United States
Environmental Protection
Agency

Air and Energy Engineering
Research Laboratory
Research Triangle Park NC 27711

Research and Development

EPA/600/S9-86/029 Mar. 1987

EPA

Project Summary

Proceedings: 1986 Joint Symposium on Dry SO_2 and Simultaneous SO_2/NO_x Control Technologies

Richard D. Stern and George R. Offen

The 1986 Joint Symposium on Dry SO_2 and Simultaneous SO_2/NO_x Control Technologies was held in Raleigh, North Carolina, June 2 through 6, 1986. Forty-nine papers were presented by EPA and EPRI staff members, representative of utility companies, equipment manufacturers, sorbent suppliers, and research and development companies under contract to EPA, EPRI, and other research groups. Additionally, researchers from Austria, Canada, Finland, the Federal Republic of Germany, and the Netherlands presented information on world wide technological developments in dry SO_2 control. Specific topics discussed included enhanced sorbent utilization through thermal pretreatment of sorbents or use of hydrated or promoted calcium-based sorbents, effects of temperature and other injection parameters on sulfur capture efficiency, economics of dry sorbent injection, post-furnace injection for SO_2 control, effects of dry sorbent injection processes on electrostatic precipitator performance, waste management options, and the global status of commercial-scale dry sorbent injection processes.

This Summary contains abstracts of the 49 technical papers presented at the Symposium and 3 unpresented papers distributed at the meeting. Abstracts denoted by an asterisk (*) describe research wholly or partially funded by EPA and have been reviewed in accordance with EPA peer and administrative review processes.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the symposium that is fully documented in two separate volumes (see Project Report ordering information at back).

Introduction

The 1986 Joint Symposium on Dry SO_2 and Simultaneous SO_2/NO_x Control Technologies was held in Raleigh, North Carolina, June 2 through 6, 1986. This symposium, jointly sponsored by EPRI and EPA, was the second meeting of its kind devoted solely to the discussion of emissions control processes based on dry injection of calcium or sodium sorbents to meet SO_2 and NO_x regulations for coal-fired power plants. Specific topics discussed included enhanced sorbent utilization through thermal pretreatment of sorbents or use of hydrated or promoted calcium-based sorbents, effects of temperature and other injection parameters on sulfur capture efficiency, economics of dry sorbent injection, post-furnace injection for SO_2 control, effects of dry sorbent injection processes on electrostatic precipitator performance, waste management options, and the global status of commercial-scale dry sorbent injection processes.

Forty-nine papers were presented by EPA and EPRI staff members, representatives of utility companies, equipment manufacturers, sorbent suppliers, and research and development companies

under contract to EPA, EPRI, and other research groups. Additionally, researchers from Austria, Canada, Finland, the Federal Republic of Germany, and the Netherlands presented information on worldwide technological developments in dry SO_2 control.

Symposium cochairmen were George R. Offen, Project Manager in the Air Quality Control Program of EPRI's Coal Combustion Systems Division; and Richard D. Stern, Chief of the LIMB Applications Branch of EPA's Air and Energy Engineering Research Laboratory. Participants in the introductory session included keynote speaker John Riggs, Staff Director of the U.S. House of Representatives Subcommittee on Fossil Fuel and Synthetic Fuels; and William Holewinski, Director of Generating Station Engineering at Wisconsin Power and Light Company, who presented the utility perspective on acidic deposition control. Overviews of the EPA and EPRI acidic deposition control programs were presented by John Skinner, Director of EPA's Office of Environmental Engineering and Technology, and John Maulbetsch, Program Manager in the Air Quality Control Program of EPRI's Coal Combustion Systems Division, respectively.

The Proceedings of the 1986 Symposium have been compiled in two volumes. *Volume 1, Sorbents, Process Research, and Dispersion,* contains papers from the first four sessions:

- Session I: Introduction
- Session II: Sorbents
- Session III: Process Research
- Session IV: Mixing/Dispersion

Contained in *Volume 2. Economics, Power Plant Integration, and Commercial Applications,* are papers presented in the remaining four sessions:

- Session V: Economics
- Session VI: Post-Furnace SO^2 Removal
- Session VI: System Impacts
- Session VIII: Commercial Scale Applications

Also included in *Volume 2* are three unpresented papers submitted in conjunction with the Symposium or associated with a poster session held during the Symposium.

SESSION I: INTRODUCTION

Chairmen, Richard Stern,
EPA, AEERL, and
George Offen,
EPRI

Paper 1A

KEYNOTE ADDRESS

John Riggs,
Fossil and Synthetic Fuels Subcommittee,
U.S. House of Representatives

This paper presents four political issues that are of primary importance to most elected officials in Washington: energy, security, the environment, electricity prices and the Federal budget deficit. Following this, is a summary of how Congress' attempt to reconcile these issues brought about the creation of the Federal Clean Coal Technology Reserve. Finally, the impact of clean coal technologies on the debate over acid rain legislation is discussed.

Paper 1B

*COAL COMBUSTION OVERVIEW/TECHNICAL PERSPECTIVE OF THE EPA PROGRAM**

John H. Skinner,
Office of Environmental Engineering and Technology,
EPA

This paper presents an overview of the program being undertaken by EPA in the area of control technology development and evaluation for coal combustion processes. It presents a perspective on the Limestone Injection Multistage Burner (LIMB) program and where it may fit into a National Acid Rain Control Strategy. Some of the technical issues which require resolution are discussed.

Paper 1C

OVERVIEW/TECHNICAL PERSPECTIVE OF THE EPRI PROGRAM

John S. Maulbetsch,
Coal Combustion Systems Division,
EPRI

This paper summarizes the technical perspective of EPRI's program for dry SO_2 control technology research and development. The results of research conducted since 1984 are discussed briefly. The current EPRI view of the applicability of dry SO_2 control technologies is presented, particularly in light of proposed acid rain legislation.

Paper 1D

UTILITY PERSPECTIVE

William Holewinski,
Wisconsin Power & Light Company

This paper describes the perspective of Wisconsin Power & Light Company, a medium-sized utility, on emissions control regulations and potential control technologies used to meet them. Of particular concern is development of cost-effective SO_2, control technologies that may be applied to smaller, older plants with cyclone-fired boilers. Dry sorbent injection is considered a prime candidate for use in this application.

SESSION II, PART 1: SORBENTS — SELECTION, PREPARATION, AND PERFORMANCE

Chairmen, Brian Gullet,
EPA, AEERL

Paper 2A

PRECALCINATION AND ITS EFFECT ON SORBENT UTILIZATION DURING UPPER FURNACE INJECTION

V. P. Roman,
S. J. Bortz,
R. J. Yang,
KVB, Inc.
P. Flament,
International Flame Research Foundation, and
G. R. Offen, Electric Power Research Institute

An experimental program using eigl sorbents was conducted to determir optimum methods of producing high su face area limes and to assess the potential for achieving high sorbe utilizations in the 1200°C-900°C sulfatic window. The performance of a fixed be calciner operated at 750-800°C and plug flow reactor operated at 900-920° were compared on the basis of the surfa area produced versus the amount calcining air on N_2 used. The plug flc reactor proved capable of producing 4 m^2/g surface areas from $CaCO_3$ sorber with about 25g air/g sorbent, while produce a similar surface area with t fixed bed reactor required an air/sorbe ratio of 100/1.

The surface areas obtained were r significantly affected by either the s

bent's trace mineral matter or magnesium content.

When the high surface area precalcines were reinjected into a flue gas environment without SO_2 at 1100°C, the precalcine was found to quickly (100 ms) sinter to the surface area generated within 100 ms when injecting the raw (uncalcined sorbent) into the same conditions. Sulfation experiments at 1100°C and a residence time of 0.5 s showed littler difference between the utilization levels obtained with 40 m^2/g precalcines or raw sorbents.

Paper 2B

*PILOT SCALE FURNACE EVALUATION OF HYDRATED SORBENTS FOR SO_2 CAPTURE**

G. C. Snow and
J. M. Lorrain,
Acurex Corporation
S. L. Rakes,
U.S. Environmental Protection Agency

Several candidate sorbent materials for the full scale Limestone Injection Multistage Burners (LIMB) demonstration at Edgewater Station in Ohio were evaluated in the EPA Innovative Furnace. Measurements of SO_2 capture were made while firing at 13.8 kW (47300 Btu/hr) on both a Pittsburgh No. 8 coal (2.6% sulfur) and doped natural gas. The sorbent injection point was at 1200°C. With a furnace quench rate of 260°C/s, the average residence time at reaction temperatures was 1.3 s. At molar Ca/S ratios of 2, Vicron 45-3 limestone produced at 38% reduction in SO_2 emissions from baseline levels. Increased SO_2 capture rates, ranging from 60 to 69% were measured for various calcitic atmospheric hydrates. Dolomitic sorbents were able to achieve captures of 73 to 75% and showed no significant difference between atmospheric and pressure hydrates. With the addition of sodium bicarbonate ($NaHCO_3$) at molar Ca/Na = 15, captures of 83 and 88% were possible for the calcitic and dolomitic hydrates, respectively.

Paper 2C

DRY SORBENT SO_2 CONTROL FOR NEW POWER PLANTS BURNING LOW SULFUR WESTERN COALS

D. P. Teixeria and
T. A. Lott, Pacific Gas and Electric Company
L. J. Muzio,
Fossil Energy Research Corporation

The Pacific Gas and Electric Company is developing a dry calcium-based sorbent injection SO_2 control process capable of high levels of SO_2 removal. The target is 95% SO_2 removal for new power plants burning low sulfur Western coals. Sorbent performance at low sulfur combustion conditions (500 ppm flue gas SO_2) has been studied in a 105,000 kJ/hr (100,000 Btu/hr) gas-fired combustion reactor. Sorbent utilization was seen to decrease significantly with decreasing SO_2 concentrations; gas-phase diffusion is probably the limiting factor. Experimental atmospheric dolomitic and calcitic hydrates were prepared and tested. SO_2 removals exceeded those of commercial materials; 60% removal was achieved at calcium to sulfur ratios of 2 to 1.

Paper 2D

*PHYSICAL PARAMETERS GOVERNING THE REACTIVITY OF $Ca(OH)_2$ WITH SO_2**

D. A. Kirchgessner and
B. K. Gullett,
U. S. Environmental Protection Agency
J. M. Lorrain,
Acurex Corporation

SO_2 capture data from bench- and pilot-scale experiments show that, among the calcium-based sorbents, $Ca(OH)_2$ is superior in performance to both $CaCO_3$ and CaO. The available data also show that hydrates vary in their ability to capture SO_2. A bench-scale atmospheric hydration process, in conjunction with a flow reactor for SO_2 reactivity testing, is being used to determine the process parameters and material characteristics that affect sulfur capture by hydrates. Thus far the effects of parent lime particle size and degree of burn, and the hydration water temperature have been evaluated. Variations in each of these parameters appear to be capable of altering the ability of $Ca(OH)_2$ to capture SO_2.

Paper 2E

ENHANCED UTILIZATION OF FURNACE INJECTED CALCIUM-BASED SORBENTS

G. F. Weber,
M. E. Collings, and
M. H. Bobman
University of North Dakota Energy Research Center

Simultaneous control of SO_x/NO_x emissions is under investigation at the University of North Dakota Energy Research Center (UNDERC). Furnace injection tests have focused on the direct injection of pressure-hydrated lime followed by particulate collection in a baghouse operated at temperatures of 63 to 149°C. SO_2 reduction as high as 80% has been observed for high-calcium pressure-hydrated lime (PHL) injected at a Ca/SO_2 mole ratio of 2.0 with all of the SO_2 capture occurring in the flue gas at temperatures exceeding 760°C.

Pilot-scale tests have shown that furnace injection of high-calcium PHL at a Ca/SO_2 ratio of 1.0 can result in 65 to 70% SO_2 capture if the baghouse is operated at 71°C, approximately 11°C above the dew point. Improved sorbent utilization has been observed both for high-calcium PHL and for additive enhanced high-calcium PHL at baghouse temperatures of 63 to 104°C. Of the 65 to 70% overall utilization, 45 to 50% of the sorbent was utilized in the upstream flue gas and an additional 15 to 25% in the baghouse.

Paper 2F

*REACTIVITY OF ATMOSPHERIC AND PRESSURE HYDRATED SORBENTS FOR SO_2 CONTROL**

J. M. McCarthy,
S. L. Chen,
J. C. Kramlich,
W. R. Seeker, and
D. W. Pershing
Energy and Environmental Research Corporation

The purpose of this study was to develop an understanding of the factors that control the reactivity of hydrated sorbents toward SO_2 in coal fired furnaces. The study focused on the impacts of the hydrate properties such as particle size, surface area, and chemical composition, and the furnace temperature of the injection location. Bench- and laboratory-scale hydrators were used to produce atmospheric and pressure hydrated sorbents, with parameters pertinent to the hydration process varied. The chemical and physical properties were characterized for these hydrates and several commercially available hydrates, and they were tested for SO_2 sorption reactivity on bench scale (17.6 kW) and pilot scale (300 kW) furnaces.

The results of this study indicated that pressure hydrates generated under well controlled conditions were more reactive than commercially produced atmospheric hydrates. The important production and operating parameters for the pressure hydration process included the size and composition of the quicklime, the hydration temperature and pressure, the water addition, and the pressure progression during discharge. Comparison of commercial atmospheric hydrates significant differences in reactivity, ranging from 40 to 58% at a calcium to sulfur molar ratio of 2. All hydrates, atmospheric and pressure, exhibited a strong dependence injection temperature.

Paper 2G

*SORBENT DEVELOPMENT AND PRODUCTION STUDIES**

J. P. Gooch, E. B. Dismukes, and R. Beittel,
Southern Research Institute
J. L. Thompson,
Dravo Lime Company
S. L. Rakes,
U. S. Environmental Protection Agency

Recent pilot-scale studies have shown that furnace injection (at temperatures of approximately 1200°C) of commercially produced calcitic hydrated lime will provide calcium utilizations in the range of 25% at Ca/S ratios of 2 to 1. This paper presents results obtained to date on an EPA-sponsored project with the objective of developing calcium-based sorbents which obtain higher utilizations than those achieved with commercial hydrated lime.

Sorbent preparation methods considered include: 1) production of high surface area calcines using modified kilns, 2) production of pressure-hydrated calcitic limes, and 3) modified hydration processes. Method 3 was chosen for laboratory- and pilot-scale studies. Laboratory experiments have produced hydrated lime with uncalcined surface areas in excess of 80 m_2/g. Preliminary calcination experiments suggest that these high surface area hydrates will sinter more quickly than conventional hydrates in a furnace environment. Efforts are underway to produce quantities sufficient for testing in a 10^6 Btu/hr (10^6 kJ/hr) pilot-scale combustor. Sulfation studies with coal-firing have been performed with pressure-hydrated calcitic lime produced by other laboratories. Results from these tests are presented, together with results obtained with several commercial atmospheric hydrates.

SESSION II, PART 2: SORBENTS — PROMOTERS AND ADDITIVES

Chairmen, Blair Martin,
EPA, AEERL

Paper 2H

*ENHANCED SULFUR CAPTURE BY PROMOTED CALCIUM-BASED SORBENTS**

D. M. Slaughter,
S. L. Chen, and
W. R. Seeker
Energy and Environmental Research Corporation

Injection of calcium-based sorbents are currently being considered as a potential method of reducing SO_2 in existing coal-fired boilers. This study investigated the ability of small concentrations of additives to enhance sulfur capture with calcium-based sorbents. The interaction between the mineral ash (produced from coal combustion) and the sorbent/additive combination was also studied. Two furnace facilities and an X-ray diffractometer were used in the experimental study. The furnances used included a 300 kW down-fired furnace capable of simulating time and temperature profiles for a variety of boilers, and a bench-scale drop-tube furnace.

The results show that calcium-based sorbents, when in contact with mineral ash, remove sulfur from the gas phase. Under combustion conditions envisioned for application of this technology, contacting between mineral ash and sorbent was small; therefore, changes in reactivity of the sorbent were small.

Addition of known promoters with sorbents has effectively increased sulfur capture. Both sodium and chromium react with the calcium to increase the accessibility of CaO sites by particle fragmentation, creation of large cracks (or pores), and the presence of a liquid phase. In general, iron did not promote an increase in sulfur capture under combustion conditions in a coal-fired boiler or promote physical changes in the sorbent.

In general the chromium eliminated by ash interaction was small, while the ash effectively prevented a significant portion of the sodium from contacting and reacting with the calcium sorbent. If the impact of the sodium promoter is to change the physical characteristics, as believed, process methods before injection may be implemented that allow interaction of the sodium without interference from the mineral ash.

Paper 2I

THE EFFECTIVENESS OF ADDITIVES FOR ENHANCING SO_2 REMOVAL WITH CALCIUM BASED SORBENTS

L. J. Muzio,
Fossil Energy Research Corporation
G. R. Offen,
Electric Power Research Institute
A. Boni,
Physical Sciences, Inc.
R. Beittel,
Southern Research Institute

Additives incorporated with calciun based sorbents have been reported t enhance sulfur capture by increasin mass transport within the sorbent particle Alkali metal additives can be added to th sorbent as physical mixtures or incorpc rated with the sorbent during the hydra tion process. Another class of additiv compounds, alcohol water solutions, ca be used to alter the hydration proces producing high surface area hydrate This paper focuses on both types hydrates. Theoretical considerations thermochemistry and vaporization/cor densation mechanisms helped define th additives used in the test program. Th experimental work was carried out in tw facilities: a coal-fired pilot scale con bustor, and an intermediate scale con bustor firing natural gas doped with SO The experimental results discussed cov the: 1) relative effectiveness of additive (sodium, potassium, lithium, cesium, iror 2) method of incorporating the additiv 3) amount of additive, and 4) effect coal ash. The SO_2 removal characteristi of a high surface area (40 m^2/g) Ca(OH material produced using alcohol additi during hydration are also discussed.

Paper

ALTERNATIVE SO_2 SORBENTS

D. O. Ham,
G. A. Simons, and
G. A. Moniz
Physical Sciences Inc.

Sulfur sorption experiments have be conducted in a fixed bed reactor in or

to screen potential mineral sorbents for use downstream from convective superheater tubes. All tests were carried out using a simulated combustion effluent (74.0% N_2, 12.1% CO_2, 4.6% O_2, and 9.2% H_2O) at 100 kPa pressure, 3000 ppm SO_2, and in the temperature range of 400 to 800°C. Four classes of sorbents have been tested: calcium hydrate, alkali based (trona), mixtures (alkali promoters), and mixed cations (shortite and gaylussite). Shortite is consistently high over the temperature range. Trona, gaylussite, and Colton hydrate promoted by trona are all very reactive at 800°C but much less reactive at lower temperatures. Promotion of Colton hydrate by trona depends on close physical contact.

SESSION II, PART 3: SORBENTS — FUNDAMENTALS

Chairmen, Dennis Drehmel, EPA, AEERL

Paper 2K

*EPA STUDY OF HYDROXIDE REACTIVITY IN A DIFFERENTIAL REACTOR**

R. H. Borgwardt,
U. S. Environmental Protection Agency
K. R. Bruce,
Acurex Corporation

Laboratory investigations of some of the factors influencing the reactivity of calcium hydroxides with SO_2 are reported. The materials examined included commercial grade $Ca(OH)_2$, pressure hydrated $Ca(OH)_2$, analytical grade $Ca(OH)_2$, and hydroxides prepared in the laboratory from calcined dolomite and limestone. In the latter case, the effects of limestone calcination conditions (time, temperature) and hydration technique were evaluated. The methods of hydration included steam (105 and 200°C) and water slaking. The effect of SO_2 partial pressure on reactivity was measured at 800°C for three types of $Ca(OH)_2$ over a range of 120 to 7000 ppm. Preliminary tests at 65°C are reported for hydroxides exposed to SO_2 and high humidity for times ranging from 5 to 120 seconds.

Paper 2L

*FUNDAMENTAL STUDIES OF SORBENT REACTIVITY IN ISOTHERMAL REACTORS**

D. W. Pershing,
G. H. Newton, and
D. J. Harrison,
University of Utah
J. A. Cole,
J. C. Kramlich,
W. R. Seeker, and
G. D. Silcox,
Energy and Environmental Research Corporation

Three aspects of sorbent reactivity were investigated in fundamental studies under isothermal conditions. The first test series examined the relative reactivity of a series of limestones, hydrated calcitic limes, and hydrated dolomitic limes. The second test series focused on the influence of particle size on sorbent utilization. Precalcined sized carbonates were sulfated under isothermal conditions. The results showed that the limitation to large stone utilization was the pluggage of the porous structure at the surface caused by local overutilization of the sorbent. Below 2-5 μm, all portions of the stone are equally accessible to the SO_2, and further size reductions do not enhance utilization. In the third series, carefully controlled isothermal experiments were used to characterize the $CaO + SO_2$ reaction. The tests were performed on sized, precalcined hydrated lime. The results show a rapid utilization within the first 100 msec. At longer times a reduction in the sulfation rate was noted which appears to coincide with blockage of the microporosity.

SESSION III, PART 1: PROCESS RESEARCH

Chairman, George Offen, EPRI

Paper 3A

*A COMPARISON OF COMBUSTION FACILITIES AND CALCIUM-BASED SORBENTS IN TERMS OF THEIR SULFUR CAPTURE PERFORMANCE**

G. D. Silcox,
R. Payne,
D. W. Pershing, and
W. R. Seeker
Energy and Environmental Research Corporation

Sulfur capture data from combustion facilities using dry sorbent injection were compared. The comparisons were performed in order to determine the similarities and differences between facilities and to understand the effects of various reaction parameters. Different sorbents were also compared in terms of their capability to capture sulfur. Gaps in data were identified.

The data and the comparisons were interpreted with the help of mathematical models of the sulfation reaction and of the calcination process. The calcination model shows that the peak surface area for hydrates occurs just milliseconds after injection, while that for carbonates is on the order of 0.2 second. This difference may explain, in part, the higher reactivity of hydrates. The sulfation model incorporates a nonlinear dependence on SO_2 concentration which is understood in terms of a surface reaction model. The sulfation and activation models are combined and used to explain the complicated dependence of capture on injection temperature and time.

Paper 3B

*THERMAL ENVIRONMENT IN A TANGENTIALLY PULVERIZED-COAL-FIRED UTILITY BOILER: COMPARISON OF FIELD TESTS WITH HEAT TRANSFER MODELING**

B. M. Cetegen and
W. Richter,
Energy & Environmental Systems
D. G. Lachapelle,
U. S. Environmental Protection Agency

Effective implementation of the in-situ desulfurization process in coal-fired boilers requires a detailed description of thermal characteristics of the boiler furnace. This paper discusses the results of the detailed field tests conducted at a 420 MW_e tangentially fired utility boiler and compares them with predictions obtained from multi-dimensional furnace heat transfer models. Results and comparisons are reported for two furnace heat inputs: 1088 MW_t (100% load) and 502 MW_t (45% load). Sensitivity studies with the model showed that significantly accurate predictions of overall thermal furnace performance require only the approximate description of furnace flow, but a realistic estimation of the overall insulation effect of wall ash deposits.

Paper 3C

*EFFECTS OF INJECTON TEMPERATURE AND QUENCH ON SORBENT UTILIZATION**

R. Beittel,
Southern Research Institute
S. J. Bortz,
KVB, Inc.
G. R. Offen,
Electric Power Research Institute
D. C. Drehmel,
U. S. Environmental Protection Agency

Two coal-fired pilot combustors were used to evaluate the effects of injection temperature and quench rate on the utilization of furnace-injected sorbents. The quench rate was varied from 38 to 316°C/s by load and configuration changes in one unit, and up to 593°C/s in the second unit. Limestone and calcitic and dolomitic hydroxides were tested. Injection temperature was found to be the primary effect. Quench rates were significant only for the calcitic hydroxide or above 316°C/s; however, increased quench rate increased the optimum injection temperature

Paper 3D

APPLICATION OF UPPER-FURNACE SORBENT INJECTION FOR SO_2 CONTROL IN COAL-FIRED CYCLONE-EQUIPPED BOILERS

H. Farzan,
L. W. Rodgers, and
G. J. Maringo
Babcock and Wilcox Company
G. R. Offen,
Electric Power Research Institute

Upper furnace sorbent injection for SO_2 capture was examined utilizing a 6 x 10^6 Btu/hr (1 7 MWt), cyclone-equipped boiler simulator The facility has a convective pass to simulate full-scale time/temperature histories, including quench rates within the sulfation temperature window (1260 - 871°C) of approximately 649°C/s.

Two limestones, one calcitic hydrated lime, a pressure-hydrated dolomitic lime, and an atmospheric-hydrated dolomitic lime were injected at the furnace exit at 1232°C. In-furnace surface area and porosity measurements were performed on the sorbents. No correlation between sulfur capture and calcine surface area was observed. Despite the rapid quench rate, more than 50% sulfur capture was achieved injecting the dolomitic materials at a Ca/S of 2, independent of the hydration process Sulfur capture increased with time due to tube and wall deposits. The deposits could be removed with increased sootblowing pressure, resulting in similar recovery of heat flux as obtained without sorbent.

SESSION III, PART 2: PROCESS RESEARCH

Chairman, George Offen, EPRI

Paper 3E

*CONTROLLING POLLUTANT EMISSIONS FROM COAL AND OIL COMBUSTORS THROUGH THE SUPPLEMENTAL USE OF NATURAL GAS**

S. L. Chen,
J. M. McCarthy,
M. P. Heap,
W. R. Seeker, and
D. W. Pershing
Energy and Environmental Research Corporation
F. R. Kurzynske,
Gas Research Institute

Natural gas can be used to enhance the economic acceptability of eastern coals for power generation under more stringent environmental regulations. The sulfur and nitrogen in coal can lead to emissions of acid rain precursors such as SO_2 and NO_x, while the non-hydrocarbon components in coal affect power plant performance because of problems associated with the ash. The application of technologies which take advantage of the clean burning qualities of natural gas offers an attractive and cost effective option for acid rain precursor control. The study discussed in this paper focuses on the use of natural gas as a reburning fuel combined with sorbent injection for combined NO_x/SO_2 control. The work is supported by the Gas Research Institute and builds upon DOE/EPA research efforts. Bench and pilot scale tests have been performed on the natural gas reburning/sorbent injection process. Results obtained indicate that 60% NO_x reduction and 70% SO_2 reduction can be achieved when 20% natural gas reburning is combined with hydrate injection (Ca/S = 2), under realistic time/temperature furnace profiles. Reburning with natural gas was found to have several distinct advantages over reburning with coal. In addition, this study has demonstrated the potential of using natural gas to enhance calcium utilization.

SESSION IV: MIXING/DISPERSION

Chairman, Nicholas Kresovich, EPA, AEERL

Paper 4A

INFLUENCE OF SORBENT INJECTION AERODYNAMICS ON SO_2 CONTROL

B. M. Cetegen,
T. R. Johnson,
D. Moyeda, and
R. Payne
Energy and Environmental Research Corporation

Mixing conditions produced by injection of calcium-based sorbents into large boiler furnaces can influence the sulfur removal efficiency. A practical means of injecting pulverized sorbents into the furnace flow is by sorbent-laden gas jets issuing from nozzles on combustor walls. This paper describes studies on the trajectory and mixing of sorbent jets with the cross-flow stream of combustion gases in the upper furnace region of a boiler Several aspects of the problem are discussed: bench scale isothermal jet mixing experiments in boiler upper furnace configurations, modeling of jet mixing in such geometries, and pilot scale combustion tests identifying the effect of mixing on sulfur removal. Key parameters controlling mixing are identified for furnace configurations, and a simple integral model based on mass, momentum, and energy conservation is developed for predicting jet injection characteristics The sensitivity of sulfur capture to mixing conditions is presented for a calcium hydroxide sorbent.

Paper 4

*SORBENT INJECTOR DESIGN FOR SULFUR OXIDE CONTROL FROM TANGENTIALLY FIRED FURNACES BY DRY SORBENT INJECTION**

R. W. Koucky,
D. K. Anderson,
P. R. Thibeault, and
J. L. Marion
Combustion Engineering, Inc.
C. C. Masser,
U. S. Environmental Protection Agency

Combustion Engineering, Inc., under Environmental Protection Agency sponsorship, is conducting a program to develop design criteria for injection of dry sorbents into tangentially fired furnaces for the control of SO_2 emissions. The program includes aerodynamic cold flow testing and mathematical modeling of sorbent injection, demonstration testing of SO_2 emission control in a 14.6 MW_t (50 x 10^6 Btu/hr) tangentially fired test facility, and pilot-scale testing to evaluate furnace slagging and fouling behavior during sorbent injection. This paper describes initial results of the flow testing and mathematical modeling. Injector development testing was conducted in a large scale cold-flow model which accurately simulates the geometry of a tangentially fired utility boiler including the pendant heat transfer surfaces installed in the sulfur capture temperature window of the upper furnace. Several sorbent injector configurations were tested to optimize injection location and injection method. The sorbent dispersion mathematical model uses cold-flow velocity and concentration data to aid in the selection of injector designs for combustion testing, to extrapolate cold-flow dispersion results to hot furnace geometries.

Paper 4C

ANALYSIS OF THE SORBENT INJECTION PROCESS FOR IN-FURNACE SO_2 CONTROL

R. M. Himes and
L. J. Muzio,
Fossil Energy Research Corporation
G. R. Offen,
Electric Power Research Institute

The effectiveness of in-furnace SO_2 control is strongly dependent upon a number of factors which primarily include the sorbent material used, the injection location in the furnace, and the degree of mixing achieved with the combustion products. The current study is directed toward establishing a framework for the design of an in-furnace sorbent injection system to optimize the dispersion of the sorbent in regions where mixing will occur under established temperature conditions. This paper focuses on the use of empirical correlations and cold-flow modeling to facilitate the design process. As the empirical correlations have been typically developed under the controlled conditions of a wind tunnel, the cold-flow model is used to evaluate the correlations under relatively uniform flow conditions as well as a more representative furnace flow field. The simplification of a two-phase jet into an equivalent gas jet having a modified density is also evaluated by comparing the trajectories of single- and two-phase jets, with identical momentum ratio found to be the predominant parameter governing the penetration and mixing of the jet under these conditions. The bulk flow patterns and turbulence generated under simulated burner flow conditions, however, significantly impacted the trajectory and mixing of the jet such that the empirical correlations were no longer valid.

SESSION V: ECONOMICS

Chairman, Dan Giovanni,
Electric Power Technologies, Inc.

Paper 5A

*CONTROL COST MODELING FOR SENSITIVITY AND ECONOMIC COMPARISON**

N. Kaplan,
D. G. Lachapelle, and
J. Chappell,
U. S. Environmental Protection Agency

Using computerized cost models developed both internally and under contract to EPA by the Tennessee Valley Authority over a period of several years, this paper presents costs for utility retrofit applications of wet flue gas desulfurization (FGD), dry FGD, and the limestone injection with multistage burners (LIMB) process. Capabilities of the models, premises, and limits of the sensitivity study are discussed. Tabular and graphical presentations of the results are included. For a base case of 300 MWe boiler size, 2.2% sulfur coal, 50% capacity factor, intermediate sorbent cost ($71/ton lime and $15/ton limestone), 1.6 retrofit factor for FGD systems, and 15 year remaining unit life, the unit control costs for wet FGD, dry FGD, and LIMB are $1337, $1220, and $997/ton of SO_2 removed, respectively. Sensitivity of costs to each of the above parameters spanning the base case is presented and discussed. Unit control costs are developed for all cases, while capital costs and levelized annual revenue requirements are also presented for the base case.

Paper 5B

ECONOMICS OF FURNACE SORBENT INJECTION FOR SO_2 EMISSION CONTROL

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Stearns Catalytic Corp.
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Electric Power Research Institute

The concept of injecting various calcium-based sorbent materials into coal-fired utility boilers is currently under development as an option for reducing SO_2 emissions from new and existing power plants. The major incentive for this development is the anticipated lower cost of furnace sorbent injection compared to conventional flue gas treatment technologies and the potential future need for incremental SO_2 control at existing units.

This paper examines the economics of furnace sorbent injection for SO_2 emission control and the major variables which impact the overall process economics. The economics examined focus primarily on sorbent injection as a retrofit technique to control SO_2 emissions on existing plants. The major variables found to affect the sorbent injection economics are sorbent performance (Ca/S ratio vs SO_2 removal), sorbent cost, inflation rate, coal sulfur content, plant capacity factor, plant size, and sorbent transportation distance. Furnace sorbent injection is also compared to wet FGD on a $/ton SO_2 removal overall control cost basis.

Paper 5C

COMPARATIVE COSTS OF FLUE GAS DESULFURIZATION: ADVANTAGES OF FURNACE INJECTION OF PRESSURE HYDRATED LIME OVER DRY SCRUBBING

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Costs of pressure-hydrated lime injection (PHLI) for the control of SO_2 emissions were developed and compared to lime spray dryer absorbers (SDA) operating under identical design conditions. Since 1981, development work, sponsored by the U. S. Department of Energy at the University of North Dakota Energy Research Center (UNDERC), has focused on PHLI as a cost effective control method, producing a dry readily disposable waste

product. In the PHLI process, dry sorbent is injected into the upper furnace region and the sulfated particulate collected in a downstream baghouse or electrostatic precipitator. In SDA processes, increasingly used for low sulfur coals, flue gas SO_2 contacts lime slurries in large reactor vessels with subsequent collection of the dried particulate in a downstream baghouse. Therefore PHLI can have decisive economic advantage over SDA due to the elimination of complex absorption vessels and water chemistry, and reactor pressure drop with overall reductions in labor and water consumption.

To determine the possible cost advantage of PHLI, costs were developed for both PHLI and SDA applied to two divergent baseline case scenarios. In the first baseline case, a new 500 MW plant, located in the upper Midwest, firing a low sulfur (1%) lignite, was considered. A stringent 90% control target was specified due to anticipated stricter regulations or location in a Class I control region. In the second baseline case, an existing and easily retrofitable 300 MW plant, located in the central Midwest, firing a moderate sulfur (2%) Eastern bituminous coal, was considered. An incremental 50% control target was specified primarily in anticipation of acid rain regulations. The impact of sulfur content in the coal was assessed at the 1, 2, and 3% sulfur levels, and for PHLI, the effect of sorbent utilization rates was determined at the 25, 50, and 75% levels For SDA, the sorbent utilization rate remained fixed at 80% for all cases evaluated.

The evaluations demonstrated PHLI's cost-effectiveness over lime SDA over the entire range of operating conditions investigated. Under the worst conditions for PHLI (i e., operating at the larger new plant, firing a 1% sulfur coal with a 25% sorbent utilization), PHLI affords a 25% savings in levelized revenue over SDA, for the analogous retrofit conditions, PHLI produces a 35% savings. When sorbent utilization rises to 75%, PHLI savings increase to about 65% of SDA costs for both new and retrofit designs In absolute terms, capital costs for retrofit PHLI are low, ranging closely about $55/kW at the 50% sorbent utilization rate, for the new plant, capital costs are more sensitive to sulfur content, ranging from $33 to $62/kW at a 50% utilization rate Under all circumstances, operation and maintenance costs dominate, due to the high sensitivity to sorbent consumption rates, typically 70% of the total cost for PHLI. Since the incremental impact of either process on particulate collection equipment is site specific, costs of additional flue gas handling, baghouses, or precipitators have not been entered into the evaluation.

Paper 5D

ECONOMICS OF SULFUR REMOVAL USING "DRY"-CARBONATED TRONA ORE FGD SORBENT

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A great many potential commercial sources of sodium are available for use in dry injection FGD systems The sorption performance of some of these materials can be improved by processing prior to injection Three examples involving raw trona and dry-carbonated trona sorbents are compared in this study, serving a new 500 MW power generating unit and starting with a selected trona ore f.o.b. Green River, Wyoming, price of $50/ton Dry carbonation at the utility site and by a producer/supplier at Green River are evaluated separately against the direct injection of trona ore. The distance between the utility site and the Green River source of trona ore was considered. The results show significantly lower first year operating costs and lower 30-year levelized costs for dry-carbonated trona, and this advantage increases with rail distance to the power plant from Green River. The key factors likely to affect this outlook are discussed.

SESSION VI: POST-FURNACE SO_2 REMOVAL

Chairman, Richard Rhudy,
EPRI

Paper 6A

LABORATORY TESTS ON FURNACE LIMESTONE INJECTION AND DEVELOPMENT OF A SECOND DESULFURIZATION STEP WITH FLI ASH THROUGH DUCT INJECTION

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Furnace conditions were simulated in a laboratory setup by putting single limestone particles with diameters of 3 to 100 μm into a hot flue gas stream for 3 to 20 seconds. The specific surface area was found to increase with calcination and to decrease very quickly after passing a maximum, the latter process being faster at a higher temperature. Furthermore, single particles were cut into slices of 2 μm and analyzed with a raster electron microscope, and the sulfur distribution throughout the particle was measured. If limestone particles are produced from one stone by milling and fractionation on sieves, the particles with 40 μm diameter will have the smallest B.E.T. surface area.

Since the utilization of the Ca in the furnace limestone injection (FLI) ash is only 10 to 15% and because the Austrian emission regulations demand (for old plants) desulfurization rates of 80% and a maximum SO_2 concentration of 800 mg/Nm^3 (270 ppm) in the flue gas, simple FLI will not be sufficient in the future. A process was developed in which the FLI ash is separated from the flue gas, milled, treated with steam and reinjected into the flue gas duct upstream from the dust collector. A pilot plant, which processed a slipstream of 500 Nm^3/h from a cogeneration plant was operated for 1900 hours. The results are satisfactory: no technical problems were encountered One project for installation of the process is underway.

Injection of sodium bicarbonate into the flue gas duct was thoroughly investigated in a 15,000 m^3/hr pilot plant more than 80% SO_2-removal was found with a stoichiometric ratio (Na_2/SO_2) of 1 The retrofit of a 110 MW plant with this process is under construction.

Paper 6B

*REACTIVATION OF SOLIDS FROM FURNACE INJECTION OF LIMESTONE FOR SO_2 CONTROL**

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Acurex Corporation
T. G. Brna and
C. B. Sedman,
U. S. Environmental Protection Agency

Six different post-furnace injectio solids and flyash from Hoot Lake Statio

(Otter Tail Power Company) experiments have been characterized using scanning electron microscope (SEM), X-ray powder diffraction, titration analysis for available CaO, and ion chromatography. The samples were tested in a bench-scale reactor for the removal of SO_2 from a mixture of N_2 and SO_2. Virtually no SO_2 removal was observed with untreated solids. However, high SO_2 capture occurred when samples were hydrated and dried prior to SO_2 exposure. The SO_2 capture by solids increased with increasing time and temperature of hydration. For the same time/temperature conditions of hydration, higher SO_2 capture was achieved with solids of higher flyash/sorbent ratio. New crystals (ettringites) were found in hydrated and dried samples. The B.E.T. surface area of the solids was significantly increased by the hydration process. A possible mechanism of enhanced SO_2 capture by hydration of the product solids is discussed.

Paper 6C

DRY HYDROXIDE INJECTION AT ECONOMIZER TEMPERATURES FOR IMPROVED SO_2 CONTROL

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G. R. Offen,
Electric Power Research Institute

Bench and pilot testing injecting hydroxides into temperatures between 427 and 649°C has shown a significant potential for removing SO_2 from a flue gas stream. The reaction rates of calcium hydroxide directly with both SO_2 and CO_2 at around 538°C are significantly faster than the reaction of CaO with SO_2 or CO_2 near 1093°C. Hydroxide injection, at a Ca/S = 1-2 into a pilot combustor simulating a typical large utility boiler quench rate of 538°C/s between 649 and 427°C, has achieved calcium utilizations (predominantly as $CaSO_3$) of 25-35% with commercially available calcium hydroxides and 35-45% with specially prepared high reactivity hydroxides.

The utilization levels achieved in 250 ms residence time near the optimum injection temperature of 538°C appear to be determined mainly by the initial porosity of the hydroxide and the ratio of $CaSO_3/CaCO_3$ formed during the reaction. Sorbent preparation methods that increase the initial hydrate porosity by 1.5 over a normal hydrate have been identified and found to also yield a greater ratio of $CaSO_3/CaCO_3$. Injection of these special hydrates resulted in a 60% increase in sorbent utilization (to 45%) compared to commercial hydrates.

Paper 6D

FUNDAMENTAL STUDIES OF LOW-TEMPERATURE SULFUR CAPTURE BY DRY CALCITIC SORBENT INJECTION

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Three experimental studies were performed to develop fundamental information on low-temperature or duct capture by dry injection of calcitic or dolomitic sorbents. These were performed for the Department of Energy's Pittsburgh Energy Technology Center. The first experiment simulated the surface of a baghouse upon which sorbent had collected. Fresh sorbent was exposed to varying concentrations of SO_2 and water vapor flowing through a fixed bed. A bench-scale reactor was used to define the relative contribution of dispersed phase and filter capture. Finally, a baghouse connected to a pilot-scale furnace was used to observe baghouse behavior when the sorbent was collecting during the experiment.

Paper 6E

SORBENT IMPROVEMENT AND COMPUTER MODELING STUDIES FOR COOLSIDE DESULFURIZATION

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Coolside desulfurization is a retrofit SO_2 control technology for coal-fired utility stations. It consists of dry sorbent injection and flue gas humidification downstream of the air preheater. Boiler lime/limestone injection (BLI) differs in that the sorbent is injected into the furnace. Field tests have shown that Coolside and BLI/humidification can achieve SO_2 removals of 80 and 65%, respectively, from high sulfur coal flue gases. For both processes, sorbent utilization is the most significant factor in process economics. In addition, both processes benefit from flue gas humidification because it enhances the SO_2 capture reactions and the particulate removal efficiency if, as is commonly the case, the station is equipped with an electrostatic precipitator (ESP). This paper describes laboratory studies of methods to improve Coolside and BLI sorbent utilizations through changes in sorbent properties and additives, and the use of sorbent recycle. This paper also describes modeling studies conducted to determine nozzle and humidifier design and operating parameters, and to identify key design issues for further development.

Paper 6F

RESULTS OF 1.0 MM BTU/HOUR TESTING OF HALT (HYDRATE ADDITION AT LOW TEMPERATURE) FOR SO_2 CONTROL

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C. Runyon,
Ohio Edison Company
E. Evans,
U. S. Department of Energy,
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J. Thompson,
Process Calx, Inc.

SO_2 removal efficiencies of 60-70% upstream of the baghouse can be achieved for a 3.2% S coal using the HALT process at a Ca/S of 2.0. Quality control of the hydrate and uniform distribution of the sorbent across the duct cross section is essential. Direct contact water spray cooling of the gas with the hydrate feed entering upstream gives high removals. Removal efficiency with downstream injection is more sensitive to approach to adiabatic saturation and Ca/S. Cold hydrate feed increases removal efficiency. Addition of NaOH to spray water is beneficial. Of the hydrates prepared with additives to hydration water, methanol-sugar formulation performed the best. Long term testing on a larger scale is required to determine the effect of approach to adiabatic saturation temperature on removal, incremental removal due to baghouse/ESP, and

factors related to improving equipment availability. These will be covered on a 5 MW pilot test unit program to follow.

Paper 6G

EPRI PILOT TESTING OF SO_2 REMOVAL BY CALCIUM INJECTION UPSTREAM OF A PARTICULATE CONTROL DEVICE

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Fossil Energy Research Corporation
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Electric Power Research Institute
V. Bland and
C. Martin,
KVB, Inc.

EPRI is developing a potentially low-cost FGD process that involves dry injection of calcium-based reagents directly into humidified flue gas upstream of a particulate control device. Currently, process development tests are being conducted on a 2000 acfm (0.9 am^3/s) pilot fabric filter. Tests using an ESP are also planned. Pilot-scale tests are being supported by laboratory-scale screening of the effects of reagent type and preparation techniques. Future process development efforts will include process economics, an engineering evaluation of the feasibility of applying the process to a larger scale, and process modeling.

Initial process development tests have been completed, and results are presented. These tests confirm that the important performance variables are Ca/S ratio and approach to adiabatic saturation Both high calcium and dolomitic hydrates have been studied. The results also indicate that the use of additives, the use of high specific surface area reagents, and sorbent reinjection may promote greater SO_2 removals and increased sorbent utilization.

SESSION VII: SYSTEM IMPACTS

Chairman, Richard Stern,
EPA, AEERL

Paper 7A

PARTICLE PROPERTIES RELATED TO ESP PERFORMANCE WITH SORBENT INJECTION AND GAS CONDITIONING

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S. L. Rakes,
U. S. Environmental Protection Agency
G. R. Offen,
Electric Power Research Institute

Processes employing dry sorbent injection for SO_2 control require additional particulate collection capability in existing electrostatic precipitators (ESPs). Both EPA and EPRI are sponsoring research with the following objectives 1) to quantify the impact on ESP performance of various process plans, and 2) to develop performance upgrading strategies designed to provide cost-effective particulate control within the constraints imposed by existing plant configurations

This paper provides results from pilot- and laboratory-scale measurements of ash/sorbent particle properties related to ESP performance. The measurements were made on particulate matter generated in a 10^6 Btu/hr (293 kW) combustor fired on high-sulfur coal, with hydrated lime injected as a sorbent. The measurements include: 1) dust resistivity obtained in situ with a point-plane probe, 2) particle size distributions obtained with cascade impactors, and 3) the effects of increased fine particle loadings of ESP voltage-current relationships. Water vapor and SO_3 were each evaluated as conditioning agents in situ and in the laboratory A mathematical model was used to project ESP performance with flue gas conditioning, over a range of SCA values up to 50 $m^2/m^3/s$.

Paper 7B

ELECTROSTATIC PRECIPITATOR UPGRADES FOR FURNACE SORBENT INJECTION

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B. Weinstein,
Cottrell Environmental Sciences
M. W. McElroy,
EPRI

The injection of calcium based sorbents, such as limestone or calcium hydroxide, directly into the furnace of coal-fired boilers is currently under development as an option for reducing SO_2 emissions from existing power plants. The sorbents react with SO_2 ' ı form calcium sulfate The calcium compounds can increase the particulate loading to a downstream ESP by a factor of 2 or 3 and can increase the resistivity of the particulate by orders of magnitude. Methods which can be used to restore ESP performance to pre-sorbent injection levels are evaluated with respect to feasibility, effectiveness, and cost Methods which are evaluated include increased collection surface area, flue gas cooling by water evaporation, cooling by heat exchange, pulse energization, and SO_3 conditioning.

Paper 7C

DESIGN CONSIDERATIONS FOR WASTE MANAGEMENT SYSTEMS FOR ADVANCED SO_2 CONTROL TECHNOLOGIES

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D. M. Golden,
Electric Power Research Institute
H. Ness,
Department of Energy

This paper is a review of waste characteristics likely to affect waste handling systems design determined in separate studies of a) calcium-based furnace sorbent injection wastes, and b) sodium based dry scrubbing wastes Chemical composition, leaching properties, and physical characteristics were determined by standard methods Areas of concern that were identified for the calcium-based processes include: special handling requirements for powdery, alkaline material high heats of hydration due to unreacted lime, alkalinity of resultant leachates large volumes of waste per weight, and rapid, flash setting upon exposure to moisture Characteristics important for utilization potential for the calcium-base wastes were identified as follows: pozzolanic capability, high surface for reaction if used as reuse sorbent, and heat generation upon hydration. For the sodium-based processes, the solubility of the sodium compounds and lack of cohesive strengths were the principal source of waste management concern. Regeneration of sodium compounds from the dry wastes may be a potential area for utilization of by-products from sodium based dry scrubbing systems.

Paper 7

*ANALYSIS OF LIMB WASTE MANAGEMENT OPTIONS**

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N. Kaplan,
U. S. Environmental Protection Agency

This paper presents the results of laboratory testing and engineering analyses intended to assess various approaches to the management of ash/sorbent waste products from the LIMB process. The feasibility of conventional landfill disposal was assessed through leachate analysis (pH and metals), permeability measurements, and reactivity (temperature-rise) studies. Based on these tests, landfill disposal appears feasible if the runoff is neutralized and the temperature rise is controlled. Laboratory tests showed that LIMB ash could be mixed with water and pelletized to make a product suitable for use as aggregate in asphaltic wearing courses. Pilot combustor studies showed that LIMB ash could be recycled by hydration and reinjection into the furnace These tests yielded sulfur captures similar to those of commercial hydrated lime when compared on the basis of equivalent available calcium Several ash/sorbent separation techniques were evaluated including use of the existing particulate collector as a separator, steam treatment for simultaneous hydration and separation, inertial separation, magnetic separation, and froth flotation The economics of various disposal, utilization, and recycle schemes are being analyzed using modified versions of the EPA LIMB cost and recycle models

Paper 7E

APPLICATION OF SPRAY DRY PRODUCTS AT THE SAND-LIME PRODUCTION

P. J. C. Bloem and
B. J. G. Sciarone,
N V KEMA

The application of a fly-ash/spray-dry product mixture was examined. Therefore, sand-lime samples with various quantities of different spray dry products were prepared on laboratory scale Autoclaving was performed for 8 hours at 187°C

After that the compressive strength, the splitting tensile strength, the absorption coefficient at capillary action, and the porosity were determined. Further examination by means of SEM, EDX, and X-ray diffraction were done.

It appeared that applying fly ash and spray-dry product as a partial substitution for sand leads to encouraging results, if the quantity of spray-dry product in the fly-ash/spray-dry product mixture is 30% or less. The best results are obtained if the ratio of sand and fly-ash/spray-dry product mixture is about 1.0.

Paper 7F

TVA'S WASTE MANAGEMENT PROGRAM FOR AFBC ASH MATERIALS-UTILIZATION/ DISPOSAL

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Tennessee Valley Authority

The Tennessee Valley Authority (TVA) is involved actively in the development of the atmospheric fluidized-bed combustion (AFBC) technology for use by the utility industry. As part of this effort, TVA has instituted a program to develop methods for the handling, disposal, and/or utilization of the unique ash materials produced by the AFBC process. Discussed will be the operating and maintenance experience for the ash handling and disposal systems of the TVA 20 MW AFBC pilot plant, the design and development work for those same systems for the 160 MW AFBC demonstration plant, and the research and development work underway on utilization options for the ash materials.

SESSION VIII: COMMERCIAL SCALE APPLICATIONS

Chairman, Michael McElroy, EPRI

Paper 8A

*WALL-FIRED LIMB DEMONSTRATION DESIGN FOR OHIO EDISON'S EDGEWATER UNIT 4**

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U. S. Environmental Protection Agency
P. S. Nolan,
Babcock & Wilcox
M. L. Kunkle,
Ohio Edison

The paper describes and discusses key design features of the retrofit of EPA's Limestone Injection Multistage Burner (LIMB) system to an operating, wall-fired utility boiler at Ohio Edison's Edgewater Station. It further describes results of pertinent projects in EPA's LIMB program and shows how these results were used as the basis for the design of the system. The full-scale demonstration is expected to prove the effectiveness and cost of the LIMB concept for use on large-scale utility boilers. Final engineering drawings are now being prepared and the equipment procured to install the LIMB system on the Edgewater boiler. System start-up is scheduled for March 1987.

Paper 8B

RESULTS OF DIRECT DESULFURIZATION FROM COMMERCIAL POWER PLANTS

M. Y. Chughtai,
L. & C. Steinmuller GmbH

One possible method of sulfur removal is direct desulfurization sulfur capture within the boiler itself. The alkalis which naturally occur in the fuel already capture a certain proportion of the SO_2 produced during combustion and this sulfur capture can be increased by the injection of suitable additives, such as $CaCO_3$, $Ca(OH)_2$, $CaCO_3.MgCO_3$, and $Ca(OH)_2.Mg(OH)_2$, into the furnace. If the additive employed is $Ca(OH)_2$ or $CaCO_3$, the initial reaction in the furnace is the dehydration or decarbonation of the additive according to the following equations:

$$Ca(OH)_2 \longrightarrow CaO + H_2O$$

$$CaCO_3 \longrightarrow CaO + CO_2$$

Capture of SO_2 within the furnace itself and in the downstream parts of the boiler is affected by the exothermic heterogeneous gas/solids reaction

$$CaO + SO_2 + 1/2\ O_2 \longrightarrow CaSO_4$$

The calcium utilization ratio, which corresponds to the proportion of injected calcium actually reacting with the SO_2, is the figure which indicates the success or otherwise of a process For the desulfurization process to take place at all, certain preconditions of reaction temperature and residence time must be met. Depending on the firing concept, the additive injection location has to be selected to achieve a rapid mixing and a proper time/temperature history of the additive in the flue gas.

Desulfurization results from different power plants with different firing systems will be presented along with the side

effects of additive injection on the boiler and its ancillary equipment.

The results achieved so far show that a desulfurization efficiency of around 60% at a Ca/S of 2 is possible with $Ca(OH)_2$. No side effects on power plants are known so far which could cause operational problems. Extensive investigations on ash disposal have shown that the ash from direct desulfurization is definitely suitable for land disposal.

The economic advantages of direct desulfurization are considerable. Additive consumption and disposal of the ash represent the greatest operation costs. Operating costs are a little bit higher than for wet flue gas desulfurization (FGD), but the plant costs are only about 10% of those for the latter. The economic advantages with direct desulfurization increase as the sulfur content of the coal and the size of the plant decrease. This process would seem to be of particular interest for older power stations where, for reasons of space, it is impossible to install FGD equipment but where, in most cases, it is relatively easy to retrofit the plants for direct desulfurization.

Paper 8C

FIELD EXPERIENCE WITH COMMERCIAL FURNACE LIMESTONE INJECTION

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Technical University of Graz
H. Schrofelbauer,
Osterreichische Draukraftwerk AG

In Austria, eight boilers, ranging from 20 to 330 MWe, having tangential or wall burners are equipped with furnace limestone injection. The fuel is local or imported brown coal.

Operating experience is 1 to 3 years.

Ca/S molar ratios of 3 to 4 give average sulfur removal rates of 50 to 60%, depending on the fuel as well as on the type and size of the furnace.

Some minor problems of operation were overcome. Surprisingly, the performance of the electrostatic precipitators was significantly improved in several installations. In one particular case the solids emission was reduced from 180 to 80 mg/Nm^3 flue gas by furnace limestone injection.

Other operating data and experiences are reported.

Paper 8D

THE TAMPELLA LIFAC SO_2 REMOVAL PROCESS

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Tampere University of Technology

Following successful laboratory and pilot plant tests, a full-scale LIFAC desulfurization plant was installed at the 250 MWe coal-fired boiler of Inkoo power plant. Because of simplicity and suitability of the LIFAC method, the plant was operating after 6 months.

By means of the LIFAC process a considerable improvement of the reduction results can be achieved as compared to limestone injection alone. The test results show that by the LIFAC process as high a degree of desulfurization can be reached as by the wet scrubbing method or the semi-dry process.

This paper includes results from previous pilot tests as well as full-scale test results which have been achieved during the last few months.

Paper 8E

DEMONSTRATION OF FRONT END ALKALI INJECTION AND COMBUSTION MODIFICATION TECHNIQUES AT BOUNDARY DAM G.S. UNIT 4 - PROGRESS REPORT

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C-E Canada Power Systems
D. Gass,
Saskatchewan Power Corporation

This report describes the field experiments which evaluated the effectiveness of a calcium carbonate and calcium hydroxide injection system in addition to combustion system modifications for the simultaneous reduction of SO_2 and NO_x emissions. The combustion system modifications consisted of the addition of both overfire air and concentric firing to the demonstration unit's tangential firing system. The effects of this alkali injection system with combustion modification techniques on the fouling and slagging behavior of the furnace were also determined. Preliminary experimental results are reported for the injection of two sorbents, calcium carbonate and calcium hydroxide, while firing two Saskatchewan lignites in a 476,190 kg/hr (1.05×10^6 lb/hr) Combustion Engineering steam generator. The demonstration plant, consisting of the alkali injection system and boiler modifications, is described.

Paper 8F

DESIGN AND TESTING OF A RETROFIT DRY SORBENT INJECTION SYSTEM ON A 300 MW PULVERIZED FUEL BOILER

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Ontario Hydro

Ontario Hydro, as part of its overall commitment to reduce SO_2 emissions, undertook full scale development and testing of a dry sorbent furnace injection system. The injection system was retrofitted to a 300 MW tangentially fired pulverized fuel boiler with electrostatic precipitators at the Lakeview Generating Station in Toronto.

Development of the overall design parameters and system design of the sorbent injection equipment, in cooperation with Combustion Engineering and GATX-Fuller, occurred from late 1984 until the December 1985 test period.

This paper describes the Lakeview Unit 4 boiler, associated equipment, and the retrofit injection system. Powdered limestone or calcium hydroxide can be injected into the furnace at a preselected elevation above the burners.

The testing procedures, equipment, and test results are described.

The results of the program indicate that 40% SO_2 reduction can be achieved at partial loads (up to 220 MW) with limestone injected at a 3 to 1 Ca/S ratio.

Results of calcium hydroxide injection show greater SO_2 reductions with lower Ca/S ratios.

Paper 8G

FULL SCALE DEMONSTRATION OF DRY SODIUM INJECTION FLUE GAS DESULFURIZATION AT CITY OF COLORADO SPRINGS RAY D. NIXON POWER PLANT

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FMC Corporation
D. B. Watts and
R. L. Ostop,
Colorado Springs Department of Utilities
R. G. Hooper,
Electric Power Research Institute

The Department of Utilities of the City of Colorado Springs, Colorado, FMC Corporation, and the Electric Power

Research Institute are conducting a full-scale demonstration and test program of the injection of dry sodium sorbents upstream of a fabric filter for SO_2 and NO_x removal The program was conducted on the Unit 1 boiler at the Ray D. Nixon Power Plant in Fountain, Colorado. This boiler is rated at 223 MW, fires low-sulfur western coal, and is equipped with two reverse-gas-cleaned fabric filters, each designed to handle 50% of the total flue gas flow. Sodium-based sorbents are injected upstream of one of the fabric filters thus providing a 100+ MW demonstration, side-by-side with an identical fabric filter operating without sorbent injection

The program consisted of three phases. Phase I was the initial start-up and characterization of the system. Phase 2 was the demonstration of 70% SO_2 removal on a 30-day rolling average basis using sodium sesquicarbonate as the sorbent. Phase 3 consisted of parametric testing using sodium sesquicarbonate and sodium bicarbonate as sorbents, as well as testing the process while burning a different coal in the boiler

The full-scale demonstration proved that dry injection of sodium sesquicarbonate can consistently and reliably meet the current federal regulation of 70% SO_2 removal. During the 55-day continuous run to demonstrate 70% SO_2 removal efficiency on a 30-day rolling average, the system averaged 74% SO_2 removal with better than expected utilization of the sodium sesquicarbonate sorbent. In addition, an unexpected benefit in the operation of the fabric filter was realized: the injection of sodium sesquicarbonate resulted in significantly reduced flue gas pressure drop Distribution of sorbent in the flue gas stream was shown to be important in achieving maximum sorbent utilization.

Paper 8H

*EVALUATION OF SORBENT INJECTION TEST AT TIEFSTACK, WEST GERMANY**

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Energy and Environmental Research Corporation
Y. Chughtai,
L & C Steinmuller GmbH

Sorbent injection for SO_2 control was evaluated at the Tiefstack Power Station, Unit 6, located near Hamburg, West Germany The boiler is tangentially fired with low sulfur bituminous coal and produces 160,000 kg/hr (352,000 lb/hr) of steam. A temporary sorbent injection system was installed and operated by the utility owner. The evaluation involved field measurements over a 3-week test period combined with flow and heat transfer modeling and small scale testing. Results of the field test showed SO_2 reductions of 22 and 43% at a Ca/S of 2 for high calcium limestone and atmospheric hydrated lime, respectively. Analysis of the results showed the injection configuration to have minimal impact on capture, with injection at a furnace gas temperature of 1520 K and adequate dispersion of the sorbent.

UNPRESENTED PAPERS

PILOT SCALE STUDIES OF LIMESTONE INJECTION PROCESS

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The limestone injection process for SO_2 control has been studied at Ontario Hydro's 620 MJ/h combustion research facility under conditions simulating the Lakeview TGS quenching rate. Various combinations of operating conditions affecting SO_2 and particulate removal have been evaluated using a non-porous local limestone, while burning a 1.7% S eastern U S. bituminous coal. The program is aimed at improving the overall efficiency of sulfur capture and sorbent utilization, and minimizing the impact of in-furnace injection on particulate removal by the electrostatic precipitator (ESP). Process variables such as limestone injection location, addition rate, and particle size have been optimized. Under optimized conditions, SO_2 removal efficiency was about 43% and sorbent utilization up to 17%. The process produced finer and about twice as much ash as coal. The carbon level of the waste on a sorbent-free basis was about 20%. Resistivity of the waste ranged between 10^5 and 10^6 ohm. cm. The ESP performed with a 10% reduced efficiency, probably because of the fineness of the waste and increased dust loading.

FLUE GAS DESULFURIZATION BY DRY ALKALINE SODIUM SORBENT INJECTION USING AN ELECTROSTATIC PRECIPITATOR

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Pilot scale tests of flue gas desulfurization using the dry injection of sodium sorbents in combination with an electrostatic precipitator have been conducted at the University of Washington. The pilot facility draws flue gas from a pulverized-coal-fired boiler using low sulfur western coal. An extended duct arrangement has been used to provide a residence time of up to 6 seconds prior to collection in the ESP.

Test results indicate SO_2 removals of 50 to 80% using pulverized sodium bicarbonate at a normalized stoichiometric ratio of 1.0, pilot gas temperature of 204°C, and 300 to 550 ppm SO_2. Removals were affected by sorbent injection rate, in-stream residence time, and sorbent particle size. Sodium sesquicarbonate appears to be less effective than sodium bicarbonate in removing SO_2 under test conditions.

Essentially all research and development activities conducted prior to this program involved the application of dry injection in combination with a fabric filter baghouse. Accumulation of sorbent material on the baghouse surface was believed to be necessary to provide an extended contact and reaction period. The results of the University's pilot tests indicate the potential for application of the dry injection technology to both new and existing coal-fired boilers equipped with ESPs. SO_2 removal rates of 50% and greater would appear to be possible. Additional research will be required to more completely evaluate the potential of this technology for higher sulfur coals and varied flue gas temperatures. It is anticipated that more efficient SO_2 removal will be achieved with higher flue gas SO_2 concentrations.

The economics of retrofit installation of the dry injection process to typical industrial and utility boilers has been briefly examined. In all cases, installed capital costs for dry injection are significantly below those of available alternate technologies such as spray dryers and wet scrubbers. Operating costs are strongly dependent on the price and quantity of sorbent used. Levelized busbar costs for dry injection are significantly below those of alternative technologies for low sulfur coals. Levelized costs are comparable for small to intermediate sized utility boilers

with relatively low capacity factors firing medium (2%) sulfur coals.

RATE CONTROLLING MECHANISMS OF SULFATION

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A sulfation model is used to analyze the SO_2 sorption data from a wide range of CaO particle diameters (1 μm - 1 mm), SO_2 partial pressures (60 Pa to 5 kPa), and temperatures (973 to 1478 K) An intrinsic SO_2 reaction order of unity has been validated through fixed bed experiments in the 60 to 300 Pa SO_2 partial pressure range, while fluidized bed data were used to validate the reaction order from 500 Pa to 5 kPa SO_2 partial pressure. The absolute value of the intrinsic rate constant and the activation energy (10,000 $\pm$ 1000 K) was derived from data on small (1 μm) sorbent particles that are in the limit of kinetic control. Rate limiting processes include· 1) the filling of the smallest pores and the subsequent loss in the internal surface area, 2) the activated diffusion of the SO_2 through the produce deposits, and 3) the loss of intraparticle diffusion due to the complete plugging of the largest pores. It is shown that the reaction kinetics and the filling of the smallest pores are generally rate controlling on time scales of 1 to 10s, but product layer diffusion may become rate controlling after approximately 100s.

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The complete report consists of two volumes, entitled "Proceedings: 1986 Joint Symposium on Dry SO_2 and Simultaneous SO_2/NO_x Control Technologies:"
"Volume 1. Sorbents, Process Research, and Dispersion," (Order No. PB 87-120 465/AS; Cost: $30.95)
"Volume 2. Economics, Power Plant Integration, and Commercial Applications," (Order No. PB 87-120 457/AS; Cost: $48.95)

The above reports will be available only from: (costs subject to change)
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