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Project Summary

Demonstration of Sorbent Injection Technology on a Tangentially Coal-Fired Utility Boiler (Yorktown LIMB Demonstration)

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Limestone Injection Multistage Burner (LIMB) technology has been successfully demonstrated on a tangentially fired coal-burning utility boiler, Virginia Power's 180 MWe Yorktown Unit No. 2. This document summarizes the activities conducted, and results achieved, under this EPA-sponsored demonstration program. LIMB combines furnace injection of a calcium-based sorbent for moderate reductions of sulfur dioxide (SO_2) with a low-nitrogen-oxide (NO_X) firing system for NO_X emissions reduction. The process is attractive for retrofit of existing coal-burning utility boilers, since the capital equipment requirements and overall sulfur reduction costs per ton of sulfur oxide removed are less than for most other options, such as wet flue gas desulfurization.

Testing was conducted on an eastern bituminous coal with a typical sulfur content of 2.3%. Five sorbents were tested: commercial hydrated lime, with and without calcium lignosulfonate treatment, each from two suppliers, and finely pulverized limestone. Short-term parametric testing showed full-load SO_2 removals of up to 56 and 63% at calcium-to-sulfur (Ca/S) ratios of 2:1 and 2.5:1, respectively. Intermediate load performance was higher, with SO_2 removals of up to 60 and 67% at Ca/S ratios of 2:1 and 2.5:1, respectively. Results varied with specific LIMB operating conditions, boiler load, and sorbent used. Results of both extensive parametric testing and continuous long-term operation of the LIMB system are presented. Results of performance testing of the Low-NO_X Concentric Firing System (LNCFS) Level II firing system are also presented. Typically, under comparable boiler operating conditions, a 42% reduction in NO_X at full load and a 33% reduction in NO_X at intermediate load, relative to baseline levels, were achieved with the LNCFS Level II System.

The effects of LIMB operation on boiler, electrostatic precipitator (ESP), and ash handling system performance are also discussed. The most significant impact on boiler performance was the collection rate of LIMB solids plus fly ash on boiler convective surfaces during continuous operation, resulting in poorer boiler heat transfer performance and higher temperatures leaving the boiler. Continuous operation of the sootblowing system minimized this effect. The results of two ESP performance tests that were conducted during continuous LIMB operation are discussed and compared to results from similar testing conducted without LIMB operation. Ash conditioning and disposal during LIMB operation at Yorktown were significantly affected by the unreacted lime in the ash. These problems, as well as suggested precautions to avoid them, are discussed.

Recommendations for LIMB commercialization and an evaluation of the economics of the technology in comparison to a conventional flue gas desulfurization system are discussed.

This Project Summary was developed by EPA's Air and Energy Engineering 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).

Introduction

Increasing concern for the environmental effects of acid rain has led to active efforts to control emissions of sulfur dioxide and oxides of nitrogen, SO_2 and NO_X, from the fossil-fuel-burning electric utility industry. The choice of control techniques for limiting SO_2 and NO_X emissions from utility boilers will most likely include a mix of technologies to achieve the desired reductions at minimum cost. The primary method for controlling SO_2 from new coal-burning boilers is flue gas scrubbing. Often, however, this technique may not be a viable option for existing power plants. Space may not be available for installing scrubbers and disposing of waste from the scrubbers. In addition, the installation of scrubbers may not be a viable economic choice for older units with less than 10-20 years of remaining useful life. The need for a method of providing a moderate degree of emission control at lower cost and with minimal retrofit to an existing boiler and minimal space has led to the development of the LIMB process. In this process for simultaneous SO_2 and NO_X control, a calcium-containing material, such as limestone ($CaCO_3$) or hydrated lime [$Ca(OH)_2$], is injected into the furnace at appropriate temperatures. The material, called the sorbent, breaks down to form lime (CaO). The CaO reacts with SO_2 in the gas to form calcium sulfate ($CaSO_4$). $CaSO_4$ is collected in the boiler's particulate removal device, along with the coal ash, and transferred to a landfill site. Concurrent with SO_2 control by injection of the calcium-containing material, NO_X is controlled by installation of low-NO_X burners that provide staged introduction of air to control flame temperature and gas chemistry in the flame region.

The LIMB process had its origin in the observation that significant sulfur is retained during the burning of coals that are high in alkali-containing ash and low in sulfur. This observation led to several investigations (in Europe, Japan, and the U.S. during the 1960s) of the feasibility of injecting calcium-based sorbents directly into the furnace of a coal-fired boiler as the primary SO_2 control technique. Early field demonstrations of furnace injection, using limestone, produced disappointing levels of SO_2 reduction. During the late 1970s, interest in direct sorbent injection for SO_2 control waned as emphasis shifted to scrubber development. However, during the early 1980s, development of improved firing systems with lowered combustion zone temperatures, provided the impetus for the development of LIMB as a low-cost retrofittable system for the simultaneous reduction of SO_2 and NO_X. The EPA established a major research and development program, both at their laboratories and with contractors, to establish LIMB as a viable, low-cost, alternative to conventional flue gas desulfurization (FGD) systems for attaining moderate reductions in SO_2 on existing coal-burning boilers. Through early research efforts, LIMB eventually evolved into the more generic "furnace sorbent injection" as sorbents that were more reactive than limestone, such as $Ca(OH)_2$, and injection locations that were more consistent with the optimum SO_2 capture "window" of 2300 to 1650°F (1260 to 890°C), such as into the upper furnace, were identified. Because tangential firing introduces special considerations for the design of sorbent injection systems due to the unique aerodynamics in the sorbent mixing region of tangentially fired boilers, the EPA established parallel development programs for LIMB application to both wall-fired and tangentially fired boilers. The Yorktown demonstration project was the culmination of a multiphase program, which included both pilot- and prototype-scale testing, to develop LIMB for tangentially fired boiler applications. The EPA selected Combustion Engineering (C-E) as prime contractor for the demonstration project in 1987. Virginia Power's Yorktown Unit No. 2, a 180-MWe coal-fired boiler located at the Yorktown Power Station in Yorktown, Virginia, was selected as the host unit. C-E, Virginia Power, Stone & Webster, and the U.S. Department of Energy all helped fund the project.

The demonstration project objectives were established as at least 50% reduction in SO_2 at a Ca/S of 2.5:1 and a reduction in NO_X emissions to 0.4 lb/10^6 Btu (0.17 kg/GJ) or below. These emissions would be reduced with no significant adverse impact on boiler operability and reliability. An eastern bituminous coal with a sulfur content of 2.0 to 2.5% was selected as the demonstration coal.

The overall program was conducted in two phases: site-specific studies to support the system design, and the field demonstration itself. The site-specific studies included a boiler characterization test to identify the location of the ideal sulfation zone through extensive mapping of the boiler temperatures profile, identification of promising injection schemes via cold-flow testing on a plastic model of the Yorktown boiler, and pilot-scale combustion testing to verify performance of both the most promising injection schemes and the proposed low-NO_X firing system. Those injection schemes that performed best during pilot-scale testing were incorporated into the LIMB system design. Computational fluid dynamics computer modeling of the ESP inlet ducts, where the flue gas humidification system would be located, showed that there was insufficient residence time in the ducts to achieve a close approach to the adiabatic saturation temperature for enhanced SO_2 capture. Humidification for ESP performance maintenance during LIMB operation had been demonstrated to be effective at two other EPA-sponsored LIMB projects: the Edgewater wall-fired demonstration project and the tangentially fired prototype test program at Richmond Power & Light. Enhanced SO_2 capture with a close approach to saturation had already been demonstrated at Edgewater. To avoid incurring additional costs to extensively modify the Yorktown ducts for enhanced SO_2 capture, the Yorktown humidification system was designed only to maintain ESP performance.

While the final system design was essentially complete by June 1990, construction did not begin until May 1991 due, in large part, to a 1-year delay in the Unit No. 2 outage, which was rescheduled to allow installation of a new steam turbine/generator set.

A 1-month baseline test to establish the performance of Unit No. 2 with its original firing system was conducted in March 1991, prior to installation of the LIMB system. An extensive ESP performance test was also conducted. The medium-sulfur eastern bituminous demonstration coal was used for this test.

The boiler was returned to service in December 1991, with the LNCFS Level II low-NO_X firing system in place and installation of the sorbent injection equipment nearly complete. Performance testing of the LNCFS system was conducted in March 1992. LIMB system start-up/shakedown testing started in May 1992 and continued through August 1992. Performance testing of the LIMB system, including three long-term demonstration tests of over 22 days of continuous operation each, extended from September 1992 to October 1993. The results of the LIMB and low-NO_X testing, plus the effects of LIMB on Unit No. 2 operation, are presented below.

NO_x Emission Reduction

A LNCFS Level II system was installed to meet the project objective of 0.4 lb/10^6 Btu (0.17 kg/GJ) NO_x emissions. The LNCFS Level II system features separated overfire air (SOFA) for staged combustion, flame attachment tips for early fuel ignition, and offset air nozzles to further minimize NO_x formation. During early testing of the LNCFS Level II system, it was determined that the new Unit No. 2 steam turbine had introduced substantial changes in the boiler waterwall and reheater heat absorption requirements. The boiler controls responded by raising burner tilts, which, in turn, adversely affected the effectiveness of the LNCFS firing system in reducing NO_x. To make the LNCFS performance data fully comparable to baseline data with the original firing system, all NO_x emissions were adjusted to the 0° burner tilt used during baseline testing and to a common fuel nitrogen content. The LNCFS system without overfire air performed at essentially the same level as the original baseline system at full boiler load, suggesting that the concentric firing system, in combination with the flame attachment tips, did not contribute to overall NO_x reduction. A 15% reduction in NO_x was measured at intermediate boiler load. Adding SOFA produced a 42% reduction in NO_x at full load and a 33% reduction at intermediate load. Carbon-in-ash levels for the baseline system and the LNCFS system with SOFA nozzles closed were comparable at approximately 7%, under similar test conditions. The effect of fully opening all three SOFA nozzles was to increase carbon-in-ash by about 85%. Comparable effects have been noted on other LNCFS Level II-equipped units burning similar coals.

LIMB System for Yorktown

The Yorktown sorbent injection system was designed to provide a great deal of operational flexibility to permit operation of the system over a wide range of boiler and sorbent injection conditions. Three elevations for injection into the boiler were provided. The elevations were selected based on the results of site-specific studies, including field and pilot-scale testing. The middle and lower elevations each provided for tangential injection of the sorbent through 16 injectors located at the eight corners of the divided furnace. The lower elevation was designated as the primary injection location for reduced boiler load operation. The middle elevation, located approximately at the "nose" of the furnace, was designated as the primary injection elevation for full boiler load operation. The third elevation, with 16 injectors across the front wall of the boiler, above the tangential injector elevations, was an alternate full-load injection location.

Parallel sorbent feed systems supplied sorbent to both sides of the divided furnace. Feed rates of from 4 to 15 tons/hr (3.6 to 13.6 tonnes/hr) (total) allowed substantial flexibility in evaluating LIMB system performance over a range of boiler loads and Ca/S molar ratios. In addition, either sorbent feed system was capable of feeding both sides of the furnace, if the other feed system was not available. Each feed system consisted of a day bin (65 tons—58.9 tonnes—of hydrate), plus feeders and transport blowers. A large fan provided additional air to achieve sorbent injection velocities into the furnace of up to 450 ft/sec (137 m/sec).

Sorbent for LIMB testing at Yorktown was delivered by rail to an unloading site approximately 9 miles (14.5 km) from the Yorktown Station. At this site, the sorbent was off-loaded to pneumatic trucks, typically holding 20 tons (18 tonnes) of hydrated lime, for delivery to the Station where the sorbent was pumped into a long-term storage bin designed to hold 390 tons (354 tonnes) (roughly 2 days supply) of hydrate. The truck unloading system worked well throughout the optimization and demonstration test periods. As many as 13 trucks were unloaded in 1 day during demonstration testing.

SO_2 Removal Performance: Optimizing Testing

A parametric test program was conducted to evaluate the effectiveness of the LIMB System over a wide range of configuration and operating variables. The primary objective of the program was to identify the LIMB configuration and operating variables that provided the greatest reduction in SO_2, consistent with good boiler performance, and identify the optimum sorbent system operation for long-term demonstration testing.

A total of 147 tests were conducted from September 1992 through September 1993. Full-load tests were conducted at all three injection elevations. One alternate injection yaw configuration was tested. Intermediate load tests were conducted at two injection elevations. The effect of Ca/S on SO_2 capture was evaluated. The effect of sorbent mixing on SO_2 capture was evaluated by varying injection air plus sorbent discharge velocity from 150 to 450 ft/sec (45.7 to 137.2 m/sec) (approximately 2.5 to 7.5% of total airflow to the boiler) and injector tilt from -35 to +35° relative to horizontal (0° tilt) injection. Commercial hydrated lime from two suppliers was tested. Tests were also conducted using calcium-lignosulfonate-treated hydrate from the same two suppliers. In addition, limited testing was conducted using finely pulverized limestone as the sorbent.

SO_2 capture did not improve significantly when testing with calcium-lignosulfonate-treated hydrate. Data for pulverized limestone (95% through 325 mesh) were limited and showed considerable variability. The limestone tests, which included low- (down to 90 MWe), intermediate- (128 MWe), and full-load (169 MWe) operation, showed a clear advantage for the increased residence time available at low load. In general, the SO_2 removal performance for pulverized limestone was about 60% of the performance for hydrated lime.

Optimized full-load SO_2 removal efficiency on hydrated lime was 56% at Ca/S = 2:1 and 63% at Ca/S = 2.5:1. At intermediate load, SO_2 removal was 60% at Ca/S = 2:1 and 67% at Ca/S = 2.5:1. The increase in SO_2 capture at intermediate boiler load is attributed to an increase in residence time in the 2300 to 1650°F (1260 to 890°C) sulfation "window" at intermediate load. SO_2 capture improved with increasing injector discharge velocity up to 300 ft/sec (91 m/sec). Tests conducted at 450 ft/sec (137 m/sec) showed no additional improvement in SO_2 capture. No significant effect of injector tilt on SO_2 capture was measured during this optimization testing. Boiler operation, however, as measured by the ability to maintain superheat and reheat outlet temperatures, was improved during injection through the middle elevation when the injectors were tilted downward. Full load boiler operation was further improved by injecting through the lowest elevation with the injectors tilted upward.

The overall performance of the sorbent injection system was good throughout the optimization test period. The primary operational problem during this period was the unreliability of the solids pumps in both the long term and day bin areas. In the long-term bin area, the solids pump was able to supply only 11 tons/hr (10 tonnes/hr) of sorbent to the day bins versus the design rate of 20 tons/hr (18.1 tonnes/hr). By removing the solids pump and discharging from the existing rotary feeder directly into a "pick-up tee," the required capacity was achieved and maintained through the remainder of the test program. The solids pumps in the day bin area also proved troublesome. While the pumps were able to achieve the required maximum capacity of 7.5 tons (6.8 tonnes)/hr/pump, it was necessary to operate the pumps at the unusually high screw speed of 1500 rpm to attain this feed rate. The pumps were not able to operate continuously at this speed. Since this was unacceptable for long-term continuous demonstration testing, the solids pumps were removed and replaced with rotary airlock feeders which, in turn, discharged into "pick-up tees." This arrangement operated well during both optimization and continuous demonstrating testing, although the rotary feeders repeatedly experienced an unanticipated problem: hard deposits on the feeder drum surfaces. This required occasional cleaning but did not interrupt the demonstration tests.

At the discharge of the injectors, hard deposits formed inside the nozzle tips which restricted, but did not completely close, the nozzles. This necessitated periodic removal and cleaning of the injectors to permit design air/sorbent flow rates. The mechanism for formation of these deposits is not yet understood.

SO_2 Removal Performance: Demonstration Testing

A primary objective of the Tangentially Fired LIMB Demonstration Project was to evaluate the long-term effectiveness of the integrated LIMB system in achieving the SO_2 and NO_x emissions reduction objectives and establish the long-term effects on boiler, ESP, and ash handling system operation. Three long-term demonstration tests were conducted. Test duration and gaseous-emission data collection objectives for these tests were established in accordance with Performance Testing requirements contained in Vol. 44, No. 113 of the *Federal Register*. These requirements may be satisfied in as few as 22 days (out of 30) if at least 18 hours of acceptable continuous emissions monitoring (CEM) data are produced each day. Because of the high quality of CEM data, it was possible to complete each of the demonstration tests after only 22 to 24 days, having satisfied test duration requirements.

During the demonstration tests, the boiler was operated in its normal duty cycle. Sootblowing and ash handling system operation were adjusted as required by LIMB operation. ESP operation and humidification of the gas and solids entering the ESP were adjusted to conform to opacity requirements, except during ESP performance tests when additional requirements were specified.

The sorbent injection configurations and operating conditions were selected for the demonstration tests to maintain good boiler performance and operability as well as achieve good SO_2 capture performance. Thus, when injection was through the middle elevation, the injectors were tilted downward to improve boiler temperature control. The first demonstration was conducted with lignosulfonate-treated hydrate as the sorbent. Untreated commercial hydrate was used for the second and third demonstration tests. The SO_2 removal efficiencies at the Ca/S molar ratios of commercial interest (Ca/S = 2:1 and 2.5:1) were essentially the same for all three tests, averaging 44% at Ca/S = 2:1 and 50% at Ca/S = 2.5:1. These levels are lower than those measured during optimization testing. Two factors that adversely impacted the SO_2 removal performance were sootblowing requirements and data interval selection. During continuous injection of sorbent, the Unit No. 2 sootblowing system was operated almost continuously to maintain critical temperatures within limits. Continuous cleaning may reduce secondary SO_2 capture by deposited sorbent material, thereby reducing overall SO_2 capture. Sootblowers were not operated during individual optimization tests. The second factor–data interval selection–was also affected by sootblower operation. While it was possible to determine maximum SO_2 capture (minimum CEM SO_2) for individual optimization test points without sootblower operation, it was not possible to obtain continuous demonstration test periods of sufficient duration without including at least one sootblowing cycle. This resulted in the requirements to use average, rather than minimum, CEM SO_2 levels to define SO_2 capture. Therefore, the impact of the continuous sootblowing requirement tends to be considerable.

Much of the first demonstration test was conducted at minimum sorbent feed in response to concerns over indications of deposit buildup on the floors and turning vanes of the ESP inlet ducts. The ducts were cleaned during a subsequent non-LIMB-related outage. The second and third demonstration tests were conducted at design sorbent feed rates with minimal deposit problems, reflecting the effectiveness of improved humidification lances that were installed for these tests.

ESP and Humidifier Performance

The Yorktown Unit No. 2 ESP has a specific collection area (SCA) of 720 ft^2/1000 acfm (14 m^2/1000 m^3/sec) of treated gas. This exceptionally large ESP provided an opportunity to evaluate the impact of LIMB on ESP performance over a wide range of conditions. Prior to the start of optimization testing, a test was conducted with design sorbent feed rates but without humidification. The ESP performance deteriorated rapidly after only a few hours of operation. This was consistent with results obtained at Edgewater. With the humidification system in operation, it was possible to maintain ESP performance at or near its pre-LIMB levels. Throughout the optimization and first demonstration test periods, water distribution was poor, resulting in repeated problems with deposits in the ESP ducts, on the ESP inlet turning vanes, and on the humidification lances themselves. Destructive examination of two lances revealed weld cracks that allowed the air and water to mix within the lances, producing severe maldistributions of water. Lances fabricated with revised procedures significantly improved water distribution with a dramatic reduction in duct and turning vane deposits. Opacity was always maintained within compliance limits throughout the three continuous demonstration tests.

ESP performance tests were conducted during the baseline test and the first two demonstration tests. Total particulates entering and leaving the ESP, particle size distributions, and particle resistivities were measured under various ESP operating conditions. Fields were taken out of service to simulate smaller ESPs, with the objective of identifying the smallest ESP that could operate with LIMB without modification. Performance test results showed that essentially no performance losses were seen during ESP operation with SCAs of 720 to 480 ft^2/1000 acfm (14 to 9 m^2/100 m^3/sec) of treated gas, under the same LIMB and humidifier operating conditions. Further SCA reductions resulted in increases in opacity. Collection efficiencies were comparable during the three performance tests. The average collection efficiency with LIMB was 99.21%, versus 99.42% without LIMB. Flyash resistivity varied over a narrow range. Baseline resistivity without LIMB was 3.7 x 10^{10} ohm-cm. Resistivity during the first performance test with LIMB was 1.4 x 10^{11} ohm-cm. During the second performance test with LIMB, resistivity was slightly lower at 1.4 x 10^{10} ohm-cm, suggesting improved humidification effectiveness with the modified lances.

An unexpected ESP performance effect was noted during LIMB testing with pulverized limestone. The humidifier was turned off during the final 2 days of testing. Opacity did not increase above non-LIMB levels. No ESP performance measurements, including flyash resistivity, were made during limestone testing.

Ash Handling Effects

The Yorktown Ash Handling Facility features a single ash silo that receives flyash from all three units. When Units No. 1 and 2 were both in operation, LIMB ash from Unit No. 2 was mixed with, and diluted by, ash from Unit No. 1. Under these conditions, the mixed ash was easier to handle and produced less steaming than in previous LIMB field demonstrations. It was, nevertheless, more difficult to entirely remove the ash from ash truck beds than when no LIMB ash was present. When Unit No. 1 was not in operation, the LIMB ash was somewhat more difficult to process through the rotary conditioner, which received the ash from the silo, added water while mixing, and discharged the mixture into trucks. Steaming was greater for LIMB-only ash than for the mixed Unit No.1/Unit No. 2 ash.

Long-term continuous testing of the LIMB system placed increased strain on the Yorktown ash handling system. The concentration of LIMB ash in the ash silo increased over that experienced during optimization testing. This resulted in a greater degree of steaming of the conditioned LIMB ash in the ash trucks and at the disposal site. The LIMB ash exhibited a much greater tendency to set up in the truck beds than did non-LIMB ash or a mixture of Unit No. 1 ash with no LIMB and Unit No. 2 ash with LIMB. Frequent problems of material setting up in the truck beds were experienced. Decreasing the water to the rotary conditioner (mixer) appeared to reduce problems of setting up and steaming.

The quantity of material produced during continuous testing taxed the Yorktown ash handling personnel and equipment. A substantial increase in the amount of time Unit No. 2 was operated at full load, following the substantial heat rate improvement as a result of the steam turbine replacement, contributed to this problem.

All of the LIMB ash was placed in one area of a single ash cell at the Yorktown ash disposal site. No significant problems were experienced due to the cementitious properties of the LIMB ash. It was possible to spread the LIMB ash by bulldozer with only occasional steaming problems.

Boiler Performance and Operability

During LIMB operation, lime, ash, and LIMB products accumulated on boiler heat transfer surfaces at a greater rate than during normal non-LIMB operation. This reduced the heat absorption effectiveness, shifted the gas temperature profile in the boiler downstream, and reduced overall boiler efficiency. Reheat outlet temperature, for example, typically dropped about 30 F° (16.7 C°) during continuous full-load sorbent injection at Ca/S = 2:1. Frequent sootblowing recovered essentially all of the temperature loss, suggesting friable, easily removable deposits. The increase in the temperature of the gas entering the ESP inlet ducts (and the humidifier) as a result of the shift in heat absorption pattern during sorbent injection was typically 75 to 80°F (23.9 to 26.7°C). This shift in absorption and the concurrent increase in gas heat loss resulting from the increase in gas flow and deposits on heat transfer surfaces typically resulted in a reduction of 1.5 points in boiler efficiency during continuous sorbent injection relative to the efficiency level during continuous testing without sorbent injection. The net boiler efficiency reduction was about 1 point after adjusting for carbon-in-ash and calcination/sulfation effects. Optimized sootblower coverage and operation would likely reduce this penalty.

During injection of finely pulverized limestone, boiler effects were significantly different than those observed during injection of hydrated lime. Superheater and reheater outlet temperatures did not drop as much as during hydrate injection, suggesting a decreased tendency of deposits to build up on the heat transfer surface. As a consequence, sootblowing requirements were significantly reduced.

No LIMB-related boiler outages were experienced during any part of the LIMB test program at Yorktown, including the three demonstration tests. Boiler operability was, however, adversely affected by the demonstration coal and operation of the LIMB system, in addition to the effects of the new Unit No. 2 steam turbine. Increased slagging at the burner corners was noted throughout the LIMB test program. However, slag formation on the waterwalls was, generally, not severe and did not require operating the wall sootblowers. Ash/sorbent deposits built up around many of the sorbent injection ports. These deposits would break away and fall into the boiler ash hopper and were ultimately removed from the boiler via the wet bottom ash removal system. Occasional problems were experienced in the bottom ash removal system due to the high lime content of this material.

Economics and Commercialization

Capital and operating costs associated with a 180-MWe "base case" LIMB system were generated, based on actual Yorktown costs, and used as a basis for a sensitivity study on the effects of unit size and various process parameters on LIMB economics. The Yorktown system, plus a new dedicated ash silo, had a total capital requirement of $81/kW, with 2.5% S coal at a Ca/S of 2.5:1. Levelized cost for the base case was $781/ton ($861/tonne) SO_2 removed. These costs are lower than those reported for previous LIMB demonstrations, indicating a maturing of this SO_2 control technology.

Capital investment increased 46%, to $118/kW, for a 100-MWe unit but decreased 23%, to $62/kW, for a 300-MWe unit, clearly showing the economy of scale for a retrofit LIMB system.

LIMB has been demonstrated as a viable low-cost option for achieving moderate levels of SO_2 reduction with capital and operating costs that are substantially below those of conventional flue gas desulfurization systems. The 1990 Clean Air Act Amendments (CAAAs) focus on high SO_2 removal efficiency technologies. They also make SO_2 allowances (credits) available at a fraction of the cost of FGD systems. Consequently, the domestic market for LIMB, with its moderate SO_2 removal, is currently best suited to older, small to intermediate units, which might otherwise be retired, and also to combinations of LIMB with back-end SO_2 removal processes. An example would be LIMB combined with the ADVACATE process to achieve high overall SO_2 removals. Thus, in the contemporary domestic utility market, LIMB alone is postured as a "niche" technology for units requiring moderate levels of SO_2 control. However, if combined with a complementary back-end system, LIMB can offer the potential for competitive (i.e., 90 +%) SO_2 removals at favorable capital and operating costs.

Summary and Conclusions

The viability of LIMB as a low-cost option for achieving moderate levels of SO_2 reduction on tangentially coal-fired utility boilers was established under the EPA-sponsored LIMB Demonstration Program at Virginia Power's 180-MWe Yorktown Unit No. 2. Extensive parametric testing to evaluate various sorbent injection configurations and process variables was conducted over a range of boiler loads. Full-load SO_2 removals of up to 56 and 63% at Ca/S molar ratios of 2:1 and 2.5:1, respectively, were achieved, substantially above the project objective of 50% SO_2 removal at a Ca/S molar ratio of 2.5:1. Higher SO_2 removals were achieved at intermediate boiler load. Testing was conducted on calcitic hydrated lime, with and without calcium lignosulfonate treatment, each from two suppliers. SO_2 removal did not increase significantly during testing with the treated hydrates. Three continuous long-term tests of the LIMB system, each of from 22 to 24 days in duration, were conducted over the normal boiler operating range. Lower SO_2 removal levels were seen during this continuous testing, due, largely, to the need to continuously operate the sootblowers to remove accumulated LIMB solids from boiler heat transfer surfaces. Commercial LIMB installations would require increased sootblower coverage to maintain boiler surface cleanliness. No boiler outages attributable to LIMB were experienced during the entire LIMB test program.

ESP performance was maintained during LIMB operation by humidification of the gas stream at the inlet to the ESP. No deep humidification for enhanced SO_2 removal was attempted. Early problems with deposition of LIMB solids on duct surfaces were resolved by improvements in humidifier lance fabrication procedures. Opacity was maintained within compliance requirements throughout the test program.

LIMB ash was collected in, and processed from, a common ash silo that received material from both coal-burning units. Problems were experienced with material setting up in ash truck beds. Steaming of material in the ash trucks varied with the concentration of LIMB ash, decreasing as dilution from non-LIMB Unit No. 1 ash increased. A dedicated ash silo would be a necessary component of a commercial LIMB installation.

The LNCFS Level II firing system achieved a 42% reduction in NO_X at full boiler load and 33% reduction in NO_X at intermediate boiler load, relative to baseline levels with the original tangential firing system, under comparable boiler operating conditions. These levels were below the program NO_X objective of 0.4 lb/10^6 Btu (172 mg/J).

Capital and levelized costs associated with the 180 MWe Yorktown LIMB system were determined to be \$81/kW and \$781/ton (\$859/tonne) SO_2 removed, respectively, based on actual equipment and operating costs for the Yorktown system, plus the cost of a new ash silo. Sensitivity studies showed the cost effectiveness of LIMB on tangentially fired units from 100 to 300 MWe operating on coals with 2 to 3% sulfur.

The commercial applicability of a standalone LIMB system is currently considered to be that of a "niche" technology for certain older units as a result of the 1990 CAAAs. In combination with a complementary "back-end" SO_2 removal process, however, LIMB offers the potential of achieving compliance levels of SO_2 removal at costs that are significantly below those of conventional FGD systems.