the technology in a full size mill at a power plant. We have had discussions with Babcock and Wilcox and a utility company about a field demonstration of the technology and we expect to be able to perform the field tests in the 2006-2007 time frame.

The commercial availability of coal flow balancing technology will create interesting opportunities to improve combustion. Used in combination with flame sensor technology or on-line coal flow sensors, it will be possible to achieve on-line closed loop control of burner stoichiometry, with resulting improvements in combustion efficiency and reductions in emissions.”

Laboratory model (in right side of picture) of top half of a pulverizer with four outlet pipes connected to cyclones for particle capture.

Coal flow imbalance during balancing process: initial imbalance was +/-16 percent. After installation of FCE’s, coal flow balance to within +/-4 percent was achieved on the third trial. After upset of balance (Trial 4), balance to within +/-2 percent was achieved within two additional trials.
One of the units suffered from frequent opacity excursions at high load conditions due to a marginally-sized electrostatic precipitator (ESP) and large flue gas temperature stratification at the ESP inlet. As a result, the unit load had to be reduced whenever the stack opacity exceeded 20 percent for more than the allowed time period. Stack opacity excursions were usually triggered by sootblowing, which was needed to control buildup of slag deposits on the furnace walls.

Our main objective at this unit was to prevent opacity excursions by controlling the amount of slag allowed to accumulate on the furnace walls between wall cleanings … and this was to be done by optimizing sootblowing. An additional objective was to use sootblowing to maintain the furnace exit gas temperature below the ash fusion temperature as a way of controlling rate of slag buildup. Finally, the station asked us to use sootblowing to maintain main and reheat steam temperatures near their set-point values to improve heat rate.

The second unit had a history of frequent tube repairs from overuse of sootblowers. Keeping up with sootblower maintenance has historically also been a significant issue for the plant staff. In addition, this unit is equipped with Selective Catalytic Reduction (SCR) for NO\textsubscript{x} control. However, the inlet gas temperature to the SCR has historically been higher than design values, which resulted in a lower than expected NO\textsubscript{x} reduction efficiency and has also contributed to high SO\textsubscript{3} emissions. For these reasons, the station engineers felt the station would benefit from better temperature control of the SCR inlet temperatures.

As a consequence, the engineers at the second unit were interested in reducing sootblower activation frequency to reduce erosion damage to boiler tubes. Improved control of Selective Catalytic Reduction (SCR) gas inlet temperature, reduction of NO\textsubscript{x} emissions, and control of burner tilt angle were additional objectives. The Lehigh team followed very similar procedures at the two units in order to carry out the sootblowing optimization process. Sootblower characterization tests were performed to determine the effects of individual sootblower groups on steam temperatures, emissions, opacity and other parameters of interest. The data collected were used to develop a database, which when combined with boiler process data and data on the cleanliness status of the boiler provided the inputs needed by IntelliCLEAN. Sarunac was joined in this effort by Xiaodong Bian and David Wei, who adapted the software for the two applications, and Carlos Romero and John Sale, who gathered sootblower characterization data at the two units.

The software was implemented on personal computers at the stations and was linked to the Plant Data Acquisition Systems. The IntelliCLEAN code, screens and modules were configured in consultation with the plant engineers and operators. The software was then placed in service in an on-line advisory mode to provide the operators with advice on which sootblowers to activate and when.

Sarunac continues, “The results we obtained showed significant benefits at both units. With IntelliCLEAN in service at the first unit, opacity spikes were more frequent, but smaller in magnitude and shorter in duration compared to those with the sootblowing sequence which had previously been used at the plant. As a result, the need for opacity-related load reductions was eliminated.

The data from this unit also showed that with IntelliCLEAN in service, the furnace exit gas temperature was reduced by 15°F, which reduced the propensity for...
slag accumulation. In addition, higher steam temperatures were achieved, and the desuperheating spray flow rate and the boiler exit gas temperature were reduced, all of which improved unit heat rate.

As a result of the improvements to plant operations obtained with IntelliCLEAN, the software was put into the closed-loop control mode at the first plant in March, 2006. Since then it has run continuously, while activating plant sootblowers automatically to meet optimization objectives. An evaluation of the long-term benefits to the plant is in progress.

With installation of IntelliCLEAN at the second unit, the number of sootblower activations has increased in the furnace and decreased in the convective pass, with a 15 percent reduction in total sootblower activation time. As a consequence of the change in sootblowing patterns, there are much smaller variations with time in furnace exit gas temperature, burner tilt angle and SCR inlet gas temperature and the average burner tilt angle has been reduced. This has resulted in reductions in NO\textsubscript{x} emissions, reheat spray flow rates and unit heat rate. In addition, the reduction in burner tilt angle has led to a large reduction in rate of formation of ash clinkers on the platen superheater.

Sarunac concludes, “These two projects provide very good illustrations of the benefits of optimizing sootblowing practice. While the benefits are obviously very site specific, the wide range of possible operational improvements and maintenance impacts is quite surprising. It is widely believed improved sootblowing will reduce heat rate and NO\textsubscript{x} emissions. Our work at these two stations show the potential benefits are much broader.”

For more information about either sootblowing optimization or coal flow balancing, please contact John Sale at jws3@lehigh.edu or at (610) 758-4545.