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Project Summary

Proceedings: 1985 Joint Symposium on Stationary Combustion NO_x Control

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Together, the more than 60 presentations from this international gathering constitute a comprehensive source of information on nitrogen oxide (NO_x) emissions control technologies. As such, they make a unique contribution toward the development of cost-effective and reliable control systems for fossil-fuel-fired power plants.

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

The 1985 Joint Symposium on Stationary Combustion NO_x Control was held May 6-9 in Boston, MA. This was the third symposium on NO_x control jointly sponsored by EPA and EPRI: the first was in Denver in 1980; and the second, in Dallas in 1982. The symposium is a consolidation of EPRI's previous NO_x Control Technology Seminars and EPA's Symposia on Stationary Source Combustion. The objective of the symposium is to give attendees the opportunity to exchange information on the latest advances in combustion technology and flue gas treatment processes for stationary sources. Such an exchange of information contributes significantly to the development of cost-effective and reliable NO_x emission control systems.

Over 60 papers were presented during the 4-day meeting which was attended by representatives of 13 nations. Topics ranged from full-scale applications of combustion modifications and flue gas treatment to fundamental combustion research. The speakers represented a variety of international organizations including electric utility companies, boiler and other related equipment manufacturers, research and development groups, and regulatory agencies.

Cochairmen of the symposium were David Eskinazi of EPRI and Michael C. Osborne of EPA. The keynote address was delivered by Robert C. Carr, Department Director of Environmental Control Systems of EPRI's Coal Combustion Systems Division and EPA's Carl R. Gerber, Director of the Office of Environmental Engineering and Technology, Office of Research and Development. The welcoming address was given by C. Bruce Damrell, Vice President, Engineering and Distribution of Boston Edison Company. The symposium proceedings are in two volumes:

- Volume 1: Utility Boiler Applications
  - —Session 1: Introduction
  - —Session 2: Manufacturer's Update of Commercially Available Technology
  - —Session 3: Low-NO_x Combustion Development
  - —Session 4: Development and Application of Fuel Staging (Reburning)
  - —Session 5: Full-Scale Boiler Application
  - —Session 7: Advanced Power Plants
  - —Session 8a: Flue Gas Treatment

- Volume 2: Industrial Processes, Fundamental Studies, and Slagging Combustors
  - —Session 6a: Externally Staged Combustors (Slagging Combustors)
  - —Session 6b: Fundamental Combustion Studies
  - —Session 8b: Stationary Engines and Industrial Process Systems
  - —Session 9a: Overview of Furnace Sorbent Injection SO_2 Control
  - —Session 9b: Fuel and Combustion Modifications for Commercial/Industrial Boilers

Session 1

Introduction

(Michael C. Osborne, EPA/AEERL, Session Chairman)

1-1. "An Overview of International NO_x Control Regulations," Peter W. Dacey, IEA Coal Research

The pace of development of NO_x emission control regulations has increased rapidly in the past 2 years. This paper looks at some of the factors underlying this acceleration and the regulatory development in different countries. The experience in the Federal Republic of Germany, Japan, and the United States has been influential in determining the timing and the form of regulations in other countries. Within a national framework, local agencies can significantly affect the stringency of regulations at individual sites.

Using conversion factors for the different sets of units used allows intercountry comparisons to be made. In general the variation between countries in their treatment of emission from different fuels is less significant than the absolute differences between emission levels for a given fuel. Treatment of particular plant sizes is generally in line with the overall stringency of a country's regulations. Potential future developments are reviewed.

1-2. "Legal Instruments and the State of Technology for Reducing NO_x Emissions in the Federal Republic of Germany," Helmut Keinhorst, Federal Environmental Agency

The air pollution situation of the highly polluted Federal Republic of Germany was presented. In this context, the considerable damage to buildings and materials was considered as well as the extent of recent forest damage. The legal basis for the Programme of the Federal Government to reduce NO_x pollution was explained. In particular the Ordinance on Large Furnaces and the Technical Instructions on Air Pollution Control (TI Air) were mentioned. The measures being taken for the limitation of NO_x in Europe were dealt with briefly.

The primary measures under consideration for the achievement of the reduction target and NO_x flue gas treatment technologies were presented. Using plants being planned or under construction as an example, it was shown which rate of reduction can be expected from the individual primary and secondary measures. In conclusion, a prognosis was made for the attainable reduction potential through the introduced measures. The result is that a considerable decline in the pollution of the environment may be counted on.

1-3. "Utility Perspective on Low NO_x Control," Dominick J. Mormile, Consolidated Edison Company of New York, Inc.

The Empire State Electric Energy Research Corporation has initiated a program to provide the New York Power Pool member utilities with information to assess the impacts of implementing alternative NO_x controls on their boilers. This paper discusses the need, basis, and approach for conducting this program.

1-4. "Role of NO_x Emissions in Acid Rain," Julius Chang, National Center for Atmospheric Research

This paper was not submitted for publication.

1-5. "Boreal Montane Ecosystem Decline in Central Europe and the Eastern United States: Potential Role of Anthropogenic Pollution with Emphasis on Nitrogen Compounds," Robert I. Bruck, North Carolina State University

A large scale decline of forests in the Federal Republic of Germany involving many tree species has been observed and extensively studied since 1979. A more limited decline of high altitude boreal montane ecosystems (spruce-fir) in the eastern United States has been in progress for perhaps 20 years. The unique nature of the observed symptoms, the location of the affected forests in areas of high anthropogenic pollution deposition, and the synchronized appearance of symptoms make it plausible that airborne pollutants coupled with secondary natural factors are responsible for the forest decline. Of recent interest is the possible role of nitrogen compounds in the forest decline syndrome. Nitrogen (unlike sulfur) compounds are highly active in forest ecosystems. Foliar or root "fertilization" of high altitude trees exposed to often violent climatic conditions could and probably do have numerous detrimental effects. These effects include reduction of frost hardiness, cell wall thinning, and radical shifts in rhizosphere and rhizoplane microorganism populations. This could result in a "stress syndrome" predisposing the affected ecosystems to secondary pathogens and climatic factors.

Session 2

Manufacturer's Update of Commercially Available Technology

2-1. "Utility Steam Generator NO_x Control Update - 1985," P. L. Cioffi, A. D. Larue, M. A. Acree, Babcock & Wilcox

Babcock & Wilcox continues to ex pand its NO_x control experience an technology along several fronts. Th Dual Register Burner/Compartmente Windbox system is successfully pe forming on 35,200 MW of capacity in wide range of coal boiler applications In addition, there are several new lo NO_x systems described in this pape The Enhanced-Ignition Dual-Registe Burner and the Hitachi-NR burners offe improvements for difficult-to-burn fuel and for further NO_x reduction, respe tively. In-furnace NO_x reduction utilize reburning technology to achieve e tremely low-NO_x emissions for gas, o or PC and can be applied in new

retrofit situations. Also, the Low NO_x Cell is being developed for direct retrofit for the unique cell burner design. Circulating fluidized beds with low-NO_x emissions are being sold for a variety of applications. Finally, Furnace Sorbent Injection combined with low-NO_x burners is providing a means of simultaneous NO_x/SO_2 reduction for PC units.

2-2. "1985 Update of NO_x Emission Control Technology at Combustion Engineering," R. J. Collette, Combustion Engineering, Inc.

Much discussion has transpired in the past several years relating to the design and development of technology associated with the control of nitrogen oxides (NO_x) from utility and industrial steam generators. As a major supplier of steam generators and fuel burning equipment for the utility and industrial marketplace, Combustion Engineering is now in a position to report the results of actual field operating data generated in the past 2-1/2 years.

The NO_x control techniques presented in this discussion are systems which Combustion Engineering has developed internally or is licensed to build by Mitsubishi Heavy Industries, Ltd. (MHI) of Japan. This paper focuses primarily on design application and recent experience with NO_x reduction techniques referred to as the PM Burner and, initially, the Low-NO_x Concentric Firing System.

2-3. "Current Development in Low-NO_x Combustion Systems," R. A. Lisauskas, C. E. McHale, Riley Stoker Corp.

The current status of low-NO_x combustion controls for wall- and turbo-fired furnaces is discussed. Pilot-scale combustion tests have been conducted on burner systems for both furnace configurations. Second generation combustion controls have been installed on two new industrial-size front-wall and Turbo-fired boilers. An advanced Turbo furnace control system has been developed which integrates low-NO_x burners with air staging at multiple levels within the furnace. Preliminary field test results have demonstrated that NO_x levels significantly below currently required emission limits can be achieved with this control system.

Advanced in-furnace NO_x and SO_2 control techniques will require well placed furnace overfire air, fuel, and sorbent injection systems which achieve good penetration and rapid mixing.

An analytical flow simulation code is being used to help establish design criteria necessary to achieve effective upper furnace overfire air, fuel, and sorbent injection systems which achieve good penetration and rapid mixing. An analytical flow simulation code is being used to help establish design criteria necessary to achieve effective upper furnace mixing.

2-4. "Industrial and Utility Boiler NO_x Control," E. S. Schindler, J. Vatsky, Foster Wheeler Energy Corp.

This paper summarizes Foster Wheeler's commercial Flow/Split-Flame Low NO_x Coal Burner and field results. Highlighted are up to 60% reduction in NO_x without changing the flame envelope or increasing unburned carbon loss; this combination makes the CF/SF burner highly suitable for new and retrofit situations. Field results for new and retrofit burners are presented. Future low-NO_x burner concepts which have the potential to further decrease NO_x emissions are discussed.

A summary is presented of Foster Wheeler's SO_2 reduction work using limestone injection into the furnace. Prototype developments of this technology along with field tests on an industrial steam boiler are presented.

Finally, Foster Wheeler's large scale combustion and environmental test facility, rated at a maximum of 75×10^6 Btu/hr heat input, is described.

Session 3
Low-NO_x Combustion Development

(Michael McElroy, EPRI, Session Chairman)

3-1. "Experimental Investigation of Retrofit Low-NO_x Combustion Systems," R. Lisauskas, R. J. Snodgrass, Riley Stoker Corp.; S. A. Johnson, Physical Sciences, Inc.; D. Eskinazi, EPRI

Pilot-scale development tests have been conducted on advanced retrofit low-NO_x combustion controls. The tests were conducted in a 100×10^6 Btu/hr test furnace designed to simulate the combustion environment in utility coal-fired boilers. Several control options were integrated by combining a low-NO_x burner with air and fuel combustion staging within the furnace. Each combustion modification technique was evaluated over a range of design and operating parameters. NO_x reductions from 50 to 75% were achieved with both advanced air- and fuel-staged combustion. Test results are presented along with a discussion of design constraints affecting the retrofit of combustion control systems to existing utility wall-fired boilers.

3-2. "Low-NO_x Coal-Firing System Demonstration Results on a Tangentially Fired Boiler," A. Kokkinos, R. D. Lewis, Combustion Engineering; D. G. Lachapelle, EPA/AEERL

The Low-NO_x Concentric Firing System (LNCFS) was installed at Utah Power and Light's Hunter No. 2 station for demonstration purposes. The LNCFS was installed at the 420 MWe station during September 1981, for the purpose of examining its NO_x emission reduction characteristics and its effects on long-term boiler operation under low-NO_x firing conditions. The paper presents the results of this long-term study.

The data analysis shows that NO_x emissions can be reduced from baseline emission levels to 460 (corrected to 3% O_2) and 360 ppm without and with overfire air, respectively, to levels of 240 to 260 ppm following the modification. Long-term testing showed no effect of the LNCFS on boiler operating parameters. Thirty-day continuous NO_x monitoring tests were also carried out averaging 0.41 lb/10^6 Btu fired.

3-3. "Air Flow Modeling of a 750 MW Gas- and Oil-Fired Boiler," D. P. Teixeira, Pacific Gas and Electric Co.; G. B. Gilbert, Dynatech R/D Co.

Flow modeling of the air supply system of Pacific Gas and Electric's Moss Landing Boiler 6-1 was performed. The

purpose of these tests was to improve the performance and NO_x emission characteristics of the fuel-oil/natural-gas fired unit. Objectives of the modeling were to achieve reduced overall excess air and flue gas recirculation (FGR) levels by providing uniform air and FGR flows to each of 48 circular cell burners. Target airflow balances to each burner were ±2% of average; flue gas recirculation balance goals were ±1% absolute (e.g., 14 to 16% FGR for 15% average).

The modeling criteria and measurement techniques necessary to achieve this level of flow and FGR balance are described. Field test results to confirm that the modeling criteria in fact duplicated the full-scale boiler behavior are presented. Finally, results of a series of modifications to achieve the flow and FGR balance targets are presented.

3-4. "Laboratory Flow Model Studies to Improve Overfire Air Mixing," R. Thompson, Fossil Energy Research Corp.; D. Eskinazi, EPRI; R. Afonso, G. Gilbert, Dynatech R/D Co.; R. Yang, KVB, Inc.; C. McHale, Riley Stoker Corp.

The installation of an overfire air system on coal-, oil-, or gas-fired utility boilers can be an effective means of reducing NO_x emissions without some of the operational or retrofit limitations of other forms of staged combustion NO_x control. However the design of early overfire air systems was not optimized and their effectiveness was strongly dependent on the degree of air penetration mixing and carbon burnout in the upper furnace region. Current design practice suggests that an overfire air velocity to bulk furnace velocity ratio of about 6 is desirable to achieve good overfire air penetration. However, a review of existing unit designs indicates a number of overfire air systems were installed with low overfire air velocity before this design practice was accepted. In addition, it has not been established whether this design practice is equally effective or optimum for all furnace firing configurations.

The objective of this research project is to develop specific design criteria for retrofit and new unit overfire air systems based on flow model test results. A one-twelfth scale model has been constructed with variable overfire air port location and injection condition, firing configuration, and furnace aspect ratio to study the mixing process. A brief fundamental analysis based on jet penetration theory was used to establish the model design criteria for simulating the flowfield in tangential, opposed, and single-wall-fired utility boilers. Preliminary test results for the single-wall-fired case are reported including overfire air concentration profiles in the mixing region above the injection ports. The overfire air injection velocity, port number, and location are shown to be critical parameters in the upper furnace mixing process.

3-5. "Status of EPDC's NO_x Control Technology," Kuniyoshi Fujiyama, Electric Power Development Co., Ltd.

EPDC has a total generating capacity of about 10,000 MW, and 3,000 MW of the total is by coal thermal generation. All of the coal thermal power stations are located near cities, and gas recirculation and/or an overfire air system (OFA) has been adopted these 10 years for low-NO_x operation. R&D work for SCR De-NO_x operation was started about the same time, and commercial operation was started 4 years ago, after successful demonstration tests at Takehara Unit No. 1.

The results of our low-NO_x operation for 10 years and of SCR operation for 4 years are described in the paper.

In Takasago Thermal Power Station, we had an accident where the evaporating tube below the OFA port burst 9 years after starting 15% OFA. Investigation revealed that thinning of the tube was concentrated in a specific region, and the thinning was regarded as a result of corrosion by a reducing gas.

In Isogo Power Station, where coal of N = 1.1 to 1.3% is fired and the NO_x value for 6 to 7 years after starting operation was 500 to 600 ppm, the NO_x value was lowered to 340 from 450 by installation of 15% OFA in 1974, to 250 from 300 ppm by that of a low-NO_x burner in 1977, and further to 150 from 160 ppm by 30% deep stage combustion in 1980.

The results on unburned carbon vs NO_x, adoption of high performance pulverized coal distributor, curtain wall by air, etc. are explained.

Operation experience on Takehara Generator No. 1 (250 MW) and No. 3 (700 MW) are shown as the newest data of the SCR operation.

AH plugging, the problems of IDF, BUF vibration, and deterioration of activity of catalysts are also referred to.

3-6. "Development of Low NO_x Cell Burners for Retrofit Applications," Albert D. LaRue, Larry W. Rodgers, Babcock & Wilcox

Continuing concern about NO_x emissions from pre-NSPS coal-fired utility boilers led EPRI and Babcock & Wilcox to embark on a project to reduce NO_x emissions from cell burner combustion equipment. Cell burners were applied extensively in large coal-fired boilers situated in the east-central U.S. These boilers have generated NO_x emissions at two to three times the limit allowed by present federal standards for new sources. The unique design of the cell burners was incompatible with existing low-NO_x burner designs. Thus, the main objective of the multiphase project was to develop directly retrofitable, low-NO_x combustion equipment for use in these units and to develop scaling techniques to reduce risks and predict performance at full scale.

This paper discusses pilot-scale (6×10^6 Btu/hr) combustion tests and related work performed to develop a low-NO_x cell burner. Screening tests compared performance of standard cell burners to low-NO_x alternatives. The resulting Low-NO_x Cell Burner achieved NO_x reductions of 65% while maintaining high combustion efficiency. In addition, field constraints and scaling techniques were evaluated in preparation for its commercialization.

3-7. "Development of the Low-NO_x Burner for the Pulverized-Coal-Fired In-Furnace NO_x Reduction System," Shigeki Morita, Tsuneo Narita, Yoshiziro Arikawa, Isuyoshi Nawata Fumio Koda, Tadahisa Masai, Keizo Untsuka, Hitachi, Ltd.

Babcock Hitachi K. K. (BHK) has developed a new low-NO_x burner specially designed as the "Main Burner" to be combined with the P. C. firing In-Furnace NO_x Reduction (IFNR) system. We call this burner the Hitachi NO_x Reduction Burner (HT-NR Burner). The burner may be called an "In-Flame NO_x Reduction Burner.

3-8. "Fire-Side Corrosion in Low-NO_x Combustion Systems," S. F. Chou, P. L. Daniels, L. W. Rodgers, G. J. Theus, Babcock & Wilcox Co.; D. Eskinazi, EPRI

Flame impingement and reducing gas are two major concerns regarding potential fireside corrosion problems in low-NO_z combustion systems. Flame impingement can cause severe corrosion by unburned pyrites and liquid pyrosulfate. In the reducing gas, sulfur is released from coal as H_2S, which will sulfidize boiler tubes at furnace wall temperatures. Laboratory test results show that carbon steel and Type 304 stainless steel have reasonably good corrosion resistance up to 700 and 900°F, respectively. However, thermal cycling degrades their corrosion resistance. Types 309 and 310 stainless steels, Inconel 671, and an Fe-Cr-Al alloy have much better corrosion resistance. Alternate oxidizing and reducing conditions are detrimental to the corrosion resistance of the carbon steel but not the stainless steels. Commercial bimetallic tubing clad with stainless steel should be of practical use in low-NO_x combustion systems.

In general, low-NO_x combustion conditions are more corrosive than conventional boiler combustion conditions. Careful control of operating conditions is critical to the corrosion problems. Combustion test results indicate that staged combustion conditions are more corrosive than low-NO_x cell burner combustion conditions, and the corrosion in the low-NO_x cell burner combustion system is expected to be manageable.

3-9. "Extrapolation of Burner Performance for Single Burner Test to Field Operation," R. A. Lisauskas, D. C. Itse, Riley Stoker Corp.; C. C. Masser, EPA/AEERL

The extrapolation of pilot scale low-NO_x burner test results to coal-fired field boilers is discussed. Single burner test results are presented for three pilot-scale test furnaces and two burner scales. Three burner designs are evaluated: a conventional pre-NSPS burner, a commercial first generation low-NO_x burner, and a prototype second generation low-NO_x burner. NO_x emissions are compared with field data from two utility wall-fired boilers equipped with low-NO_x burners. A burner zone heat release parameter is used to account for differences in thermal environment between the test furnaces and field boilers.

Session 4

Development and Application of Fuel Staging (Reburning)

(R. Hall, EPA/AEERL, Session Chairman)

4-1. "Pilot Scale Evaluation of NO_x Control From Pulverized Coal Combustion By Reburning," W. R. Seeker, B. J. Overmoe, J. M. McCarthy, S. L. Chen, G. D. Silcox, D. W. Pershing, Energy and Environmental Research Corp.

This paper described results from a research project supported by the U.S. EPA in which a 10×10^6 Btu/hr reburning tower was designed and constructed for the purpose of studying reburning processes on a scale large enough to involve realistic mixing phenomena. The facility, which was $4 \times 4 \times 26$ ft overall, was down-fired with coal or gas and was refractory-lined and water-jacketed. Multiple rows of ports were included in the design to allow the study of injection location, residence time, thermal environment, injection configuration, jet diameter and velocity, and the important process variables. The NO_x reduction levels achieved over uncontrolled levels were found to be between 40 and 70%, depending on the process parameters. The results of this study indicated that many of the process variables identified on earlier bench-scale studies could be directly applied to larger scale units. In particular, increasing rich-zone residence time and furnace temperature decreased NO_x emissions, and about 15% reburning fuel produced a minimum in emissions. Increasing the reburning mixing rate was also found to decrease NO_x emissions in the exhaust. This paper supplies general guidelines for the application of reburning to pulverized-coal-fired boiler furnaces.

4-2. "The Effect of Fuel Nitrogen in Reburning Application to a Firetube Package Boiler," J. A. Mulholland, R. E. Hall, EPA/AEERL

An experimental investigation of the effect of volatile fule-bound nitrogen in reburning application to a pilot-scale firetube package boiler is described. It is shown that the fixed nitrogen content of the reburning fuel is a limiting factor in applying reburning to boilers with baseline NO_x levels of less than 250 ppm. With reburning fuels containing more than 0.1% nitrogen, 50% NO_x reduction was the maximum achievable when the initial NO_x level was less than 200 ppm. For fuels containing more than 1% nitrogen, no reduction was possible from initial levels of less than 200 ppm. In tests with ammonia-doped natural gas (up to 1% nitrogen), pyridine-doped distillate fuel oil (0.5% nitrogen), and a residual distillate fuel oil mixture (0.14% nitrogen), minimum net fractional conversion of reburning fuel nitrogen to exhaust NO_x was found to range from 30 to 50%. To minimize the conversion of reburning fuel nitrogen to NO_x, primary flame excess air level is minimized and fuel-rich reburning zone residence time is maximized.

4-3. "Screening and Optimization of In-Furnace-NO_x-Reduction Processes for Refinery Process Heater Applications," Fernando J. Garcia, Robert Yang, Skillman C. Hunter, KVB, Inc.

The effectiveness and applicability of In-Furnace-NO_x-Reduction (IFNR, also known as reburning or fuel staging) process in controlling NO_x emissions from refinery process heaters has been studied. A two-phase approach was taken first to screen the various IFNR firing arrangements in an idealized subscale test furnace for their NO_x-reducing capabilities, followed by selecting the most promising IFNR firing arrangement and evaluating its applicability in a subscale process heater simulator. The screening test results showed that, while "conventional" reburning (air-

staging plus fuel injection to create a fuel-rich zone between the main burner and the staging air injection point) was only as good but not better than air-staging in reducing NO_x, the firing arrangement that achieved the greatest NO_x reduction is the one called "biased firing" which was found to be capable of reducing stack NO_x by greater than 90% from the unstaged baseline conditions. Following the screening tests, the applicability of biased firing as both a retrofit and a new burner concept was further studied in a subscale process heater simulator. The results of these tests showed that biased firing is a viable concept to be implemented for substantial reduction of NO_x emissions from refinery process heaters.

4-4. "Evaluation of In-Furnace NO_x Reduction," H. Ikebe, S. Miyamae, K. Makino, K. Suzuki, J. Mogi, Ishikawajima-Harima Heavy Industries Co., Ltd.

Reburning by secondary fuel injected after the main firing zone produces a NO_x reducing region in which hydrocarbon radicals resolve NO_x into N_2. Bench-scale tests were conducted using gas fuels and gas-phase volatile matter evolved from pulverized coal as secondary fuels. The results indicated the molar ratios $(O_2)/(HC)$ and $(HC)/(NO)$ as well as gas temperature residence time in the reducing region, and a kind of secondary fuel to be the dominant variables controlling the reaction. Pilot-scale tests using the 12 MWt furnace were performed to see if in-furnace NO_x reduction could be applied to gas, oil, and pulverized coal firing. While maintaining excess O_2 in the first stage combustion zone at 1 to 2%, NO_x reduction of more than 50% was possible by reburning. In the case of commercial boilers firing oil and pulverized coal, 15 to 20% NO_x reduction was possible by quasi-reburning with a conventional burner arrangement.

4-5. "Three-Stage Pulverized Coal Combustion System for In-Furnace NO_x Reduction," Y. Sekiguchi, N. Okigami, Y. Miura, K. Sasaki, R. Tamaru, Hitachi Zosen Corp.

A comprehensive effort was made toward the development of low-NO_x combustion methods in pulverized coal combustion, and this effort led to the development of a new NO_x reducing combustion system called "Three-Stage Combustion System." In this process, pulverized coal and air are combusted in a conventional method in the first stage, then additional coal is injected and NO_x formed previously is reduced to nitrogen.

Finally, more air is supplied to complete combustion. The performance of this method was tested using a small-scale test furnace with a coal-burning capacity of 200 kg/h at first, and then a large-scale test was conducted at demonstration facilities with a coal-burning capacity of 2 t/h. It was clear that the new combustion system provided an improved NO_x suppression rate and good combustion characteristics in comparison with conventional NO_x reduction methods. This new low-NO_x combustion system has been applied to actual coal firing plants.

4-6. "Application of Reburning for NO_x Control in Cogeneration," R. Brown, W. C. Kuby, Acurex Corp.

This paper describes the results of a design and experimental program to develop a post-combustion NO_x control technique for gas-fired IC engines and gas turbines as applied to cogeneration. Emissions and performance data of both rich- and lean-burn engines were used to develop a conceptual reburner design to be placed between the engine and a waste heater boiler. This reburner design was then modeled for testing in a 100,000 Btu/hr subscale test facility. Parametric testing achieved 50% reduction at a fuel fraction of 30% for rich-burn and mid-O_2 range engine exhausts. Lean-burn NO_x reductions were limited to 35% at the same fuel fraction. It appears that increased temperatures and overall fuel-rich conditions in the reburn zone are necessary to achieve up to 50% reduction. Other parameters explored include reburner stoichiometry, NO input level, fuel fraction, and mixing techniques.

Session 5

Full-Scale Boiler Application

(C. Allen, Arizona Public Service Co., Session Chairman)

5-1. "Guidelines for Retrofit Low NO_x Combustion Control," Richard E. Thompson, Fossil Energy Research Corp.; Michael W. McElroy, EPRI

EPA has sponsored a study to determine the potential of applying retrofit NO_x controls to coal-fired utility boilers and to develop guidelines for use by utility boiler operators in identifying cost-effective control options. This paper summarizes: 1) boiler NO_x emissions by design type, 2) current and emerging NO_x control options, and 3) a methodology for determining the relative retrofit potential, performance, and cost of implementing NO_x control on boilers of various design.

Total annual NO_x emissions and unit capacity by boiler type are compared on a national basis to provide an appreciation for the dependence of NO_x emissions on boiler design. The design, performance, operational, and cost characteristics of three conventional retrofit NO_x control techniques are summarized. A synopsis of emerging control techniques highlights current R&D efforts. The screening methodology for selecting NO_x control options addresses many of the specific design and physical hardware constraints in selecting a control method.

5-2. "Evaluation of Long-Term NO_x Reduction on Pulverized Coal-Fired Steam Generators," S. Hunter, V. P. Roman, KVB, Inc.

Long-term NO_x emission data from eight pulverized-coal-fired steam generators were analyzed to quantify the effectiveness of various combustion modifications. All of these boilers, except one, were modified specifically to reduce NO_x emissions. These combustion modifications included changes of both a hardware and operational nature. All of the boilers were subject to the NO_x provisions of the 1971 New Source Performance Standard (NSPS).

In several instances long-term emission data for the time period before the modification were not available. In these cases the quantification of the NO_x reduction was based on the result of the performance test required by the 1971 NSPS. NO_x reductions ranging from 5.1 to 60% were determined without incurring significant adverse impacts on unit operation. NO_x emission levels as determined from the performance tests, ranged from 146 to 473 ng/J

(0.34 to 1.10 lb/10^6 Btu) before control implementation and from 148 to 281 ng/J (0.34 to 0.65 lb/10^6 Btu) after combustion modifications were applied.

5-3. "Application of a Pulverized-Coal-Fired Low-NO_x PM Burner for Steam Generators," T. Namiki, Mitsubishi Heavy Industries, Ltd.

Mitsubishi Heavy Industries, Ltd. has engaged in research and development of a new technology related to coal-fired thermal powerplants for many years, and had developed coal-fired low-NO_x burners to meet the severe emissions regulations that become more and more severe every year. This time, we have successfully developed and put into practical use a pulverized-coal-fired super low-NO_x PM burner (Mitsubishi Pulverized Fired PM Burner).

This paper introduces pulverized coal-fired boilers with capacities of 250 t/h equipped with this PM burner that has been installed at Iwanuma Mills of Daishow Paper Mfg. Co. and a 350 MW reheat unit that has been installed at Sakata Power Station of Sakata Joint Power Generating Co., Ltd.

5-4. "Field Evaluation of the Distributed Mixing Burner," B. Folsom, A. Abele, J. Reese, Energy and Environmental Research Corp.

The Distributed Mixing Burner (DMB) is a low-NO_x pulverized coal burner for wall-fired applications. It consists of a circular burner with outboard air ports to provide staged combustion. The circular burner operates under reducing conditions to minimize NO_x emissions while an overall oxidizing environment is maintained in the furnace to minimize slagging and corrosion.

The paper presents the results of a field evaluation of the DMB funded by the U.S. EPA on a 98 kg/hr (215×10^3 lb/hr) steam four-burner front-wall-fired boiler. Prior to the DNB retrofit, field tests were conducted on the pre-NSPS burner originally installed in the boiler to establish a baseline. Following DMB installation, the boiler was operated and tested with the DMBs for 17 months. Under routine operation, the DMBs reduced NO_x emissions by about 50%. Under optimum conditions, NO_x emissions were reduced by about 70%.

5-5. "Designs and Development of a Retrofit Low NO_x Burner," I. J. Stuart-Sheppard, W. K. Summons, J. A. Arnott, Ontario Hydro

Initial tests, aimed at reducing the turbulence of combustion, involved removing the impellers from a single row of burners. Though it proved possible to sustain combustion, severe roping of the coal occurred.

Subsequent installation of venturies substantially improved combustion while maintaining a significant reduction in NO_x. However, excessive pressure drop in the primary air system was experienced.

In light of the experience gained, a scaled-down version of the boiler manufacturer's Low-NO_x Burner, suitable for retrofitting into existing burner openings was developed. Testing of a single row of these burners enabled problem areas to be identified and modifications made to bring their performance to a standard acceptable for a complete retrofit. The results from the first unit retrofitted proved the burners to be highly effective in reducing NO_x, and a second unit was, therefore, retrofitted.

Over a period of time, substandard PF fineness contributed to increases in unburned carbon which led to opacity problems. A decision was, therefore, made to try and modify the burners in a way which would compensate for such adverse influences.

Following model tests, small coal spreaders were incorporated in the burner of one unit. Substantial improvement in flame stability was achieved enabling the NO_x to be varied over a wide range by adjusting burner settings. No opacity problems were experienced, and testing is continuing to establish settings which minimize NO_x while maintaining an acceptable level of unburned carbon.

5-6. "Application of the MACT In-Furnace NO_x Removal Process Coupled with a Low-NO_x SGR Burner," N. Murakami, Mitsubishi Heavy Industries (Japan)

Mitsubishi Heavy Industries, Ltd. (MHI) of Japan has developed the in-furnace NO_x removal process, named MACT. The application for a new 600 MW coal/oil dual-fired supercritical unit has been done. With the MACT, extremely low-NO_x emissions were achieved, coupled with a low-NO_x firing SGR burner, and the unit proved stable, reliable, and easily operated.

5-7. "Long Term Corrosion and Emission Studies of Combustion Modification Effects at Coal-Fired Utility Boilers," P. S. Natanson, R. M. Vaccaro, Exxon Research and Engineering Co.; J. M. Ferraro, Exxon Chemical Co.; D. G. Lachapelle, EPA/AEERL

Combustion modifications (CMs) (e.g., low excess air, staged combustion) can decrease NO_x emissions from coal-fired utility boilers. However, these modifications may create chemically reducing environments within the boilers and therefore affect the rate of fireside corrosion of boiler tubewalls. To address this issue, several utility boilers were characterized to determine the effects of various combustion controls and modifications on boiler operations and emissions. Other aspects of the research program included the measurement of furnace tubewall corrosion rates, and the performance of several 30-day continuous emission monitoring (CEM) tests for NO_x and other gaseous pollutants.

In the "as-found" (baseline) condition, all boilers were in compliance with the applicable New Source Performance Standard (NSPS) for NO_x. On the average, the typical NO_x emission rate was 256 ng/J (0.6 lb/10^6 Btu or 435 vppm at 3% O_2, dry) as NO_2. By instituting additional CMs, NO_x emissions could be decreased by another 20 to 40% without adverse side effects (excessive slagging, loss of control, etc.). EPA Level 1 environmental assessments (EAs), performed on two of the boilers, showed no unusual environmental hazards resulting from low-NO_x operation. For all boilers tested, tubewall corrosion rates were comparable to rates in boilers not using CMs for NO_x control, averaging about 2 mils per year.

Session 6a

Externally Staged Combustors (Slagging Combustors) (Concurrent Session)

(C. Derbidge, EPRI, Session Chairman)

6a-1. "Development of a Low NO_x/SO_x Burner," O. W. Dykema, Rocketdyne Division/Rockwell International

For more than 5 years, Rockwell International has been developing a unique burner capable of simultaneous control of SO_2 and NO_x, and removal of sufficient flyash to allow retrofit of gas- and oil-fired boilers to coal with minimal derating. Underlying process theory was largely verified in a 20 GJ/hr (17×10^6 Btu/hr) pulverized-coal-fired burner and further development at a utility pilot-scale level (26 GJ/hr or 25×10^6 Btu/hr) is nearing completion. A full-scale burner demonstration (106 GJ/hr or 100×10^6 Btu/hr) is scheduled to start in late spring of 1985.

6a-2. "NO_x Control in an Air Cooled Cyclone Coal Combustor," B. Zauderer, Coal Tech Corp.; K. S. Fujimura, Southern California Edison Co.

This paper reports on the analysis of experiments on NO_x control in a 10^6 Btu/hr, staged, air-cooled cyclone combustor. The combustor exhausted into two ceramic-lined vessels, which simulated the radiant furnace section of a boiler. Final combustion air was introduced between the two vessels, at a point where the cyclone combustion gas exhaust had cooled from 3000 to about 2200°F. The stoichiometric ratio (SR) of the combustor was varied from 0.6 to 1.15. About a factor of 3 NO_x reduction, to less than 100 ppm, was obtained at a SR of 0.65, based on the coal and air feedrates to the cyclone combustor. The NO_x results are consistent with other experiments in a water-cooled cyclone combustor and in conventional pulverized coal flames, which show that the minimum emissions of the three primary fuel bound nitrogen compounds occur at about this SR. It is shown that the placement of the tertiary air injection in the simulated furnace was consistent with kinetic rate predictions for optimum NO_x reduction in staged combustion. The application of this NO_x control technique to commercial scale utility boilers is briefly described. Also, a brief description is given of experiments in which significant reductions in the SO_x emissions were observed, as a result of limestone injection in this cooled combustor.

6a-3. "Coal-Fired Precombustors for Simutaneous NO_x, SO_x and Particulate Control," G. C. England, J. F. La Fond, R. Payne, Energy and Environmental Research Corp.

A major obstacle to the conversion of gas- and oil-fired equipment to coal is the high cost of controlling emissions of particulate matter and acid rain precursors (NO_x, SO_x). The presence of mineral matter in the coal and relatively long burning time required also complicated conversion. The ash formed during combustion of coal can deposit on heat transfer surfaces, reducing efficiency and causing corrosion and erosion. The volume of gas- and oil-fired furnaces typically does not provide sufficient residence time at high temperatures to completely burn the solid coal particles. Substantial derating of unit capacity may be required in order to minimize these potential drawbacks. Coal-fired precombustor devices offer the potential for simultaneous removal of ash and reduction of NO_x/SO_x emissions at the burner prior to the boiler or heater furnace. This could reduce or eliminate derating and other ash-related problems, as well as reduce requirements for exhaust gas cleanup. The successful development of such devices would facilitate conversion to coal in the U.S., easing the burden of imported fuel supplies.

This paper presents background information related to the control of ash, SO_x, and NO_x in precombustors. In addition, this paper describes results of tests in a small pilot-scale precombustor conducted under EPA Contract 68-02-3130. This program is intended to establish the potential and compatibility of requirements for simultaneous control of all criteria pollutants.

Session 6b

Fundamental Combustion Studies (Concurrent Session)

(J. Haebig, EPA/AEERL, Session Chairman)

6b-1. "Mechanisms Governing the Destruction of Nitrogen Species During Staged Coal Combustion," J. O. L. Wendt, K. M. Dannecker, University of Arizona

Effects of coal composition on fuel nitrogen mechanism during fuel-rich combustion of pulverized coal were experimentally investigated in a 2 kg/hr downfired combustor. Although there is some variation from coal to coal, the data support the hypothesis that N_2 formation, NH_3 formation and destruction and NO destruction follow the Fenimore mechanism HCN destruction is also consistent with Fenimore, although there appears to be a source causing HCN formation.

6b-2. "Oxidation and Pyrolysis of Fuel Nitrogen in a Lignite–Both as Received and After Ammonium Ion-Exchange," A. F. Sarofim, L. D. Timothy, J. M. Beer, Massachusetts Institute of Technology

The dependence of the conversion of the organically bound nitrogen in coal to NO on the volatility and amount of fuel nitrogen was studied by the pyrolysis and oxidation of a low rank Montana coal, both as-received and after ion-exchange with ammonium acetate. The nitrogen content of the coal was increased on treatment from 1.11 to 2.34% by weight (dry). Nitrogen retention by the chars obtained during pyrolysis of both the raw and treated coals was measured over a temperature range of 550 to 1650 K. The added nitrogen was more volatile being released completely by 1400 K, compared to 60% release of the nitrogen in the untreated coal at 1400 K. Conversion of the nitrogen to NO for combustion in different oxygen concentrations was found to vary from 35 to 55%, with the lower nitrogen content untreated coal having slightly higher conversion efficiencies than the treated coal.

6b-3. "Reduction of NO_x Emission from Natural Gas Flames by Staged Fuel Injection," J. M. Beer, W. F. Farmayan,

M. Togan, Tae-U Yu, Massachusetts Institute of Technology

One of the major thrusts of the experimental effort was to clearly differentiate between temperature and stoichiometric effects on overall NO_x emission.

In considering the problem of differentiating temperature and stoichiometric effects on NO emissions, particularly when the various staging configurations are compared, it would of course be desirable to maintain as similar a temperature history in the furnace for each case as possible. However, the temperature history for each case could not be identical. Two parameters were identified as having gross effects on the average temperature of the combustion mixture which merited close examination and control when various staging strategies were studied.

6b-4. "NO_x Prediction for Practical Pulverized Coal Reactors," L. Douglas Smoot, Scott C. Hill, Phillip J. Smith, Brigham Young University

The model of nitrogen pollutant formation and destruction in pulverized coal reactors is briefly outlined and then evaluated by comparisons of predictions with measurements. The model incorporates effects of turbulence on NO reactions, and subsequent predictions show these effects to be important. Model applications show effects of key parameters on NO emissions and illustrate the use of the NO model for interpreting experimental results. The model predicts the observed initial decrease followed by a gradual increase in NO emissions with increased swirl number. The model also predicts the measured increase in NO emissions with increased stoichiometric ratio; but, at higher SR values, the model underpredicts NO concentrations, partly because of increased thermal NO levels which were not considered. The model also predicts the observed increase in NO with a decrease in particle size and increase in moisture percentage. Results suggest that nitrogen release during devolatilization and gas-phase reactions of HCN and oxygen control NO formation, while fuel nitrogen conversion to HCN may be near quantitative and rapid. According to the predictions, NO reduction is dominated by HCN-NO reactions and not by the char-NO reactions. Practical application of the method to pulverized coal reactors is discussed.

6b-5. "Optimized Low-NO_x Pulverized Coal Combustion by Zone Control," Ken Okazaki, Kazutomo Ohtake, Toyohashi University of Technology

Zone control is one of the most effective technologies to minimize NO_x formation in the pulverized coal combustion furnace. To get the fundamental and general concept for the optimization of low-NO_x pulverized coal combustion by zone control: (1) separated influences of various basic factors affecting NO formation behaviors were derived by use of a one-dimensional combustion furnace; and (2) an optimal condition for zone control was investigated by experiments of one-dimensional multistage combustion.

These experimental investigations have led to the following important results. The NO formation rate in the early stage of combustion process increases with the oxygen-fuel stoichiometric ratio for large particles, decreases with the particle size, and less effect by the stoichiometric ratio appears for small particles. The conversion ratio from fuel N to NO decreases with nitrogen content and increases with the stoichiometric ratio, especially for high volatile coals, and temperature has little effect on it except for fuel-rich conditions for high volatile coals. As for zone control, most effective reduction of NO was attained by setting the reduction zone just after the initial NO formation zone, and the oxygen-fuel stoichiometric ratio of 0.8 is preferable for the effective reduction of NO without increases of unburned materials.

Session 7

Advanced Power Plants (Concurrent Session)

(D. Teixeira, PG&E, Session Chairman)

7-1. "NO_x Control and Atmospheric Fluidized-Bed Combustors," E. Petrill, W. C. Howe, T. C. Derbidge, EPRI; R. J. Divilo, Pope Engineers

One of several advantages of burning coal in atmospheric fluidized-bed combustion (AFBC) boilers for electric power generation is the inherent low emission of NO_x. Because of the many advantages of AFBC, EPRI is actively promoting development of both bubbling and circulating fluidized-bed combustion technology for utility applications through involvement in two rest facilities and three utility-scale demonstration projects.

Pilot-scale and industrial AFBC units have shown NO_x emissions to fall well below those from both conventional and advanced pulverized-coal-fired boilers, as well as easily meet the current New Source Performance Standards (NSPS) for coal. It is expected that utility-scale units will also meet NSPS.

Further reduction of NO_x emissions in a bubbling bed by air staging was investigated in an EPRI project. The study, conducted by Babcock & Wilcox at EPRI's 6 × 6 ft FBC facility at B&W's Alliance Research Center, indicated that up to 50% reduction of NO_x is possible. However, the project also identified performance and reliability issues that must be solved before operation at minimum NO_x conditions is feasible.

7-2. "The Cool Water Project Clean Power from Coal," R. H. Wolk, N. A. Holt, EPRI

The Cool Water project is a 100 MW (net electrical output) integrated coal gasifier combined cycle project that produces the cleanest power generated from coal that the world has ever seen. Design goals for gas turbine stack emissions are 9 ppm SO_x (0.033 lb/10^6 Btu fuel), 27 ppm NO_x (0.065 lb/10^6 Btu fuel), and 0.01 lb of particulates/10^6 Btu fuel for operations on low sulfur Utah coal. All of these goals have been exceeded. Other products from the plant are bright yellow sulfur which is sold commercially and glassy nonleachable slag which is disposed of in an onsite clay-lined pit.

In late 1985 and early 1986, a series of test runs are scheduled on high-sulfur Illinois and Pittsburgh coals. Sulfur emissions for those coals are designed to be 175 lb/hr which corresponds to 97% sulfur removal.

The plant is located at the Cool Water station of the Southern California Edison Company in Daggett, CA. Initial commercial operation began in late June 1984, about 6 weeks after the com-

pletion of construction which required 28 months. The construction and start-up cost was $263 million, which was about 10% below budget.

In this paper, the plant is described with specific emphasis given to the approach to NO_x control.

Session 8a

Flue Gas Treatment (Concurrent Session)

(E. Cichanowicz, EPRI, Session Chairman)

8a-1. "Operating Experiences of Southern California Edison's 107.5 MW Selective Catalytic Reduction $DeNO_x$ System," Harold A. Kerry, Alexander Weir, Jr., Southern California Edison Co.

The Southern California Edison Company's 107.5 MW Selective Catalytic $DeNO_x$ System has been tested to develop performance and operational data on this post-combustion NO_x removal system. Tests have been conducted for more than 2 years. This paper reviews operational experiences from the system.

8a-2. "Reduction of NO_x-Emissions for Brown Coal Combustion Systems in the Federal Republic of Germany," K.R. G. Hein, J. Konig, V.Hoppe, Rheinisch-Westfalisches Elektrizitatswerk

Stringent environmental standards in the Federal Republic of Germany require the application of NO_x-control techniques for both new and existing powerplants with a capacity of >50 MWt. Also it is expected that all units should be fully equipped with denitrification installations before the end of this decade.

Among the major sources of primary energy, brown coal is of great importance because almost 30% of the electricity production is based on this fuel. Due to properties which differ widely from bituminous coals, also different combustion systems have to be used. As a consequence specific flue gas conditions with regard to composition and temperature prevail.

Therefore, the direct application of NO_x-removal techniques, which are operating since some years abroad, is impossible at present, and further development is needed.

After a brief introduction of fuel-related problems with brown coal for utility operation, the paper describes the available method for NO_x-reduction. Particular emphasis is on the removal of NO_x from flue gases. Various technical solutions for the application of the SCR-technique, as well as the combination with FGD systems, are introduced, and first results from pilot studies are presented.

8a-3. "Introduction of IHI-Denitrification System for Coal Fired Steam Generator," H. Aoki, T. Suzuki, R. Ishimoto, Ishikawajima-Harima Heavy Industries Co., Ltd.

The application of a dentrification system is widely considered for coal-fired steam generators not only in Japan but also in the world. For a coal-fired steam generator, the erosion and plugging of the catalyst are the major problem for high ash flue gas; furthermore, NH_4HSO_4, which can be produced by reaction of the injected NH_3 and SO_3 converted from SO_2 in the flue gas, will be deposited on the surface of the heating elements of GAH. As for the countermeasures of the above items, proper grid dimension of 7.5 mm, proper linear gas velocity of 5 to about 6 m/s at the design point, and vertical downward gas flow arrangements were selected, and then three IHI denitrification systems for coal-fired utility powerplants have been continuously operating with excellent performance for 1 or 2 years. The sootblower could be omitted from the denitrification system. Denitrification performance of more than 80% has been kept for more than 2 years.

8a-4. "Thermal $DeNO_x$ Technology Update," Boyd E. Hurst, Exxon Research and Engineering Co.

The original thermal De-NO_x installations involved positioning a gridwork of pipes in the flue gas stream for injecting a mixture of NH_3 and carrier air or steam. In the most recent designs, the injection grids have been replaced by wall injectors which offer many advantages, such as higher performance, lower costs, better load following, and lower maintenance. Also, development of a fundamental kinetic model of the process chemistry and a three-dimensional flow model have provided significant process optimization capability.

One application of thermal De-NO_x incorporating the most recent technology involves a 440,000 lb/hr boiler generating steam and power in a Japanese chemical plant. In this installation, 70% De-NO_x was achieved through utilization of the optimized design techniques at a cost about 20% of a comparable selective catalytic reduction facility.

Other advantages of the most recent technology include the ability to deal more successfully with particulate-laden flue gas streams and methods of minimizing or eliminating effects of ammonium salts in the exhaust flue gas. In its present form, thermal De-NO_x offers a highly developed, practical means of achieving deep NO_x reduction in all types of stationary-fired equipment.

8a-5. "Application of $DeNO_x$ Technologies in the Federal Republic of Germany and Europe," O. Rentz, W. Heer, University of Karlsruhe (Th)

In view of the present extent of dam age, the state government of Bader Wurttemberg felt compelled, in agree ment with operators of large boile installations, to arrange programs fc the far-reaching reduction of Emission whereby previous demands of the Go ernment Ordinance for Large Boiler Ir stallations (GFAVO) were surpasse This concerned, first, all the polluar SO_2 in the Electricity Supply Sect (EVU), a program which was complete in 1983 and which finally led to a redu tion in SO_2 emissions from about 86,0(to about 20,000 t/a. Subsequently, a analogous program was agreed on f the pollutant NO_x from coal-fired pow stations. This was based on the fixe target limit of 200 mg NO_x/m^3 (≈1(vpm), which was agreed on in Janua 1984 between operators, equipme suppliers, and the state governmer both for dry- and wet-bottom boile This emission level is to be observed f

dry-bottom boilers until 1988, and for wet-bottom boilers until 1990, in both cases for new and existing plants. The programs mentioned up to now concern only the Electricity Supply Sector and here in the first instance coal-fired installations. A further program for the pollutants SO_2 and NO_x, with regard to boilers outside the utility sector and nonboiler applications, is being prepared and will probably be approved toward the end of 1985.

The Baden-Wurttemberg program was thus, as a program covering a whole area, the first of its kind; in the meantime, however, analogous programs from other federal states now exist.

8a-6. "Operating Experience on SCR System for Steam Generators," K. Suyama, Mitsubishi Heavy Industries, Ltd.

Since the first commercial SCR system was supplied in 1976, many SCR systems for steam generators were supplied by Mitsubishi Heavy Industries, Ltd. (MHI), and successful operations have been experienced.

This paper describes experiences of the existing SCR system for a coal-fired steam generator and outlines an SCR system for a combined cycle powerplant.

The SCR system for a coal-fired unit at Chugoku Electric—Shimonoseki No. 1 unit (175 MW)—was installed in 1980 and has been operating for more than 5 years (more than 35,000 hours from initial operation).

In addition to the above, SCR systems on heat recovery steam generators coupled with gas turbines have recently started their commercial operation at Tohoku Electric's Higashi-Niigata unit No. 3. The unit is a 1,090 MW combined cycle plant composed of two 545 MW trains. Operating results of the coal-fired SCR system and features of the combined cycle plant are summarized in this paper.

8a-7. "Economics of NO_x, SO_2, and Ash Control Systems for Coal-Fired Utility Powerplants," J. D. Maxwell, L. R. Humphries, Tennessee Valley Authority

An EPA-sponsored economic evaluation was made of three processes to reduce NO_x, SO_2, and ash emissions from coal-fired utility powerplants: one is based on a 3.5% sulfur eastern bituminous coal, and the other two, on 0.7% sulfur western subbituminous coal. NO_x control is based on an 80% reduction from current new source performance standards (NSPS); and SO_2 and flyash control are based on meeting current NSPS. Selective catalytic reduction (SR) is used for NO_x control with both coals. Limestone scrubbing and a cold-side electrostatic percipitator (ESP) are used with the 3.5% sulfur coal. Lime spray dryer flue gas desulfurization (FGD) and a baghouse for particulate collection are used with one 0.7% coal, and limestone scrubbing and a hot-side ESP with the other.

The economics consist of detailed breakdowns of the capital investments and annual revenue requirements. For systems based on a 500-MW powerplant, capital investments range from $167 to $187 million (333 to 373 $/kW) and first-year annual revenue requirements from $54 to $60 million (29 to 33 mills/kWh). The 3.5% sulfur coal case is highest because of the higher SO_2 control costs. The case with the spray dryer and baghouse is marginally lower in cost than that with limestone scrubbing and hot-side ESP. Costs for NO_x control range from 25 to 50% of the total costs, largely because of the high catalyst cost. The costs of the overall systems and the relationship of the component costs are complexly interrelated because of the interactions of the three processes.

Session 8b

Stationary Engines and Industrial Process Systems (Concurrent Session)

(J. McSorley, EPA/AEERL, Session Chairman)

8b-1. "Utilization of Methanol as Fuel for a Gas Turbine Cogeneration Plant," Dale E. Shore, Gary H. Shiomoto, KVB, Inc.; Gerald R. Bemis, California Energy Commission

A field test demonstration of the use of methanol in an industrial-sized gas turbine cogeneration unit was conducted in 1984 at the Central Heating Plant of the University of California at Davis. This program, sponsored by the California Energy Commission, was one of four full-scale demonstrations of the use of clean fuels in mobile and stationary engine applications. These demonstration programs were directed toward the evaluation of clean fuels potentially derived from coal, for meeting California's future energy needs.

A 3,250 kW Allison 501-KB gas turbine, designed originally for either natural gas or distillate fuel oil operation, was converted to methanol and operated for 1036 hrs. A methanol storage and handling facility for fueling the engine was designed and built onsite. Engine modifications specific to the utilization of methanol and preliminary test work of the specialized components were performed by the turbine manufactuer. The components were then installed on the engine, and the unit was operated on methanol. Emissions and performance data were monitored throughout the test. The relatively low-NO_x emissions expected from methanol operation were further reduced by the implementation of water injection via mixing with the methanol before being supplied to the engine. Engine operating problems attributable to methanol were not encountered during the demonstration testing; therefore, engine performance was judged satisfactory. However, difficulties of methanol pumping compatibility with the engine-driven, high-pressure fuel pump necessitated the use of an off-board centrifugal pump to complete the program.

8b-2. "Development and Field-Demonstration of a Low-NO_x Burner for TEOR Steamers," G. England, Y. Kwan, R. Payne, Energy and Environmental Research

This paper describes the results obtained in a program to demonstrate in the field a full-scale 16 MWt prototype low-NO_x burner for thermally enhanced oil recovery (TEOR) steam generators which burn high-nitrogen crude oils. NO_x emissions from these TEOR "steamers" have been linked with deteriorating air quality in Kern County, CA, and stringent local regulations have been promulgated limiting these emissions to preserve ambient air quality. These regulations can potentially restrict oil production in Kern County.

The burner described in this paper is

designed based on a two-stage combustion concept developed from earlier bench- and pilot-scale work. The concept comprises physically separate zones in which conditions have been optimized to minimize both fuel and thermal NO formation.

The full-scale 16 MWt commercial prototype burner has been evaluated in a laboratory test furnace and was successfully retrofitted to a field-operating steam generator in Kern County. Results of field test firing heavy crude oil (0.83%N) showed that NO_x emissions below 70 ppm (at 3% excess O_2 with low CO and smoke emissions) could be achieved with acceptable flame conditions in the steamer radiant section. Detailed emissions characterization also showed that emissions of particulates and organic compounds were well below allowable levels. The burner is currently still operating in the Kern Front oilfield.

8b-3. "Heavy Oil Low-NO_x Burner Application to an Oil Field Steamer–Emissions Measurements," H. Mason, C. Castaldini, L. Waterland, R. DeRosier, Acurex Corporation.

Comprehensive emission measurements and 30-day flue gas monitoring were performed on a 16 MW (55×10^6 Btu/hr) enhanced oil recovery steam generator equipped with the EPA low-NO_x burner firing high-nitrogen crude. The 1-day comprehensive measurements included source assessment sampling system (SASS) quantification of semivolatile organics and 73 trace elements; volatile organic sampling train (VOST) quantitation of volatile organic priority pollutants; EPA Method 5/8 for particulate and SO_x; controlled condensation system (CCS) for SO_x; Andersen impactors for particle size distribution; grab samples for N_2O; and continuous flue gas monitoring. NO_x emissions during the comprehensive tests averaged 70 ppm at 3% O_2, well below the target level of 85 ppm. CO emissions were below 30 ppm, and SO_2 averaged about 550 ppm. Solid particulates were emitted at about 27 ng/J (96 mg/dscm); condensible particulates were about half that level. Volatile organics (benzene, toluene, and ethylbenzene) were measured in the 0.4 to 20 ppb range. Semivolatile organics (naphthalene and phenol) were detected in the 0.3 ppb range. Subsequent continuous monitoring of flue gas criteria emissions showed NO_x blow 80 ppm at 3% O_2 with an average 70 ppm. CO emissions were generally less than 30 ppm.

8b-4. "Reduction of Nitric Oxide Emissions on a Full-Scale Cement Kiln Using Primary Air Vitiation," R. C. Benson, S. C. Hunter, KVB, Inc.

KVB has been funded by the U. S. EPA to conduct research for emission reduction from industrial processes. One phase of this research effort concerns reduction from cement kilns. Tests were conducted on a 1100 ton/day long, dry process cement kiln to evaluate the effect of primary air vitiation on NO emissions. Primary vitiation was accomplished by injecting nitrogen gas into the primary air. As-found test results (17 days, 89.75 hr) prior to the nitrogen injection test were used to assess the inherent variability of the cement-making process. The NO emissions average about 8 lb NO_2/ton of clinker and varied approximately 30% during the as-found test series. Lowering kiln exit oxygen from 1.8 to 0.7% reduced NO by 15 to 20%. Three days of nitrogen injection tests for primary air vitiation were also performed at the test site. Although the testing demonstrated that nitrogen injection will reduce NO, the extent of reduction is extremely viable and is based on the operations and kiln feed at the time. NO mass emissions did decrease 20 to 30%, based on altering the burning zone temperature profile (2550 to 2490°F), lowering the primary air O_2 from 21 to 13% and maintaining a constant kiln exit oxygen of 1.5%. No deterioration of clinker quality was observed.

8b-5. "NO_x Control for Glass-Melting Tanks," F. Richard Kurzynske, Gas Research Institute; Donald K. Fleming, Institute of Gas Technology

The Gas Research Institute (GRI) is undertaking a program to evaluate factors that influence the production of NO_x in glass-melting tanks. This discussion presents the results to date of the ongoing program, as developed under contract by the Institute of Gas Technology (IGT).

Glass melting is a high-temperature operation, generally employing regenerative furnaces with preheat temperature for the combustion air of 2000 to 2300°F. Consequently, an uncontrolled glass-melting tank may produce NO_x concentrations of 3000 ppm. Techniques for reducing these emissions are being evaluated in this program. Work has advanced through pilot-scale testing, and the results from that effort have been correlated to indicate the effects of temperature, excess air utilization, and combustion geometry factors. Staged combustion (both air and fuel and flue gas recirculation) also have been evaluated. Testing is now underway in a commercial furnace to determine scale-up factors for the control parameters.

8b-6. "Diesel Engine NO_x Control with SCR," J. Wasser, R. B. Perry, U. S. EPA/AEERL

EPA's Air and Energy Engineering Research Laboratory is conducting a long-term test evaluation of a selective catalytic reduction (SCR) system on a stationary diesel engine. The overall goal of this project is to establish the NO_x reduction performance of a diesel SCR unit over a 4000-hr period. This paper reports the interim results obtained during the first 2300 hr of operation. For most of the first half of the test program, NO_x reductions of over 90% were obtained. However, as the 2000-hr point was approached, a drop in NO_x reduction (below 80%) was experienced. Cleaning restored part of the catalyst's original activity, and the test program continued.

8b-7. "Environmental Assessment of Catalytic Reduction of Natural-Gas-Fired Engines," C. Castaldini, L. R. Waterland, H. B. Mason, Acurex Corp.

Field tests were performed on two large-bore natural-gas-fired reciprocating internal combustion engines, one rich-burn and one lean-burn, equipped with catalytic gas treatment systems for NO_x control. The rich-burn engine was equipped with a nonselective catalytic reduction (NSCR) system in which reducing gases (CO and unburned hydro

carbon) reduce NO and N_2. The lean-burn engine was equipped with a selective catalytic reduction (SCR) system in which NH_3 injected in the engine exhaust gas acts as the reducing agent for NO_x control. The test program for each engine consisted of comprehensive emission measurements for NO_x, CO, unburned hydrocarbon (HC), CO_2, and O_2 by continuous monitors; particulate, cyanide, NH_3, volatile and semivolatile organics; and trace metals at catalyst inlet and outlet. In addition, 15-day continuous emission monitoring was performed to record catalyst performance under extended typical engine operation: NO_x reduction by the NSCR system ranged between 54 and 81% during the comprehensive engine tests, but degraded to below 40% during the extended monitoring, because of changes in engine air/fuel (A/F) ratio. The test engine was not equipped with an A/F controller. HC, CO, and total organic levels decreased across the catalyst, while both cyanide and NH_3 emissions increased, SCR NO_x reduction performance for the lean engine was constant at about 80%. NH_3 concentration at the SCR outlet averaged about 90 ppm.

Session 9a

Overview of Furnace Sorbent Injection SO_2 Control (Concurrent Session)

(R. Hangebrauck, EPA/AEERL, Session Chairman)

9a-1. "Review of International Development Activities for Furnace Sorbent Injection," Dan V. Giovanni, Electric Power Technologies, Inc.

At the 1982 Joint Symposium on Stationary Combustion NO_x Control in Dallas, TX, an entire session was devoted to discussing emission control processes based on dry injection of calcium sorbents to meet SO_2 regulations for coal-fired powerplants. In November 1984, EPRI and EPA sponsored the 1st Joint Symposium on Dry SO_2 and Simultaneous SO_2/NO_x Control Technologies in San Diego, CA. Forty-six papers were presented, addressing the latest advances in fundamental research and process design, powerplant integration and economic issues, and results from field applications. The scope of technical information discussed at the symposium was a reflection of the significant and widespread developmental activities currently in progress, which involve furnace sorbent injection (FSI) for SO_2 control. This paper attempts to summarize that information by defining the current status of FSI process developments, acknowledging advances in process understanding and design, and identifying yet unresolved technical issues.

9a-2. "Technical Status of EPA's LIMB Program," G. Blair Martin, James H. Abbott, U. S. EPA/AEERL

SO_x and NO_x, two pollutants resulting from the combustion of coal, are believed to be major precursors of acid rain. Limestone Injection Multistage Burners (LIMB) is a potentially low-cost technology for control of SO_x and NO_x from existing utility and industrial boilers. The LIMB R&D program has provided a detailed understanding of the key processes governing sulfur capture with sorbents. While it appears that limestone alone will not achieve program goals, several other promising sorbents have been identified. Based on the R&D results and cost estimates for use of these sorbents, LIMB shows substantial promise as a SO_x and NO_x control technology for retrofit applications. The ongoing R&D program should resolve the remaining technical questions and provide a basis for widespread private sector commercialization. This paper summarizes the technical status of LIMB-related R&D.

9a-3. "EPRI's Research Program on Furnace Sorbent Injection," M. McElroy, EPRI

The concept of injecting calcium-based alkaline sorbent materials directly into the furnace of coal-fired utility boilers to reduce SO_2 emissions is the subject of major research and development programs in the U.S. and abroad. EPRI is contributing to these efforts by sponsoring an experimental test program to develop an understanding of fundamental process chemistry and optimizing the process for maximum SO_2 removal and calcium utilization. Complementary EPRI projects are addressing engineering system design, economic, and powerplant integration issues. These projects will provide the technical basis for designing and operating prototype furnace sorbent injection systems at 50 to 150 MW utility boilers, which is the next logical step toward commercializing the process.

Session 9b

Fuel and Combustion Modifications for Commercial/Industrial Boilers (Concurrent Session)

(J. Wasser, EPA/AEERL, Session Chairman)

9b-1. "Combustion Modification Techniques for Coal-Fired Stoker Boilers," G. C. Quartucy, H. J. Buening, R. J. Yang, KVB, Inc.

Combustion modification techniques were applied to full-scale coal-fired stoker boilers for the purposes of optimizing boiler operation and reducing emissions. Five full-scale stoker boilers of different designs were evaluated. Three of these (two spreader stoker and one vibrating grate stoker) boilers were fitted with flue gas recirculation for the purposes of reducing NO_x emissions and improving boiler efficiency. Test results showed that boiler efficiency improvement and NO_x reduction can be achieved with flue gas recirculation for spreader stoker boilers with intermediate or high minimum excess oxygen levels. Its application to mass-fed stoker boilers (which typically have very short combustion zones) and spreader stoker boilers with very low baseline excess oxygen levels (5% or lower) was not successful. NO_x emissions were found to decrease with decreasing excess oxygen levels for spreader stoker boilers, but were relatively independent of excess oxygen levels for mass-fed stoker boilers. Overfire air system modifications to enhance jet penetration resulted in significant stack opacity reduction. Particulate emissions were found to be correlatable to the third power of bulk combustion product gas velocity (volumetric throughput rate divided by boiler cross-sectional area). This indicates that reductions in excess air level will result in efficiency improvement, NO_x reduction, and significant particulate emissions reduction.

9b-2. "Emissions Assessment of Coal/Water-Slurry-Fired Industrial Boilers,"

L. R. Waterland, R. DeRosier, D. Van Buren, and H. B. Mason, Acurex Corporation

This paper describes emission results obtained from field testing of two industrial boilers test-fired with coal/water slurries (CWS). Emission measurements performed included continuous monitoring of flue gas emissions; source assessment sampling system (SASS) sampling of flue gas emissions, with subsequent laboratory analysis of samples to obtain total flue gas organics in two boiling point ranges, compound category information within these ranges, specific quantitation of the semivolatile organic priority pollutants, and flue gas concentrations of 73 trace elements; EPA Method 5 sampling for particulate; EPA Method 8 sampling for SO_2 and SO_3 emissions; volatile organic sampling train (VOST) testing for volatile organic priority pollutant emissions; gas grab sampling for onsite C_1 to C_6 hydrocarbon emission measurements; gas grab sampling for N_2 emission measurements; and grab sampling of the CWS fuel and ash streams for inorganic composition determination. Complete emissions measurement results for the two units are presented.

9b-3. "Development of Low-NO_x Combustion for Industrial Application," Tomio Suzuki, Kotaro Morimoto, Keiichi Ohtani, Ryuichi Odawara, Tatsuo Kohno, Yuichi Matsuda, Mamore Suyari, Kobe Steel, Ltd.

Low-NO_x emission combustion has been developed for industrial furnaces, boilers, pelletizing kilns, cement plants, and gas turbines. More than 350 low-NO_x burners of the slow-combustion type for industrial furnaces have shown a reduction of 30 to 70% in NO_x value and 5 to 10% in fuel consumption. NO_x emission reduction of low-NO_x burners for boilers has attained 30 to 60% in the 17 boilers of 2 to 15 t/h evaporation. The boiler efficiency of low-NO_x burners was higher than that of conventional burners by 2%. The NO_x value of low-NO_x burners for pelletizing kilns has decreased with an increase in multifuel-firing percentage of coal in coke-oven gas and coal firing. Low-NO_x combustion of the Dual Combustion and Denitration (DD) process for a 3600 t/d cement plant has decreased to 110 ppm (10% O_2) in NO_x value and 735 kcal/kg-cl in fuel consumption. A new low-NO_x combustor of a premixed, prevaporized, and fuel-lean type for gas turbines has resulted in an NO_x reduction of about 90%.

9b-4. "Emissions Assessment of Cofiring Coal and Waste Plastic in a Commercial Boiler," L. R. Waterland, R. DeRosier, H. I. Lips, H. B. Mason, Acurex Corporation

This paper describes emission results from field testing a stoker-fired commercial boiler firing a coal/waste plastic mixture. The two tests were performed; one with the unit firing its typical coal fuel (test 1), and one with shredded waste polyethylene terphthalate (PET) beverage bottles added to the coal to about 16% by weight in the mixed fuel (test 2). NO_x, total unburned hydrocarbon (TUHC), and solid particulate emissions were relatively unchanged for the two tests as was the emitted particle size distribution. SO_x emission decreased with the coal/PET fuel in keeping with its lowered sulfur content; average CO emissions were also decreased. Flue gas emissions of most trace elements were comparable for both tests, as were the trace element compositions of corresponding ash streams. However, lead emissions were significantly increased for test 2. This increase reflects the increased lead content of the mixed coal/PET fuel. The cyclone hopper ash for the coal/PET test had consistently lowered leachable trace element and anion content than that for the coal fuel test. Total flue gas organic emissions were comparable for both tests, although levels of several semivolatile priority pollutants were higher for test 2.

9b-5. "A Low-NO_x Burner for Gas-Fired Firetube Boilers," John P. Kesslring, Wayne V. Krill, Alzeta Corporation.

A field evaluation has been conducted, sponsored by the Gas Research Institute, to evaluate the durability of the fiber burner in gas-fired firetube boilers. The fiber burner is a radiant surface burner that typically operates with NO_x emissions of 15 ppm, CO emissions of 20 ppm, and essentially no hydrocarbons. Under this program, four firetube boilers ranging in size from 245 to 980 kW (25 to 100 hp) were retrofit with the fiber burner and operated for up to 24 months. Tests of the burners installed at these sites show a 1 to 2 percentage point increase in efficiency, 80% reduction in NO_x, and up to 80% reduction in CO. In addition, the ability of the burner to allow increased boiler loads has been demonstrated, and flame noise has been virtually eliminated.

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***Michael C. Osborne** is the EPA Project Officer (see below).*
The complete report consists of two volumes, entitled "Proceedings: 1985 Joint Symposium on Stationary Combustion NO_x Control:"
"Volume 1. Utility Boiler Applications," (Order No. PB 86-225 042/AS; Cost: $52.95, subject to change)
"Volume 2. Industrial Processes, Fundamental Studies, and Slagging Combustors," (Order No. PB 86-225 059/AS; Cost: $34.95, subject to change)
The above reports will be available only from:
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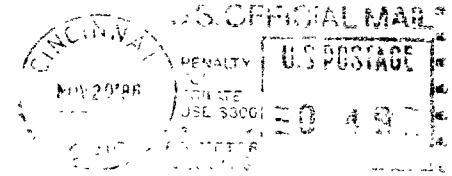

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