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Project Summary

Evaluation of Sulfur Capture Capability of a Prototype Scale Controlled-Flow/Split-Flame Burner

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This report describes large pilot demonstration of sulfur capture using *copulverization* of limestone with a high sulfur eastern bituminous coal and combustion of the mixture using Foster Wheeler's commercial Controlled-Flow/Split-Flame (CF/SF) Low NO_x burner. Optimization of the sulfur capture was attempted through the use of overfire air and two proprietary flame temperature control methods. Additionally, the effects of excess air changes, load changes, and different calcium/sulfur mole ratios (Ca/S) were evaluated. The CF/SF burner was chosen because of its internal staging and proven low NO_x capabilities; its use in combination with two flame temperature reduction methods could reduce the flame temperature to minimize dead burning of limestone and thus enhance SO_2 capture. Although the use of flame temperature reduction and overfire air improved the SO_2 capture, the optimum SO_2 capture of 29% at a Ca/S of 2.15 was low. Operation under optimum SO_2 capture mode resulted in measured NO_x emissions of 0.19 lb/10^6 Btu*; CO was less than 25 ppm at an excess oxygen level of 3.0%. The testing was done at a 42 x 10^6 Btu/hr heat input horizontally fired pilot plant configured like a conventional pulverized-coal-fired boiler.

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

This report summarizes a joint Environmental Protection Agency (EPA)/Foster Wheeler Energy Corporation (FWEC) test program to evaluate the in-situ SO_2 reduction capabilities of limestone injection with a low NO_x internally staged burner when the limestone and coal are copulverized and injected through the coal nozzle. The tests were performed between April 13 and May 16, 1983. The burner used is Foster Wheeler's commercial Controlled-Flow/Split-Flame (CF/SF) burner (Figure 1). The test program was based on EPA's concept that, if the limestone is intimately mixed with the coal during the pulverization process and burned under low NO_x conditions, high SO_2 capture levels can be obtained. When this method of limestone injection is combined with the low flame temperature characteristics of the CF/SF burner and FWEC's proprietary flame temperature reduction methods, the total SO_2 capture may be enhanced. Successful achievement of the Limestone Injection Multistage Burner (LIMB) process may result in SO_2 reductions at a much lower cost than with conventional wet removal methods. Although this technique may

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

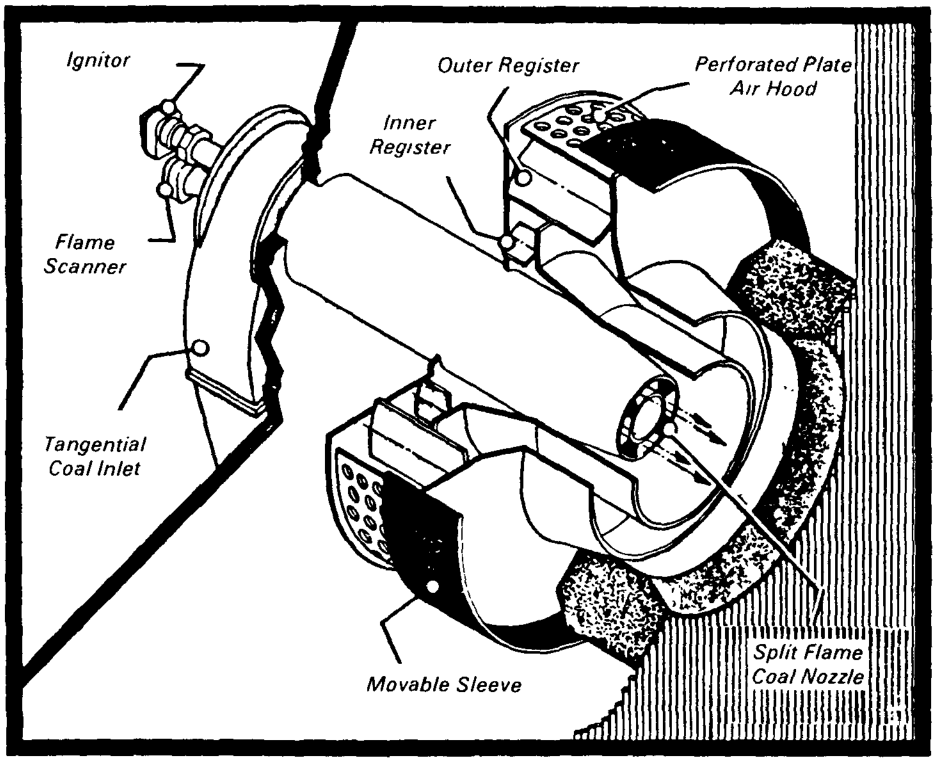

Figure 1. *Controlled-flow/split-flame (CF/SF) burner*

not replace wet methods of SO_2 reduction, it would be appropriate for retrofits of existing uncontrolled boilers firing high sulfur coals.

The relatively short flame produced by the CF/SF burner is especially favorable for retrofits where the depth of the furnace is limited. Flames do not extend into the upper furnace which would increase the furnace exit gas temperature (FEGT). Increasing FEGT can cause fouling and slagging as well as uncontrolled steam temperatures and reduced efficiency.

The tests were run at FWEC's Japanese licensee Ishikawajima Harima Heavy Industries Co., Ltd. (IHI) Aioi Works in Japan where IHI has a large coal combustion test facility. The fuel used is a high sulfur western Pennsylvania bituminous coal from the Middle Kittaning Seam with a sulfur content of about 3.1%. An analysis of the fuel is shown in Table 1.

This fuel was chosen because it is typical of the fuels used in older boilers that may be susceptible to acid rain control legislation. The limestone chosen is Vicron from California's Lucerne Valley. It is a high calcium limestone and was chosen because it had been used before in other EPA test programs and would allow more relevant comparison of SO_2 capture among EPA test programs. An analysis of the limestone is shown in Table 2.

Table 1. *Analysis of Test Fuel*

Fuel Name *Origin*	*Middle Kittaning* *Western PA*
Proximate	
Fixed Carbon, %	*50.1*
Volatiles, %	*34.6*
Ash, %	*9.5*
Moisture, %	*5.8*
Ultimate	
Carbon, %	*68.7*
Hydrogen, %	*4.6*
Oxygen, %	*7.1*
Nitrogen, %	*1.2*
Sulfur, %	*3.1*
HHV, Btu/lb	*12,818*
Operating Conditions	
Fuel Rate	
kg/hr	*1,500*
Heat Input	
10^6 Btu/hr	*42.3*

Table 2. *Analysis of Test Limestone*

Name	*Vicron*
Origin	*Lucerne Valley, CA*
$CaCO_3$, %	*98.1*
$MgCO_3$, %	*0.9*
SiO_2, %	*0.11*
Al_2O_3, %	*0.01*
Fe_2O_3	*0.01*
Moisture, %	
Surface, %	*0.03*
Inherent, %	*0.1*

Test Facility Description

IHI's test facility is designed to evaluate fuels and combustion systems on a prototype scale (up to 50 x 10^6 Btu/hr). Functionally useful steam is not generated so that operation and design changes do not affect the steam supply to industrial or power generation equipment. This provides an atmosphere conducive to testing without interruption.

The pulverized coal system differs from that which is in current commercial practice on pulverized coal-fired boilers. An indirect storage system is used and allows wide variations in air/coal ratios. The limestone bunker supplies, via a feeder, a Foster Wheeler vertical pulverizer. The coal and limestone are mixed and pulverized in the mill to a minimum coal fineness of 70% through 200 mesh. The pulverized fuel is carried pneumatically to a cyclone separator where the fuel is separated from the carrier air and fed into a pulverized fuel bin; a baghouse filters the air before exhausting to the atmosphere, and collects the fines which are also fed into the fuel bin. A screw feeder at the botton of the fuel bin feeds the pulverized fuel over a weighing device and into a fuel/primary air mixer. This allows great flexibility in controlling the primary air to fuel ratio.

The facility is fired by a single burner which simplifies burner flame studies since flame interactions do not occur. The furnace is refractory lined to simulate utility size furnace heat release rates. Nine view ports along each side of the furnace at the burner level, along with five others at upper elevations, allow the operator to observe the flame and take temperature measurements at different points along the flame's length. Overfire air ports are available for staging tests.

The combustion air takes the following path through the system. A forced draft fan supplies atmospheric air to the shell side of a tubular air preheater where it is heated up to the range of 536 to 653°F. Hot air is mixed with cold tempering air to obtain the desired primary air temperature. The remaining hot air is then supplied to the windbox. Combustion products pass out of the furnace, through a convection section and through the tube side of the preheater, after which it is cleaned of particulate matter in a multiclone and then a baghouse. After the baghouse, an induced draft fan forces the combustion products to the stack. Table 3 summarizes basic system parameters.

Table 3. *System Specifications*

Furnace	*Width*	*3100 mm (10.2 ft)*
	Depth:	*4500 mm (14 8 ft)*
	Height.	*11,000 mm (36 ft)*
Burner	*Coal*	*200 kg/h (4,400 lb/h)*
	Overfire Air	*As Necessary*
	Heat Liberation·	*Max 111 x 10^6 kcal/m^3hx* *(12.5 x 10^3 Btu/ft^3h)*
Coal Handling	*Elevator*	*1. 5 T/h (11 x 10^3 lb/h)*
	Bunker·	*1. 10 m^3 (350 ft^3)*
	Table Feeder:	*2. 15 T/h (33 x 10^3 lb/h) max.*
Pulverizer	*Type:*	*IHI-FW Ring & Roller Mill MBF-16*
	Capacity.	*8 T/h (17 x 10^3 lb/h)*
	Fineness:	*70% through 200 mesh*
Tubular Air Preheater	*Air Flow Rate:*	*31 T/h (68 x 10^3 lb/h)*
	Air Temp. Inlet:	*20°C (70°F)*
	Air Temp Outlet:	*320°C (610°F)*
Particulate Collection Equipment	*Type:*	*Baghouse following a multiclone*
	Gas Flow Rate·	*20,000 Nm^3/min (12440 scfm)*
	Dust Loading	
	Inlet:	*36, g/Nm^3 (87 gr/scf)*
	Outlet:	*0.1, g/Nm^3 (0.242 gr/scf)*
Limestone Handling	*Bunker.*	*225 kg/h (500 lb/h) Max.*
	Feeder:	*20-320 kg/h (50-700 lb/h)*

Test Methodology

The intention of the test program was to evaluate various operating modes for their potential to improve SO_2 reduction obtainable by copulverization of coal and limestone. A number of variables were evaluated:

Overfire Air
Furnace Excess Oxygen
Calcium to Sulfur Mole Ratio
Two Proprietary Flame Temperature
  Reduction Methods
Load
Overfire Air Injected Higher
  in the Furnace
Burner Parameters

These variables were thought to have the greatest potential in improving SO_2 capture. This was especially true of the two flame temperature reduction methods where, in the past, peak flame temperature reductions of 70 to 90°F were seen singly and over 200°F was obtained when these methods were combined

The in-depth evaluation consisted of a complete full factorial matrix of tests: testing each variable in combination with every other combination of other variables Furnace excess oxygen was an exception in that only a half factorial was planned

Simultaneously with the determination of the effect each variable has on SO_2 reduction, SO_3, NO_x, CO, and total hydrocarbons were measured. The intention was to observe the effect each variable had on other emission species to evaluate the overall emission characteristics of each combination that improved SO_2 reduction.

Major Results and Conclusions

Gaseous Emission Levels

- SO_2 Emissions

The addition of limestone to the fuel at a Ca/S of 2 15 resulted in an optimum emission reduction of 28%. This is an improvement over the 22-23% found without any changes in operation of the burner-furnace. This optimum was found with a combination of 3% excess O_2, 20% overfire air, and with FW's proprietary flame temperature reduction method #2 (FTRM#2). Another combination of operating variables (5% excess O_2 and FTRM #2) resulted in higher SO_2 reduction at the same Ca/S, but it also increased NO_x emissions such that the total of acid forming emissions of SO_2 and NO_x was higher than for the optimum case.

Increasing the limestone addition rate during otherwise normal operating conditions (i.e., optimum NO_x burner settings, 3% excess O_2, no limestone, no overfire air, full load, and no flame temperature reduction methods in use), to a Ca/S of 3.26 resulted in 33.4% reduction. This increase in SO_2 reduction is essentially linear up to Ca/S = 3.26. If the optimum SO_2 control method is extrapolated to Ca/S = 3.26, the SO_2 reduction would increase to 43%. Although it is generally conceded that SO_2 reduction is not linear with Ca/S, a linear relationship was found up to a Ca/S of 3.26, the maximum value tested. However, this optimum occurred with overfire air ports open, resulting in slagging.

- NO_x Emissions

In general, adding limestone to the fuel reduced NO_x by 10%. Under normal operating conditions, the NO_x emission rate measured for the CF/SF burner was 0.32 lb/10^6 Btu.

This represents a 60% reduction from the predicted uncontrolled NO_x emission rate of 0.8 lb/10^6 Btu using this fuel and a pre-NSPS burner at this test facility. Under the conditions of optimum SO_2 reduction, the NO_x decreased to 0 19 lb/10^6 Btu, an additional 41% reduction from 0.32 lb/10^6 Btu (or a total of a 76% reduction from the uncontrolled level). About 25 to 30% of this additional NO_x reduction can be attributed to overfire air (OFA), 10% can be attributed to adding limestone to the fuel, and 1% is attributed to the use of FWEC's proprietary FTRM #2. The negligible NO_x reduction due to the FTRM #2 is expected since the peak flame temperature is already substantially below 2900°F.

- CO Emissions

In general, adding limestone at a Ca/S of 2.15 reduced CO concentrations at the economizer outlet to below 35 ppm corrected to 0% excess

O_2, with one exception. Under normal operating conditions, the CO averaged 39 ppm. Under the optimum SO_2 reduction test conditions, the CO concentration dropped to 24 ppm, a 38% reduction. Half of this reduction can be attributed to limestone addition; the remainder can be attributed to FTRM #2.

- SO_3 Emissions

  In general, adding limestone to the fuel at a Ca/S = 2.15 always reduced SO_3 concentrations to below 20 ppm corrected to 0% excess O_2 regardless of the initial concentration. Under normal operating conditions SO_3 concentrations averaged 28 ppm. Under conditions of optimum SO_2 reduction the SO_3 concentrations were reduced to 8 ppm, a 71% reduction. About equal percentages of this reduction can be attributed to OFA and limestone addition.
- Total Hydrocarbons (THC)

  Limestone addition in many cases decreased the THC emissions, but there were many exceptions. The only operating variable that had a consistent effect on THC was FTRM #1, and it increased THC. Neither excess oxygen nor overfire air had a consistent effect on THC. Under normal operating conditions the THC concentrations averaged 3 ppm corrected to 0% excess O_2. Under conditions of optimal SO_2 reduction the THC was reduced to 1.7 ppm, a 43% reduction. The reduction is attributed to a synergistic effect of the combination of OFA, FTRM #2, and limestone addition since none of these (alone) consistently reduced THC.

SO_2 Capture in the Baghouse

No significant SO_2 or SO_3 reduction was measured across the baghouse with or without limestone addition. SO_3 reduction was measured across the air heater. SO_3 change across the air heater cannot be explained; additionally, the reduction is virtually independent of the presence of limestone. SO_3 concentrations dropped from an average 8 ppm to about 0.3 ppm when limestone was being added; SO_3 was reduced from 18.3 to 0.6 ppm when limestone was not being added, and was further reduced to 0.4 ppm across the baghouse. The air heater is tubular with an exit temperature of about 500°F. Consequently, there should be no SO_3 condensation prior to the baghouse. At these temperatures the SO_3 level should remain constant unless absorption is occurring on some surface. All test results are corrected to 0% excess oxygen.

Table 4. *Ash Fusibility Temperature*

	Ash Fusion Temperatures, °F	
	Test 42	Test 43
Ca/S	0	2.15
Oxidizing Atmosphere		
Deformation	2372	2426
Softening	2408	2453
Hemisphere	2507	2516
Flow	2561	2705
Reducing Atmosphere		
Deformation	1940	2156
Softening	1958	2246
Hemisphere	1976	2345
Flow	2453	2552

Effect on Equipment

- Furnace and Slagging Potential

  No detrimental side effects were noted. The addition of limestone to the fuel did not increase the slagging potential of the coal. The coal was considered to be of medium to high slagging potential. During normal combustion, both with and without limestone, slagging was not evident; but, when overfire air was used, slagging was evident, both with and without limestone. This was fully expected based on an analysis of the ash constituents and oxidizing/reducing fusion temperatures shown in Table 4. These results show that the ash fusion temperatures are higher when limestone is being added at a Ca/S mole ratio of 2.15.

  All ash fusion temperatures increase as the furnace conditions change from reducing to oxidizing. In this case the ash softening temperature increases by 450°F without limestone addition; and by 207°F with limestone. Also all ash fusion temperatures increase with the addition of limestone. The increase is largest under reducing atmosphere. The reducing ash softening temperature increases 288°F, and the reducing hemisphere temperature increases by 369°F when limestone is added to the fuel.
- Baghouse

  The baghouse operated normally during the test program. No increase in pressure drop was seen. The daily start-up/shutdown cycle did not precipitate any bag blinding.
- Burner

  No detrimental side effects were noticed on the burner, flame, or combustion in general.

Metric Conversion

Readers more familiar with metric units may use the following factors to convert to that system.

Nonmetric	Times	Yields Metric
Btu/hr	1.054	kJ/hr
Btu/lb	2.32	J/g
°F	5/9(°F-32)	°C
lb/10^6 Btu	430	ng/J

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***Charles C. Masser** is the EPA Project Officer (see below).*

The complete report, entitled "Evaluation of Sulfur Capture Capability of a Prototype Scale Controlled-Flow/Split-Flame Burner," (Order No. PB 87-168 670/AS; Cost: $18.95, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
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Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

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