



Project Summary

Pilot-Scale Evaluation of LIMB Technology

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In support of EPA's LIMB (Limestone Injection Multistage Burner) development program, Southern Research Institute (SoRI) performed pilot-scale studies of sulfur capture in the LIMB process and the effect of LIMB on particulate properties and electrostatic precipitator (ESP) performance. The sulfur capture studies showed that hydrated lime was generally superior to limestone as a sorbent for in-furnace sulfur removal. For both sorbents, downstream injection was found to be preferable over near-flame injection. With hydrated lime, the optimum injection temperature was found to be about 1200°C, where utilizations as high as 30% were achieved. The injection of either sorbent resulted in a large increase in the electrical resistivity of the ash, which could severely impact ESP performance. Laboratory and pilot-scale studies showed that the resistivity increase could be offset by flue gas conditioning using sulfur trioxide (SO₃) or water vapor. With limestone injection, acceptable resistivity levels were restored by the injection of 30 ppm of SO₃.

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

EPA's Air and Energy Engineering Research Laboratory (AEERL) is developing the Limestone Injection Multistage Burner (LIMB) process as a low-capital-

cost control option for compliance with possible acid rain legislation. The purpose of the LIMB process is to achieve a 50% reduction in emissions of sulfur oxides (SO_x) at a calcium-to-sulfur (Ca/S) molar ratio of 2. This would make the process applicable to a significant number of existing coal-fired boilers that would probably be impacted by acid rain legislation. In a retrofit application of LIMB, the sorbent (limestone or hydrated lime) is injected downstream of the burner zone using a retrofitted system for sorbent handling and injection. The resulting particulate (calcium sulfate, unreacted calcium oxide, and fly ash) is collected in the existing ESP or baghouse. Since sorbent utilization is generally low (~ 12-15% for limestone and 25-30% for hydrated lime), it is necessary to use more than (typically twice) the stoichiometric requirement of the sorbent. This results in a significant increase in the particulate loading that must be handled in the boiler system and particulate collector. The particle size and electrical resistivity of the particulate are also affected by the sorbent injection, and these effects can severely impact particulate collection efficiency.

Objectives and Scope

The original goal of this research program was to study the effect of the LIMB process on particulate properties and ESP performance. As part of this work, it was necessary to evaluate the effectiveness of various sorbents in terms of sulfur capture. The latter evaluations prompted an expansion of the project scope to include a study of sulfur capture in the LIMB process. Thus, the project report covers two areas of LIMB-related research: (1) Studies of sulfur capture in



the LIMB process, and (2) Studies of the effect of LIMB on particulate properties and ESP performance. The goal of the sulfur capture studies was to investigate the effects of sorbent type, injection conditions, particle size, and promoters on sulfur capture. The goal of the particulate and ESP work was to examine the effects of LIMB on particulate loading, particle size distribution, and electrical resistivity (three of the major factors influencing ESP performance). Prior to the sulfur capture or particulate work, however, it was necessary to verify the ability of the SoRI pilot-scale coal combustor to simulate utility boiler conditions and ash characteristics. This was necessary to ensure that the LIMB-related testing done in this unit could be applied to full-scale utility boilers. The goal of the verification effort was to show that the ash produced by the SoRI combustor was similar to full-scale ash from the same coal in terms of particle size distribution, morphology, electrical resistivity, and chemical composition. These comparisons showed excellent correspondence between the combustor ash and ash produced from the same coal in a full-scale unit.

Results and Discussion

Sulfur-capture screening studies of sorbent type and injection location were conducted with three sorbents: Vicron 45-3 calcitic limestone (V), Longview calcitic hydrated lime (L), and Corson pressure-hydrated dolomitic lime (C). Tests were performed with both coal firing and SO₂-doped natural gas firing. The injection location was varied from the burner (B) to furnace section 4 (S-4), which is near the furnace outlet. The corresponding gas temperatures and sulfur captures (at Ca/S = 2) are:

Injection Location	Coal Firing		Capture, %		
	Temperature °C		V	L	C
B	ND		35	37	ND
S-3	1237		40	61	81
S-4	1132		32	53	ND

Injection Location	Natural Gas Firing		Capture, %		
	Temperature °C		V	L	C
B	1477		30	29	ND
S-3	1332		24	40	80
S-4	1126		28	45	ND

At equivalent Ca/S ratios, the sorbents are ranked in performance: pressure-hydrated dolomitic lime > calcitic hydrated lime > limestone. This may be misleading, however, since the dolomitic lime also contains 1 mole of magnesium per mole

of calcium. Thus, a much greater weight of dolomitic lime is required to achieve the same Ca/S ratio. When compared at equivalent mass injection rates, the calcitic and dolomitic hydrated limes give virtually identical performance, despite the fact that the magnesium is inert and does not react with SO₂ under furnace conditions. This suggests that the magnesium acts to facilitate the reaction between the CaO and SO₂. For both the limestone and the hydrated lime, the optimum injection temperature was about 1237°C with coal firing. Since this was optimum for both the limestone and hydrated lime, the other injection locations were not tested with the pressure-hydrated dolomitic lime.

The dependence of sulfur capture on the sorbent particle size was investigated using size-fractionated samples of ash/sorbent mixtures collected isokinetically at the exit of the combustor system. Chemical analyses of these fractions showed that sorbent utilization was a strong function of particle size for both the limestone and the hydrated lime. The data obtained with both sorbents injected at S-4 (~1132°C) are:

Particle size, μm	0.5	1.0	2.0	5.0	10	20
Utilization, %						
Vicron limestone	35	32	22	15	14	ND
Longview hydrate	25	26	25	18	15	13

Sorbent utilization decreases with increasing particle size for both sorbents. This points out one advantage of hydrated lime over limestone: the mass median particle size is much smaller (~2 vs. 15 μm). It also illustrates the potential performance gains from ultrafine grinding of the limestone, to the extent it is practical.

The promotion of sulfur capture by the use of a sodium-based additive was investigated using 5 wt% of sodium bicarbonate premixed with the Vicron limestone. With natural gas firing and sorbent injected through the burner, the sulfur capture (at Ca/S = 2) was almost doubled by the promoter (32% vs. 60% capture). However, this effect was largely eliminated when fly ash was added to the system to simulate coal firing and when similar tests were conducted during coal firing. This suggests that the volatilized sodium is being lost to the fine fly ash particles, so that it is not available for promotion with coal firing.

The effect of sorbent injection on the electrical resistivity of the ash was determined through in situ resistivity measurements in the pilot-scale combustion system and through IEEE laboratory tests

in controlled environments. The baseline (without sorbent injection) resistivity values ranged from 2x10⁸ to 10¹⁰ ohm-cm in the presence of 22 to 40 ppm of naturally occurring SO₃. When limestone was injected, and virtually all of the SO₃ was removed (< 0.2 ppm remaining), the in situ resistivity was increased to about 10¹² ohm-cm. In laboratory tests performed at the same temperature (~150°C), the resistivity was 9x10¹² ohm-cm in the absence of any SO₃. With 5 ppm of SO₃ in the laboratory test cell, the resistivity was reduced to 5x10⁸ ohm-cm, illustrating the extreme sensitivity to residual SO₃ levels. Higher levels of SO₃ are required to produce this effect in the combustor system due to the much shorter exposure time (days in the laboratory vs. seconds in the combustor system). The ability to restore acceptable SO₃ levels and resistivity values was demonstrated using a catalytic SO₃ generator and injection system. The results of these studies are:

SO ₃ injected, ppm	0	10
Resistivity, ohm-cm	1.5x10 ¹²	2x10 ¹¹

20	30	40
3x10 ¹⁰	3x10 ⁹	2x10 ⁹

These results indicate that resistivity can be restored to acceptable levels at reasonable SO₃ injection rates. This was also true with hydrated lime injection, although more SO₃ was required, and the amenability of the ash to conditioning was much more sensitive to sorbent injection location. With injection at S-3 (~1237°C), 120 ppm of SO₃ was required to reduce resistivity to 10¹⁰ ohm-cm. Despite this large injection rate, less than 8 ppm of SO₃ remained in the gas phase at the exit of the system, suggesting that almost all of the SO₃ was adsorbed on the particulate.

The effect of sorbent injection on the particulate size distribution was evaluated through in situ measurements made in the pilot-scale system using cascade impactors, an optical counter, and an electrical mobility analyzer. With limestone as the sorbent, burner injection produced fine (0.1-1.0 μm) particle concentrations that were an order of magnitude higher than with downstream injection at S-4. This suggests that the limestone decrepitates at the higher temperatures associated with burner injection. With downstream injection at

S-4, the particle size distributions obtained with limestone and hydrated lime were similar, despite the much finer size of the original hydrated lime.

The effect of sorbent injection on ESP performance was predicted using the resistivity values and the particle size data in the EPA/SoRI model of electrostatic precipitation. The results for the baseline (no sorbent) and the limestone injection cases are:

	<i>Baseline</i>	<i>Limestone</i>
<i>Total particulate loading, mg/m³ (gr/ft³)</i>	<i>6,876(3.00)</i>	<i>15,586(6.8)</i>
<i>Mass median particle size, μm</i>	<i>14</i>	<i>16</i>
<i>Resistivity, ohm-cm</i>	<i>2x10¹⁰</i>	<i>2x10¹²</i>
<i>SCA, m²/m³/sec (ft²/kacfm)</i>	<i>44.3(225)</i>	<i>44.3(225)</i>
<i>Average applied voltage, kV</i>	<i>41.7</i>	<i>29.7</i>
<i>Current density, nA/cm²</i>	<i>26.3</i>	<i>1.50</i>
<i>Predicted collection efficiency, %</i>	<i>99</i>	<i>93</i>

The predicted degradation in ESP performance corresponds to a factor of 16 increase in emissions. If the original resistivity and electrical operating conditions are restored by flue gas conditioning, the collection efficiency can be brought back to about 99%, but the emissions would still be higher by a factor of 2.3 due to the higher inlet loading. Further improvements to the ESP internals would be required to restore original emission levels with such a small ESP. Larger units may have excess capacity that would allow emissions to be controlled at a comparable level without further modifications.

Conclusions and Recommendations

Based on the sulfur capture data from this study, it appears that hydrated lime must be used in lieu of limestone to meet the performance objective of 50% SO₂ control at Ca/S = 2. The studies of size-fractionated samples suggest that further improvements in hydrated lime performance may be possible by fractionating out the smallest particles. The practicality of this concept has not yet been evaluated. Although limestone performance improves with decreasing particle size, it does not seem feasible to attain 50% removal by ultrafine grinding due to the power requirements and cost. Improvement of sorbent performance by the use of a sodium-based additive does not appear feasible due to the apparent loss of the volatilized sodium on the fly ash particles. Additives that enhance the specific surface area of the sorbent may be advantageous. Whatever sorbent is selected, it should be injected downstream

from the burner, away from the flame zone. This study suggests that the optimum injection temperature is about 1237°C, although a higher injection temperature may be needed in a full-scale boiler to allow for mixing effects.

A retrofit application of LIMB technology can have a devastating impact on ESP performance, especially for older plants with undersized ESPs. In these

plants, it appears likely that flue gas conditioning and modification of the ESP internals will be necessary to restore acceptable performance. The use of water sprays may be advantageous to gain the benefits of cooling, conditioning, and reducing the gas flow. This would provide an increase in the effective specific collection area (SCA) to complement the reduction in resistivity. Other potential remedial measures would include the installation of a cold-pipe precharger section, conversion of the ESP to an ESOX process, or even the use of a wet ESP. Enlargement of the SCA is not feasible unless it is accompanied by the use of conditioning or other modifications. Space limitations also make this difficult at many older plants. Pilot testing of various ESP modifications is required to select the optimum remedial measures for a LIMB retrofit. Such pilot test should include an evaluation of electrode deposits and rapping requirements.

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The complete report, entitled "Pilot-Scale Evaluation of LIMB Technology," (Order No. PB 87-224 630/AS; Cost: \$18.95, subject to change) will be available only from:

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