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Project Summary

Prototype Scale Testing of LIMB Technology for a Pulverized-Coal-Fired Boiler

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The report summarizes results of a project conducted to evaluate furnace sorbent injection for control of sulfur dioxide (SO_2) emissions from coal-fired utility boilers. The project, sponsored by the U.S. Environmental Protection Agency (EPA) and the Electric Power Research Institute, is one of three sorbent injection projects conducted on full-scale, coal-fired utility boilers in the U.S. The emphasis of the project was on evaluating a wide range of process parameters during relatively short-term periods of operation to enhance understanding of the process, as opposed to a demonstration of sorbent injection over an extended period of time under optimum sorbent injection conditions. The process parameters which were evaluated included sorbent type, boiler operating conditions, and injection parameters. A very flexible sorbent injection system was installed at the host boiler and tested over a wide range of conditions. A flue gas humidification system also was installed and tested to enhance electrostatic precipitator performance during sorbent injection. Energy and Environmental Research Corporation conducted the project.

This Project Summary was developed by EPA's National Risk Management Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Program Goals

Primary goals of the program were to provide information on parameters that affect calcium utilization in tangentially fired boilers and to document the impacts of sorbent injection on the boiler, ancillary equipment, and pollutant emissions. Secondary goals were to document humidification system performance and to establish an information base for future combined sorbent injection/humidification designs that are optimized for SO_2 removal.

Host Boiler

The host boiler for the program was Richmond Power and Light's Whitewater Valley Unit 2 in Richmond, Indiana. This unit, one of the smallest existing tangentially fired utility boilers, is a Combustion Engineering (CE) VU-40 steam generator with a nominal rating of 61 MWe. Pendant and spaced superheaters in combination with a baffleless boiler bank result in a single-pass cross-flow arrangement of heat transfer surfaces. It has a finned tube economizer and a rotating regenerative air heater. At full load, 540,000 lb/hr* of steam at 1320 psig and 955°F is generated. Unit 2 was commissioned in 1972 and is a balanced draft design. Three elevations of burners are located at the furnace corners (12 burners total). The burners were previously modified by CE with a low nitrogen oxide (NO_x) concentric firing system. The plant fires a medium sulfur (2.5 lb sulfur per 10^6 Btu) bituminous coal blend.

Unit 2 is equipped with a Lodge-Cottrell cold-side electrostatic precipitator (ESP), erected with the boiler. The ESP treats 227,000 acfm of flue gas at 285°F. The design specific collection area of the ESP is 198 ft^2/1000 acfm. It has two mechani-

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* Readers more familiar with metric units may use the factors listed at the end of this Summary to convert to that system.

cal fields, four equal electrical fields in series, and a design particulate removal efficiency of 99.0%.

Baseline Tests

Baseline tests were performed on the host boiler to establish normal performance prior to operation of the prototype furnace sorbent injection and flue gas humidification system. The test results were used to establish the impact of sorbent injection/humidification on boiler and ESP performance over a wide range of operating conditions. The baseline tests included characterization of air pollutant emissions; boiler thermal performance, including slagging and fouling tendencies; ESP operation and performance; and furnace flow and temperature characteristics.

Baseline Emissions

Average emissions of NO_x, SO_2, and particulate were determined on the host boiler over a range of boiler loads and coal sulfur contents. NO_x emissions ranged from 0.65 lb/10^6 Btu at full boiler load to 0.53 lb/10^6 Btu at low load. The baseline NO_x levels are significantly below the uncontrolled emissions from the host boiler prior to the low NO_x concentric firing system retrofit. During the baseline tests, the coal sulfur content varied from 1.7 to 3.1% on an as-received basis. SO_2 emissions were found to correlate well with coal sulfur content. Typical of bituminous coals, essentially no inherent sulfur capture in the coal ash was detected. Particulate emissions were 0.04 to 0.13 lb/10^6 Btu over the range of conditions tested.

Baseline Boiler Efficiency

An on-line boiler performance monitoring system developed by Energy and Environmental Research Corporation (EER) was used to determine boiler efficiency, which ranged from 88.1% at the nominal low load condition (40 MWe) to approximately 87.7% at maximum boiler load (64 MWe). The measured efficiency was approximately equal to the manufacturer's predicted design efficiency.

Baseline Gas-Side Fouling

Fouling of gas-side tube surfaces in the superheaters and convective passes is expected to increase during sorbent injection because the spent sorbent will result in a large increase in the total amount of particulate matter entrained in the gas. Baseline fouling characteristics were determined so that the impact of sorbent injection could be quantified. A surface "cleanliness coefficient" was defined for each boiler section as the ratio of actual heat absorbed to average heat absorbed at a given boiler load. This was monitored on-line during operation with the boiler performance monitoring system. The standard deviation of cleanliness coefficient was used to represent the range of baseline gas-side fouling. Measurements were also made using an air-cooled fouling probe to quantify the rate of deposit buildup in the upper furnace and superheater sections.

Baseline ESP Performance

Baseline performance of the ESP was determined while firing the baseline and high sulfur coals. The baseline coal had a sulfur content of 2.0 to 3.0%, while the high sulfur had between 3.5 and 5.3% sulfur. The collection efficiency of the ESP was slightly below the design value, even when firing the high sulfur coal. However, stack opacity remained well below regulated levels. Fly ash resistivity was normal for the coal type and flue gas conditions occurring during the tests. No significant difference in fly ash resistivity between baseline and high sulfur coals was observed.

Process Design Measurements

Flow and temperature fields were extensively characterized to provide information needed to support the detailed design of the sorbent injection system and flue gas humidifier. Tests included measurement of gas temperature, velocity, gas species concentration, and radiative flux at locations in the furnace and superheaters. Additionally, physical measurements were taken of ductwork and areas of interference to accommodate the process equipment that would be installed during the sorbent injection/humidification system retrofit.

Baseline Test Conclusions

The baseline tests indicated that the host boiler and ESP for the sorbent injection/humidification prototype were performing essentially as designed, within normal limits. Relatively minor problem areas (excessive air heater leakage, air heater basket corrosion, missing tube shields, ESP plate misalignment) were corrected during the tests to ensure that sorbent injection/humidification was evaluated under conditions representative of normal boiler thermal operation. The tests provided baseline data for air pollutant emissions, boiler thermal performance, fouling trends, and performance of the ESP, fans, and coal pulverizers. Additionally, historical data provided by the plant were used to establish baseline reliability and availability of the unit.

Prototype System Design

The sorbent injection and humidification systems were designed in two steps:

- Process design studies were conducted to establish design specifications expected to result in optimum system performance on the host boiler and to develop boiler specific conceptual designs.
- Engineering design studies were conducted to translate the conceptual design into engineering designs that included specification of equipment, controls and instrumentation, and process equipment arrangement.

Sorbent Injection System

The approach to the design of the sorbent injection system was based on a generalized methodology developed by EER, which involves (1) the application of various experimental and analytical methods to determine boiler locations at which temperature levels are optimum for sorbent injection, and (2) to define injection conditions that will produce uniform dispersion of the sorbent material. The optimum injection configuration developed for full boiler load operation consisted of eight 3-in. diameter injectors located near the plane of the boiler nose with an injection velocity of 140 ft/sec. Sorbent transport air corresponded to 2.5% of total combustion air. The optimum injection configuration for low boiler load operation consisted of four 2-in. diameter injectors with an injection velocity of 326 ft/sec. Sorbent transport air corresponded to 2.0% of total combustion air.

Sorbent Selection

Bench-scale testing of 15 candidate sorbent materials was conducted to establish their relative reactivity towards SO_2. Four sorbents representing a range of available materials were selected for use in the field evaluation studies. These included highly and moderately reactive calcitic hydrates, a highly reactive atmospheric dolomitic hydrate, and a limestone of relatively low reactivity characteristic of this sorbent class.

Humidification System

Sorbent injection was expected to increase particulate emissions due to (1) an increase in total particulate matter entering the ESP by a factor of 2 to 3, (2) a decrease in the mean particle size at the inlet, and (3) an increase in dust resistivity that would degrade ESP performance. The methodology for designing the humidification system included experimental and computational efforts. Twin-fluid atomizers were selected and installed as an array of 28 atomizers in the existing flue gas duct close to the air heater. Compressed air was used as the atomizing medium. Spacing was chosen to minimize overlap of adjacent sprays and impaction on the duct walls while achieving rapid and uniform mixing of the water droplets and flue gas. The design was capable of achieving complete evaporation of water down to a 75°F approach to adiabatic saturation temperature.

Waste Management

The product of SO_2 removal by sorbent injection is solid calcium compounds, primarily unreacted calcium oxide and the reaction product, calcium sulfate. These solids are removed from the flue gas, with the fly ash creating a solid waste stream. Modifications to normal fly ash handling and disposal practices necessary to accommodate this additional solid waste burden included

- Removal of the ash mixture through the dustless unloader into a 20-ton dump truck;
- Segregation of spent sorbent/fly ash mixtures from conventional fly ash and disposal at the landfill; and
- Treatment of the ash system sluice/ Hydroveyor water with sulfuric acid to neutralize pH.

Sorbent Injection Results

The test program was limited to parametric tests of short duration that focused on establishing data quality, sorbent utilization data, and the effects of injection parameters and boiler operating conditions on SO_2 removal. Three sorbents were selected for evaluation during the parametric tests program: Marblehead hydrate, Linwood hydrate, and Marblehead hydrate containing a calcium lignosulfonate additive. Sorbent injection parameters investigated included

- Injection location (upper and lower furnace),
- Number of sorbent injectors,
- Sorbent jet velocity at the injector exit,
- Sorbent nozzle tilt and yaw, and
- Sorbent type.

SO_2 Removal

Marblehead hydrated lime was used as the baseline sorbent during the parametric tests. SO_2 removal ranged from 23 to 48% at a Ca/S (molar) ratio of 2.0, depending on injection configuration and boiler load. SO_2 removal of 50% was achieved at a Ca/S of 2.5 with the boiler operating at 50 MWe (82% of maximum continuous rating). At near full load (60 MWe), a Ca/S of 3.0 or greater was required to achieve 50% SO_2 removal.

In addition to load, other boiler operating parameters, (e.g., excess oxygen (O_2) and burner adjustments) were varied. SO_2 removal generally increased with increasing excess O_2, especially near full load. Increasing furnace exit gas temperature caused SO_2 removal to decrease, suggesting that the gas temperature at the point of sorbent injection in the upper furnace was higher than optimum, particularly at full load. The capability of favorably modifying the burner air distribution to affect the upper furnace thermal environment was also evaluated. At full load, the impact of burner adjustments on SO_2 removal was estimated to be 2 to 4%.

In general, sorbent injection parameters such as injection velocity and nozzle tilt/ yaw had only a second order impact on SO_2 removal. Calcium utilization for the three sorbents was evaluated at Ca/S of 1.7 and 2.3 and 60 MWe boiler load. Ironically, the highest calcium utilization was not achieved at the design configuration, but with sorbent injection higher up in the furnace and with higher injection velocity. Injection velocity was increased by increasing the sorbent transport air flow with constant injector diameter. Attempts to further optimize sorbent injection were limited by the available furnace wall penetrations. Shifting more of the sorbent above the nose plane of the superheater region resulted in lower calcium utilization. This was likely due to a combination of less than optimum temperatures and reduced residence time. Calcium utilization was similar for all three sorbents.

ESP and Boiler Impacts

ESP performance was substantially degraded by sorbent injection. However, humidification of the flue gases to moderate levels (approximately 130°F approach to adiabatic saturation temperature) restored performance. In most tests, opacity remained near baseline levels and was below 20% for nearly all the tests.

Boiler performance was carefully monitored throughout the tests, using the online boiler performance monitoring system. Sorbent injection resulted in significant superheater fouling, but this was easily controllable by operating the six retractable sootblowers in the superheater and boiler banks on a 1-hour cycle. There was no impact on furnace fouling or slagging. The host boiler is equipped with a finned-tube economizer and a rotary regenerative air heater. There are no sootblowers in the economizer, and decreased heat absorption was observed in the economizer during sorbent injection, although unacceptable buildup of deposits did not occur. Air heater performance was also satisfactory, and there was no evidence of permanent fouling. Heat loss efficiency was slightly lower with sorbent injection, primarily due to the increase in deposits which resulted in increased stack gas temperature.

Discussion

SO_2 removal for the nominal design conditions was considerably below the level predicted during the design phase. A contributing factor is thought to be boiler cleanliness and its impact on the furnace gas temperature at the injection locations. Temperature and velocity probing of the test unit disclosed a very complex flow temperature and flow field. Significant gradients were observed. These factors were considered in the design phase and were accommodated to the extent possible in the actual installation of injectors subject to physical limitations and interferences. Sorbent injection clearly tended to increase gas temperatures at the injection plane, which contributed to a large part of the difference between predicted and measured results. However, it is not sufficient to explain the entire difference. Tests were conducted to estimate the degree of sorbent dispersion. The measurements revealed considerable variation in the local Ca/S ratio, indicating non-uniform sorbent dispersion, which in turn contributes to a decrease in SO_2 removal. The analysis suggests that the complex flow and temperature field can potentially contribute to low SO_2 removal.

Conclusions

The efficiency of sorbent utilization in small tangentially fired boilers may be affected by complex flow and temporal characteristics, requiring higher rates of sorbent injection to achieve SO_2 control targets than less complex systems. The maximum rate of sorbent practically achievable on a long-term basis will be boiler specific and most probably limited by fouling tendencies. In applications of sorbent injection to tangentially fired boilers where substantial temperature and velocity gradients may exist in the upper furnace, the design of the sorbent injection system must recognize the potential influence of local conditions in order to maximize sorbent utilization. In addition, sorbent injection itself may have an impact on gas temperatures at the injection location, which may affect SO_2 removal if the impact is large.

Metric Conversions

Readers more familiar with metric units may use the factors in Table 1 to convert to that system.

Table 1. Metric Conversion Factors

Nonmetric	*Multiplied by*	*Yields Metric*
acfm	*4.719×10^{-4}*	*m^3s*
Btu	*1.055×10^{3}*	*J*
°F	*5/9 (°F-32)*	*°C*
ft	*3.048×10^{-1}*	*m*
ft^2	*9.290×10^{-2}*	*m^2*
ft^2/1000 acfm	*1.968×10^{-2}*	*m^2/1000 m^3/s*
in.	*2.540×10^{-2}*	*m*
lb	*4.536×10^{-1}*	*kg*
psig	*6895 (psig + 14.7)*	*Pa (absolute)*
ton	*9.072×10^{2}*	*kg*

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The complete report, entitled "Prototype Scale Testing of LIMB Technology for a Pulverized-Coal-Fired Boiler," (Order No. PB96-183850; Cost: $21.50, subject to change) will be available only from

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