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Project Summary

Proceedings: 1987 Joint Symposium on Stationary Combustion NO_x Control, New Orleans, LA, March 1987

B. B. Emmel, Compiler

The two-volume proceedings document the 1987 Joint (EPA and EPRI) Symposium on Stationary Combustion NO_x Control, held March 23-26, 1987, in New Orleans, LA. The papers discuss: low-NO_x combustion developments (e.g., reburning and burner design modifications); coal-, oil-, and gas-fired boiler applications; flue gas treatment processes; fundamental combustion studies; and industrial and commercial applications. Also presented were manufacturers' updates of commercially available technology and an overview of environmental issues involving NO_x control.

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 two separate volumes of the same title (see Project Report ordering information at back).

Introduction

The 1987 Joint Symposium on Stationary Combustion NO_x (nitrogen oxides) Control was held March 23-26, 1987, in New Orleans, LA. The symposium, jointly sponsored by EPRI and EPA, was the fourth of its kind devoted solely to the discussion of the control of NO_x emissions from stationary sources. Topics discussed included low-NO_x combustion developments (e.g., reburning and burner design modifications), coal-, oil-, and gas-fired boiler applications, flue gas treatment processes, fundamental combustion studies, and industrial and commercial applications. Also presented were manufacturers' updates of commercially available technology and an overview of environmental issues involving NO_x control.

The 4-day meeting was attended by persons from 14 nations. Forty-nine papers were presented by EPRI and EPA staff members, utility company representatives, boiler and related equipment manufacturers, research and development groups, and university representatives.

The Proceedings are in two volumes. Volume 1 contains papers from:

- Session I: Background and Environmental Issues
- Session II. Low-NO_x Combustion Development
- Session III: Manufacturers' Update of Commercially Available Technology
- Session IV: Coal-Fired Boiler Applications

Volume 2 contains papers from:

- Session Va: Flue Gas Treatment
- Session Vb: Fundamental Combustion Studies
- Session VI: Cyclone-Fired Boilers
- Session VIIa: Oil- and Gas-Fired Boilers
- Session VIIb: Industrial and Commercial Applications

The remainder of this Summary consists of abstracts of the 49 technical papers presented at the symposium. To conserve space, authors' addresses are

listed alphabetically at the end of the Summary, rather than before each abstract.

Volume 1

Session I: Background and Environmental Issues

The New Environmental Agenda and the Coming Commitment to NO_x Control

Richard E. Ayers

As the recent ideological approach to environmental problems wanes, a new environmental agenda for the remainder of this century is emerging. Controlling NO_x emissions from stationary sources — a pollutant with serious effects on public health, environmental integrity, and esthetic experience — is part of this agenda. Development of new technology is welcome. But political leaders must not be permitted to use technological change as an excuse for avoiding the use of existing NO_x control technologies now.

Decline of Boreal Montane Forest Ecosystems in Central Europe and the Eastern North America—Links to Air Pollution and the Deposition of Nitrogen Compounds

Robert I. Bruck

Recently presented evidence of anomalous growth declines and dieback of eastern forests has captured public concern and strengthened the call to resolve the longstanding question of the role of atmospheric deposition in the decline of forest trees. This paper summarizes recent evidence relevant to determining if there are effects of atmospheric deposition on forests of the eastern U.S. A scenario might involve various forms of concentrated pollution being deposited via cloud deposition, causing above- and below-ground nutrient and microbial imbalances or direct physiological aberrations to spruce and fir trees. These chronic perturbations could lead to a predisposition of the ecosystem, to the effects of many indigenous pathogens and insects, and/or weaken the trees' resistance to the effects of severe climate. Continued research to integrate the findings of long term studies with relevant atmospheric monitoring data will create a clearer picture of the potential of atmospheric pollution to affect U.S. forest resources.

An Overview of Environmental Issues Related to Nitrogen Oxides in the Atmosphere

Charles Hakkarinen

Atmospheric NO_x compounds, including N_2O, NO, and NO_2, have been implicated in a variety of environmental effects, from both their direct emission to the atmosphere and their role in the formation of secondary compounds, such as ozone and nitric acid. High temperature fossil fuel combustion is a principal source of atmospheric NO_x emissions, hence the electric utility industry has a strong interest in understanding their environmental fate. This paper is an overview of the current state of scientific knowledge on the transport, conversion, and fate of NO_x compounds in the atmosphere. Emphasis will be given to: the relationship between NO_x/ozone and effects on human health; the role of nitrogen compounds/ozone in the perceived decline of some North American forests; the contribution of nitrogen compounds to the formation of acidic precipitation; and the role of NO_x (principally, N_2O) in regulating global climate (the "greenhouse effect") and influencing the stratospheric ozone layer (the "polar ozone hole"). The paper summarizes major research underway at EPRI and elsewhere that addresses environmental issues related to NO_x.

The Role of Nitrous Oxide (N_2O) in Global Climate Change and Stratospheric Ozone Depletion

Dennis A. Tirpak

Several recently completed scientific assessments have concluded that there is a significant potential for global atmospheric change — climate change and stratospheric ozone depletion — to occur in the next few decades. N_2O is a critical element in both issues. Although the problem of global climate change was once synonymous with CO_2, there is growing recognition of the role of other trace gases. Chlorofluorocarbons, N_2O, methane, and other trace gases now account for roughly half of the warming from greenhouse gases in the atmosphere, and by the year 2030 may lead to twice as much warming as from CO_2 alone. The U.S. Congress has asked the U.S. EPA to prepare a report on policy options to stabilize these trace gas concentrations. This paper will evaluate the role of NO_2 in global climate change and stratospheric ozone depletion. It will summarize trends in N_2O concentrations review our understanding of current and projected emission sources and emission factors, discuss the twin issues of climate change and ozone depletion, and recommend topics for further study.

Overview of Recent Developmer in NO_x Control in Europe

O. Rentz and R. Leibfritz

Based on the emission control legisl tion in some European countries, rece developments are presented leading the current status of NO_x abatement tec nologies and their application to static ary sources (power plants and industr processes). The state of DeNO$_x$ imp mentation in Europe in the field of p mary and secondary NO_x emission c trol is outlined. This includes informat on initial status at both full-scale and p plants, available and applied control te nologies, transfer problems with regar site specific conditions, advance prob solutions, and state of commissioni The future application of DeNO$_x$ tech ogies to industrial processes is bri outlined. Investment and cost figures disclosed.

Session II: Low-NO_x Combust Development

Large Scale Testing and Development of the R&W Low NO_x Burner

M. J. Clark, A. D. LaRue, A. D. L and D. Eskinazi

Due to environmental concerns, fuel power plants built prior to Source Performance Standards (N may be required to reduce NO_x sions. A large segment of these uni equipped with cell burners whic producing relatively high NO_x em in the 1.0 to 1.8 lb/10^6 Btu Babcock & Wilcox and EPRI have oped a low NO_x burner that is c retrofittable to cell burner units paper describes the continued de ment of this new burner. Results cent pilot combustion tests (100 Btu/hr) conducted at EPA's Large tube Simulator (LWS) agree we prior smaller-scale pilot perfor NO_x reductions were typically

while achieving combustion efficiency of 3.5% in the test furnace. A full scale Low NO_x Cell was installed at Dayton Power and Light's Stuart Station and has been in operation since March 1985. The Low NO_x Cell retrofit involves near-burner coal piping operation and mechanical reliability has been demonstrated over a 2-year period. A full scale retrofit demonstration is planned to confirm the commercial viability of this burner in a full scale retrofit.

Low NO_x Developments on an Integrated Combustion and Environmental Test Facility

J. Vatsky and R. McMillan

A test facility, equipped for a wide range of combustion and emission-control related testing, has been in operation for about 18 months, firing a wide variety of pulverized fuels, from subbituminous coals to very low volatile fuels such as petroleum coke. Initially, an extensive test program was performed with both petroleum coke and bituminous coal with an arch-fired furnace configuration. More recently, testing has begun with a two-burner high horizontally fired configuration. Although these programs were designed to evaluate NO_x emissions, and levels of about 0.15 lb/10^6 Btu have been obtained, the Combustion and Environmental Test Facility (CETF) is also designed to facilitate testing of SO_2 control systems. This paper describes the CETF and summarizes initial results obtained from both the arch- and horizontally fired modes.

Development of Overfire Air Design Guidelines for Front-Fired Boilers

Robert A. Lisauskas, Claire E. McHale, Rui Afonso, and David Eskinazi

Experimental flow model data and technical and economic studies have been used to develop design guidelines for overfire air (OFA) NO_x control systems. Conventional and novel OFA configurations were investigated in a 1/12-scale furnace model using detailed temperature and velocity maps to quantify overfire air injection and mixing. Data analyses focused on translating the flow model test results into practical designs for front-fired utility boilers. Based on the experimental results, the feasibility of retrofitting new OFA configurations on a specific utility boiler was examined. The results for several test configurations are used to develop preliminary OFA design guidelines for front-fired boilers. For traditional design configurations with one OFA port located over each burner column, the best mixing occurs at an injection to furnace velocity ratio of 4 to 6. A significant improvement in upper furnace mixing can be achieved by adding wing OFA ports and biasing the air flow and velocity from the center to the wing ports.

Furnace Design and Application on Low NO_x Pulverized Coal Combustion

Takashi Kiga, Shigehiro Miyamae, Keiji Makino, and Hiroshige Ikebe

Coal properties such as fuel ratio and fuel nitrogen are generally well-known to affect NO_x emission. We have already developed a low NO_x pulverized coal burner which gives 150 ppm of NO_x or less for Japanese domestic coal with conventional staged firing; however, most of various kinds of imported coals ensured significantly higher NO_x emission with a conventional furnace. Therefore, we attempted to develop a low NO_x furnace, applying the INPACT method, according to results of fundamental research. Applying this method to a 600 MW utility boiler, we obtained low NO_x emission of less than 150 ppm of the guarantee value for coals ranked from 1.5 to 2.2 as fuel ratio. A remarkable NO_x reduction of less than 100 ppm was also obtained. This paper introduces the fundamental furnace design concept and its application results.

Gas Reburning-Sorbent Injection—A Combined NO_x/SO_x Control Technology

W. Bartok, B. A. Folsom, and F. R. Kurzynske

Gas Reburning-Sorbent Injection (GR-SI) involves co-firing pulverized coal with natural gas in combination with sorbent injection and/or coal cleaning to allow for cost effective reduction of acid rain precursor emissions (NO_x and SO_x) from pre-NSPS coal-fired utility boilers. This would provide the utility industry with flexibility in fuel selection to satisfy potential acid rain control legislation. This paper describes a demonstration project which will be cooperatively funded by the Department of Energy, the Gas Research Institute and the State of Illinois Department of Energy and Natural Resources, to demonstrate GR-SI on three coal-fired utility boilers in Illinois. GR-SI will be applied to one each of wall, corner, and cyclone fired boilers with overall reduction targets of 60% in NO_x and 20% in SO_x emissions. The overview of the planned demonstration project will be discussed, including design considerations and economic projections for GR-SI applications.

Pilot Scale Studies on the Application of Reburning for NO_x Control

J. M. McCarthy, S. L. Chen, W. R. Seeker, and D. W. Pershing

This paper describes a pilot scale experimental study which addressed parametric and mixing effects of the reburning process, an in-furnace NO_x reduction technology, and provides scaling information and design and operation guidelines for application of reburning under a wide variety of conditions for coal- and oil-fired boilers. The results demonstrate the potential of reburning for NO_x reduction, and indicate that important parameters include: primary zone NO_x level; primary zone burnout; reburning zone time, temperature, and stoichiometry; and reburning coal transport medium. Rapid dispersion of the reburning fuel is desirable for primary NO_x incineration but can lead to an overall decrease in efficiency if the reburning fuel contains fuel nitrogen and is carried by an oxygen-rich medium. Recirculated flue gas is the optimal reburning coal transport medium, but efficient NO_x reduction with air transport can be achieved if higher reburning fuel ratios and optimal reburning mixing rates are employed. Natural gas is more effective than either coal or heavy fuel oil for reburning, especially at low primary NO_x concentrations. Reburning with coal or natural gas has little adverse affect on burnout performance. Comparison of pilot scale results and bench scale data shows that parametric effects are independent of scale and that a 50% reduction in emissions is achieved with 20% coal reburning at normal primary NO_x levels.

Reburning with Low and Medium Btu Gases

S. J. Bortz and G. R. Offen

Experiments have been conducted in a 0.5 x 10^6 Btu/hr test furnace to assess

the effectiveness of low and medium Btu gases as reburning fuels. These fuels, produced by coal gasification, have only trace amounts of hydrocarbons; the combustion fraction is mainly H_2 and CO. Situations where gasification fuels may be of interest for reburning would be cyclone combustors which used crushed coal as a fuel, or boilers where there is insufficient residence time for reburning with coal. The experimental results show that the gasification fuels can reduce NO_x created in the primary flame although not as effectively as hydrocarbon fuels. Typically, the gasification fuels gave 20-30% reduction of primary zone NO_x compared to 60-70% for natural gas. If the primary zone NO_x emissions are controlled by reducing the primary zone stoichiometry to between 1.0 and 1.05, 60% overall NO_x reduction (compared to an uncontrolled flame) can be achieved with 15-20% use of simulated Lurgi reburning fuel. Under the Same conditions, nearly 80% overall NO_x reduction was achieved with natural gas reburning.

Session III: Manufacturers' Update of Commercially Available Technology

1987 Update on NO_x Emissions Control Technologies at Combustion Engineering

M. S. McCartney, A. Kokkinos, R. D. Lewis, T. D. Hellewell, and M. B. Cohen

As the owners and operators of fossil fuel steam generators plan for the 1990s new emphasis is being placed on the control of NO_x emissions. This emphasis is the result of a resurgence in the concern, both domestically and internationally, for the effects that NO_x emissions may have on the environment. At Combustion Engineering (CE), work is continuously underway to support these owners and operators. As shown in previous Joint NO_x Control Symposia, CE has a diverse array of NO_x Reduction Technologies available to address a range of possible reductions dictated by future regulations. These technologies have been developed by CE and Mitsubishi Heavy Industries (MHI); MHI-developed technologies have been licensed to CE. A synopsis of each of these technologies and the application and operating experience related to them is presented here.

Update of NO_x Control Technologies at Riley Stoker

C. E. McHale and R. A. Lisauskas

Recent design and operating experience with Riley Stoker low-NO_x combustion systems in pilot scale and commercial furnaces is reviewed. The performance of several commercial low-NO_x burner installations in wall- and Turbo-fired furnaces is described. Both emissions reductions from uncontrolled levels and the impact of the combustion process modifications on furnace temperatures are discussed. Pilot scale results focus on in-furnace NO_x and SO_2 control processes such as reburning and sorbent injection. Recent activities include CCV burner design refinements, and developing staged combustion systems for utility boilers, industrial stoker-fired boilers, and circulating fluidized-bed combustors. Since jet aerodynamics influence combustion and NO_x reduction efficiencies, two-phase jets in furnace enclosures are discussed.

Industrial and Utility Boiler Low NO_x Control Update

Joel Vatsky and Edmund S. Schindler

NO_x control has been passing through various phases as the regulatory and commercial climate has changed since the early 1970s. During the decade of the 70s, emphasis by boiler manufacturers was on developing and field demonstrating NO_x controls to meet the New Source Performance Standards of 1971 and 1979. More recently, with the reduced need for new utility generating capacity, emphasis has shifted to retrofittable technologies to meet pending acid rain control legislation. This paper discusses field experience with Foster Wheeler's low NO_x coal burner, which is an inherently retrofittable design, on industrial and utility boilers. New concepts and their potential uses are also outlined.

NO_x Control Update—1987

Albert D. LaRue and Paul L. Cioffi

Babcock & Wilcox is expanding its low NO_x technology and product lines to include systems directly suited for un controlled sources and for an increasin variety of new boiler applications. Th low NO_x cell burner has successfull completed two scales of combustio testing and initial field trials, and awaits full boiler demonstration. The XCL burne was developed to reduce NO_x belo existing low NO_x burner capabilities whil providing individual burner air flo measurement and other features t improve performance. Reburning is beir investigated as a NO_x control measure f cyclone-fired boilers. NO_x emissions a controlled with gas- and oil-fired units t use of PG-Dual Register Burners cor bined with NO_x ports and gas recirc ation. Further NO_x reduction can achieved by use of In-Furnace N Reduction. Fluid beds provide N control by virtue of the combusti methodology, and lower NO_x levels c be reached by staging. Refuse syste often face a wide range of emission li tations, and the Controlled Combust Zone (CCZ™) furnace offers potential improved combustion and lower N when firing refuse-derived fuel. An upd is provided on the technology and pr ucts used by B&W to control emissi in these applications.

Session IV: Coal-Fired Boiler Applications

The Federal Clean Coal Program

Jack S. Siegel

The Department of Energy's C Coal Technology Program is broad scope than just the control or preve of pollutants from coal using machin also addresses the energy needs c U.S. economy; i.e., coal technol which can compete with oil and ga markets which are now dominated l and gas; coal technologies whic allow utilities to cut the long lead now necessary to design and con conventional coal-fired boilers with s bers; and coal technologies whic only control SO_2 and NO_x to NS better levels, but which also are efficient and produce more easil posal wastes than conventional nologies. It is our objective to e the scope of this effort, prese overview of the R&D activity, in the recently initiated clean coal c

tration program, and discuss the attri- ıtes of the technologies which should ısure that, once demonstrated, they will ɔe used commercially.

Development Status of B&W's Second Generation Low NO_x Burner—The XCL Burner

lbert D. LaRue, Michael A. Acree, ıd Charles Masser

Due to the national concern with acid in, the U.S. NO_x emission standards ıay become more stringent for new ources, and uncontrolled sources may ce NO_x emission limits. B&W has con- equently proceeded to develop a econd generation low NO_x pulverized oal (PC) burner suitable for new or trofit applications. A primary objective to minimize NO_x by burner design to void slagging and corrosion concerns sociated with staged furnace operation. evelopment of the XCL burner stemmed om the technology of Babcock Hitachi's T-NR burner design. The development ogram was cosponsored by the EPA, ıd consisted of full scale (80 x 10^6 u/hr) tests of a standard Dual Register ırner, an HT-NR burner, and an XCL ırner. Air flow tests were conducted to aracterize flow patterns and improve virl efficiency, and combustion tests ere performed to evaluate and minimize nissions. The XCL burner proved ɔable of NO_x emissions (unstaged) of 3-0.5 lb/10^6 Btu with high efficiency and ljustable flame shape. Consequently, a ll complement of XCL burners were trofitted to Ohio Edison's Edgewater nit 4 for the EPA Limestone Injection ultistage Burner (LIMB) demonstration. ıe paper describes development and ld results with the XCL burner.

ductions in NO_x Emissions ɔm a 500 MW Corner Fired ɔiler

W. Allen, W. J. D. Brooks, N. A. rdett, F. Clarke, and G. Foley

The Central Electricity Generating ard is investigating methods for lucing the emissions of NO_x from sil-fired power stations. Low NO_x tech- ɔgies usually involve radically different nbustion regimes within the boiler npared to conventional units; there- ı, it is necessary to investigate their t-effectiveness by undertaking large le and long term trials. This paper ɔrts on the results of a programme undertaken to investigate the characteristics of the "rich-fireball" technique installed in a 500 MW(e) coal fired boiler at Fiddler's Ferry Power Station, England. Data are presented showing the impact of operational parameters on NO_x emissions. It is concluded that the introduction of this technique has resulted in a reduction of NO_x emissions of 31-38%, depending on the mills in service.

Application of Mitsubishi "Advanced MACT" In-Furnace NO_x Removal Process at Taio Paper Co., Ltd., Mishima Mills No. 18 Boiler

M. Araoka, A. Iwanaga, and M. Sakai

Mitsubishi Heavy Industries, Ltd. has been engaged in the research and development of new technology concerning the prevention of air pollution. In the field of low NO_x combustion technology, we have already developed and utilized many countermeasures; for example, super low NO_x PM burners and MACT systems which have already been introduced at former symposiums. This time, we have successfully developed and put into practical use the "Advanced MACT" system. This paper introduces the outline of this "Advanced MACT" system and its application and operating experience at Taio Paper Co., Ltd., Mishima Mill No. 18 Boiler.

Operating Experiences of Coal Fired Utility Boilers Using Hitachi NO_x Reduction Burners

Tsuneo Narita, Fumio Koda, Tadahisa Masai, Shigeki Morita, and Shigeru Azuhata

Babcock-Hitachi K.K. has replaced Dual Register Burners with Hitachi NO_x Reduction burners (HT-NR) on two coal fired 200 MWe boilers. The HT-NR burner was developed, as previously reported, to apply the concept of In-Flame NO_x Reduction. The two retrofitted boilers have achieved further NO_x reduction, without increased unburned carbon contents or any other operating problems. Actual NO_x emissions depend on the volatile matter content of the coal: with highly volatile coal, emissions range from 70 to 75 ppm (6% O_2). Five different coals are being fired in these units. Rapid ignition and flame stabilization are enhanced by use of a new type ceramic stabilizer. Even lower levels of NO_x and unburned carbon can be achieved by increasing the coal fineness.

Long-Term Versus Short-Term Data Analysis Methodologies—Impact on the Prediction of NO_x Emission Compliance

Lowell L. Smith, Wallace S. Pitts, III, Randall Rush, and Timothy Flora

Over the last two decades, considerable NO_x data from utility and industrial boilers have been accumulated. The data sources range from short-term test results to data obtained from continuous emission monitors from Subpart Da utility boilers. Depending upon the ultimate use of these two types of data, different interpretations of the emissions results can be obtained. This can have far reaching impacts if the interpretation of the data is used to establish the long-term effectiveness of NO_x control technologies or to establish new or revised emission standards. This paper discusses the potential ultimate uses of both short- and long-term data. The value of both is discussed in terms of their use for establishing emission control trends, operating and retrofit guidelines, and emission standard setting. Statistical analysis methodologies are presented for interpreting long-term data, and illustrations of Time Series Analysis are presented for interpretation of these data.

Engineering and Economic Analysis of Retrofit Low-NO_x Combustion Systems

R. A. Lisauskas, R. D. Snodgrass, S. A. Johnson, and D. Eskinazi

The feasibility of retrofitting low-NO_x combustion controls on four utility wall-fired boiler designs has been evaluated. This evaluation included an engineering analysis of all equipment modifications, and a cost estimate for each retrofit option. Consideration was given to boiler physical limitations and operating constraints, as well as achieving NO_x reduction. NO_x emission predictions were based on correlations developed from both field installations and large pilot-scale combustion tests. The following low-NO_x combustion processes were evaluated: Low-NO_x burners, Conventional air staging (Overfire air), Advanced air staging (Overfire air), and Reburning. Costs are presented in terms of $/kW, mills/kWh, and $/ton of NO_x removed. The cost of retrofit NO_x controls was

found to vary with unit size and retrofit complexity. Depending on the level of boiler modifications required, the capital cost of retrofit combustion controls can vary from less than $3 to more than $20/kW.

The Influence of Fuel Properties and Boiler Design and Operation on NO_x Emissions

J. H. Pohl, G. C. Dusatko, P. C. Orban, and R. W. McGraw

Methods to predict the dependence of NO_x emissions on coal properties, burner design and operation, and boiler design and operation are unreliable, complicated, or both. This paper determined the functional dependence of NO_x emissions on a number of these parameters using data available in the literature. The functional dependences were then used to successfully explain the changes in NO_x emissions observed for: (1) a 660 MWe boiler firing two bituminous coals with volatile contents of 26.3 and 18% as received, and (2) two wall-fired 30 MWe units and a 137 MWe tangential unit firing a single coal with a volatile content of 24% as received. The change in the NO_x with coal, primary air velocity, load, and excess oxygen content was explained using the dependences derived in this paper.

Volume II

Session Va: Flue Gas Treatment

Current Status of SCR in Japan

Yasuyuki Nakabayashi and Rikiya Abe

Selective Catalytic Reduction (SCR) of NO_x is widely applied to utility and industrial boilers in Japan. Among utility boilers, 99 units (about 110 x 10^6 Nm^3/h) have been equipped with SCR including 22 units of coal firing boilers (about 20 x 10^6 Nm^3/h). Among industrial boilers, 31 units (about 3.3 x 10^6 Nm^3/h) have also been equipped with SCR (as of April 1986). SCR installation started in 1977 for oil and gas and in 1979 for coal firing boilers. These operating experiences suggest that the cost and performance of SCR should be discussed again, because the catalyst itself (life, volume requirement, etc.) has been improved remarkably. This paper will describe those factors from a utility standpoint.

Operating Experience with the SCR $DeNO_x$ Plant in Unit 5 of Altbach/Deizisau Power Station

P. Necker

The SCR $DeNO_x$ plant in Unit 5 (420 MW) of Altbach-Deizisau Power Station has been in operation since late 1985. The plant represents a retrofit to an existing plant and is designed as a partial flow plant (1.1 x 10^6 m^3/h at 80% boiler load). The experience obtained after 6,000 hours of operation (by the end of 1986) has shown that it is possible to observe the 200 mg NO_x/m^3 limit value stipulated in Germany when consideration is given to the accompanying conditions illustrated with full flow plants. The demands placed on the partial flow plant of Unit 5 are particularly high. The reduction in activity of the catalytic converter is within the expected range after 6,000 hours of operation. A partial air preheater wash carried out on a test basis produced air preheater water which had a high NH_3 content initially only. The waste water from the flue gas desulfurization plant contains only a small quantity of NH_3. The NH_3 values for the flue dust must be monitored carefully, since they may result in special stipulations being made for operation of the $DeNO_x$ plant. The maintenance effort for the operational measuring equipment required for the $DeNO_x$ plant is relatively high.

VKR Full-Scale SCR Experience on Hard Coal Fired Boilers

Klaus Goldschmidt

VEBA Kraftwerke Ruhr (VKR) operates power plants in Northrine-Westfalia of the Federal Republic of Germany with a total capacity of 5500 MW gross. Most of the boilers are fired with high ballast hard coal. Older boilers have wet bottom furnaces; newer ones are dry furnaces. The great furnace ordinance of Germany calls for a NO_x emission rate 200 mg/m^3 (i.e., 98 ppm), so all great boilers must be retrofitted by $DeNO_x$. Meanwhile, VKR reduced NO_x emissions from their boilers by primary methods as far as possible. Since the end of 1984, VKR handles up to eight pilot plants to prove the SCR technology. Since the end of 1985, 100% of flue gas from district heating boiler Buer (dry bottom, 150 MW), and since mid-1986, sponsored by UBA, 50% of flue gas from boiler Knepper C (molten ash, 370 MW) is treated by SCR high dust technology. Based on pilot-plant tests, the paper describes both DeN demonstration units, their operation, a the findings.

Applicability of European SCR Experience to U.S. Utility Operation

J. Edward Cichanowicz and Georg R. Offen

About 2200 MW of SCR capacit operating or in start-up in Europe a February 1987. Five full-scale syst are currently operational in the Fed Republic of Germany and two in Aus Each unit has logged between 2000 6000 hours of operation. Experience these SCR installations will help d the cost and technical feasibility of for potential U.S. application. This p discusses the relevant experience a pated from these and other Euro installations. Experience that will dir apply to U.S. conditions is summa as are topics which are not releva U.S. application due to plant desig fuel limitations. The European installations are first briefly surveyed the significant design and oper features reviewed. Relevant experie categorized into four topics: SCR c design, catalyst lifetime, process c and plant integration. Finally, i critical to the analysis of SCR tec feasibility and cost for high sulfur fired plants are summarized.

Comparison of Four Catalys Used in Selective Catalytic Reduction of NO_x

Bo Herrlander

Tested catalysts all show a pseu order reaction. High activity an specific surface are beneficial performance, even though high surface also means smaller pit higher pressure drop. The op experiences are good, with no activity deterioration.

The Improvement of NH_3 Injection Control System fo Selective Catalytic NO_x Re System

K. Suyama

Mitsubishi Heavy Industries l plied Selective Catalytic NO_x (SCR) systems for more than

)oth in Japan and abroad since it 'livered the first SCR system for a)iler in 1976. This paper describes the :ontrol system of an SCR system devel-)ped with a new concept to cope with the ecent trend to operate a thermal power)lant as a load swing operation unit and 's service results in a 600 MW boiler.

)evelopment of Low Level NH_3 Measuring Method

'asuyuki Nakabayashi, Rikiya Abe, nd Takusuke Izumi

Performance of NO_x reducing catalysts ill be continuously checked by meas-ring slip NH_3 downstream of the SCR actor. There are two ways to measure)w level NH_3: one direct, and the other ndirect. The indirect method uses a atalyst, the same kind we use to check erformance, in order to convert NH_3 to O. EPDC and Anritsu Corporation eveloped jointly the direct NH_3 meas-rement and applied it at Takehara #3 '00 MW) unit. This instrument detects traviolet absorption of NH_3 spectrum by equency modulation. Sampling method also important to measure low level H_3 (0-20 ppm) and is developed by us. nis paper will describe the principle of ese methods.

pdated Technical and :onomic Review of Selective :atalytic NO_x Reduction ystems

E. Damon, P. A. Ireland, and D. V. iovanni

Selective Catalytic NO_x Reduction is)w being used on coal-fired units in pan, in both retrofit and new unit)plications. This update lists Japanese al-fired units using SCR. In addition, it dates the technical design require-nts to help prevent air heater plugging ammonia-sulfur compounds. The jor new requirement is a lower NH_3 p limit of 3 - 5 ppm which in turn re-ires significantly lower space veloc-s. Hence greater catalyst volumes and)cess costs are realized than were ntified 2 or 3 years ago. In addition, impact of the devaluation of the dollar ainst the yen is reviewed. Current SCR st analyses for both a new utility coal-d unit application, and retrofit utility l-fired units are provided. The new ustrial NSPS NO_x limits are presented, an SCR cost analysis on a small ustrial generator is reviewed. Finally, conclusions based on Japanese SCR experience in terms of updated costs and its present applicability to U.S. coal-fired units are presented.

Session Vb: Fundamental Combustion Studies

Mechanisms of Fixed Nitrogen Reduction in Pulverized Coal Flames

John C. Kramlich, Thomas W. Lester, and Jost O. L. Wendt

Although the major features that mark the conversion of coal nitrogen have been identified through extensive research, some portions of the process are not well understood. An understanding of these processes, and their associated rates, will provide the information needed to develop process models. Three areas have been identified for which present process models fail to predict the observed fixed nitrogen reduction: (1) the reduction in nitrogen that occurs at very short time, including devolatilization and reaction in the immediate vicinity of the coal particle; (2) nitrogen reduction in the bulk fuel-rich regions that are characteristic of staged combustion and reburning applications; and (3) fixed nitrogen reduction at the final leaning-out point. The work reported here examines these problems through tasks on: homogeneous kinetics, NO reduction by heterogeneous media, and the overall process of fixed nitrogen reduction in direct coal combustion.

The Interplay Between Chemistry and Fluid Mechanics in the Oxidation of Fuel Nitrogen from Pulverized Coal

Charles Kruger, Greg Haussmann, and Steve Krewson

The evolution and subsequent reaction of gas-phase nitrogenous species from pulverized Montana Rosebud subbituminous coal have been measured in the Stanford entrained-flow reactor under uniform and well controlled conditions. Experiments have been performed at atmospheric pressure with temperature up to 1850 K and oxygen concentrations varying from zero to 15.0 %. Gas-phase measurements have been made of carbon oxides, light hydrocarbons, NO, NO_2, N_2O, NH_3, and HCN. Chemical and physical analyses of party reacted coal particles provide data on the carbon and nitrogen content, porosity, and the rate of tar pyrolysis. A major focus of this research has been the role of tar in the evolution of fuel nitrogen. At high heating rates, substantial quantities of tar are evolved in very short reaction times, and the pyrolysis products are rich in nitrogen. The rate of reaction of these products in and around a volatile cloud surrounding the parent coal particle controls the oxidation of fuel nitrogen. The measurements show that, when the pyrolyzing coal particles are exposed to oxygen concentrations as low as 4%, a significant portion of the fuel nitrogen can be oxidized to NO, although some of this NO is subsequently reduced in the gas phase.

Reduction of NO_x by Fuel Staging

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Results are reported of theoretical and experimental studies in which natural gas was used as "reburn" fuel for NO_x reduction in a No. 6 fuel oil flame. A Sandia chemical kinetic code with kinetic parameters of hydrocarbon/NO reactions, developed by J.M. Levy and B.R. Taylor at MIT, was used to predict chemical species concentrations in the "reburn" zone as a function of residence time, initial NO concentration, gas temperature, and fuel equivalence ratio (Ø). The fractional reduction of high initial NO concentrations(~ 800 ppm) in the reburn stage is shown to be proportional to the concentrations of CH_i and NH_i species. At high temperatures (2000 K), the abundance of CH_i and NH_i species causes a reduction of NO from 800 to 46 ppm at a Ø of 1.3. At lower initial NO concentrations (~ 40 ppm), NO formation dominates over its reduction, with the result that better reduction of NO is achieved at the lower temperature of 1800 K: for an initial 25 and 38 ppm at 1800 and 2000 K, respectively. For a given gas temperature the CH_i radical concentration increases with increasing fuel equivalence ratio in the "reburn" zone, and the fractional conversion of NO to N_2 as a function of Ø follows the usual trend of showing an optimum at around Ø = 1.3. At lower than optimal fuel equivalence ratios the NO reduction becomes strongly temperature dependent. (At Ø = 1.1 calculated NO reduc-

tions are 18% at 1780 K and 60% at 2000 K.) Experimental data obtained in a 1.5 MW No. 6 oil flame with 400 ppm (doped) initial NO concentration and at Ø = 1.1 showed good agreement with predictions.

Fuel Bound Nitrogen Evolution During the Devolatilization and Pyrolysis of Coals of Varying Rank

J. D. Freihaut, W. M. Prosica, and D. J. Seery

The near-term use of coal for power generation involves the development of low NO_x burners for retrofit applications or the design of new boiler systems. Intermediate and long-term applications propose using dry or slurried micronized coal feeds in modular, load-following high-intensity combustion systems. All systems anticipate a form of stoichiometric staging of the micro-scale combustion process to obtain acceptable levels of NO_x emissions. However, maximizing carbon burnout while minimizing NO_x formation in these systems will require the formulation of quantitative models of the micro-scale combustion process of coals of varying rank characteristics. The complexity of the processes involved will necessitate models more empirical and phenomenological than mechanistic, but will need to take into account the significant variation in nitrogen evolution pathways with coal type. This paper reports results of an investigation of the nitrogen evolution behavior of a range of coal ranks in a variety of heating conditions and the initial formulation of a kinetic model of coal nitrogen devolatilization. With respect to the total mass fraction of coal nitrogen volatilized during transient heating of particles to 1000°C, the evolution of fuel bound nitrogen appears relatively rank-insensitive in moderate heating rate conditions for high volatile bituminous coals and lower ranks. The mass fraction of nitrogen evolved follows the mass fraction of coal volatilized and, under conditions where secondary reactions of tar are minimized, the distribution of parent coal nitrogen between tar and light gases follows the distribution of parent coal mass between these volatile types. The distribution of coal nitrogen in volatile types varies as the distribution of coal mass between the volatile types. For medium volatile and higher rank coals, the mass fraction of nitrogen evolved during particle heating to 1000°C varies as the volatility of parent coal and is therefore rank sensitive. However, in moderate heating rate conditions, the distribution of parent coal nitrogen between volatile types continues to follow the distribution of parent coal mass between these types. The susceptibility of devolatilization-produced tar species to secondary pyrolysis reactions varies significantly with coal rank characteristics. Secondary reactions of tar occur within the devolatilizing particle, in the boundary layer around the particle, and the free stream. High temperature secondary pyrolysis reactions of tars occurring in fuel rich conditions result in the release of tar-bound nitrogen to the light gas component of the volatile yield, primarily in the form of HCN. The high temperature secondary reaction network leading to the production of cyanide species also produces acetylene, ethylene, and carbon monoxide and appears to commence the onset of soot production. The secondary reaction network for tars commences at particle or gas temperatures of 900°C with a strong temperature and coal rank dependence. The formation of light gas nitrogen species, NO_x precursors, is strongly rank-dependent because the temperature sensitivity of secondary reactions of the heavy hydrocarbons formed at relatively low particle temperatures, 300-600°C, varies with the mix of hydrocarbon species present in the parent coal; i.e., the rank characteristics of parent coal. Progress in the formulation of a rank-dependent model of nitrogen evolution is discussed.

Session VI: Cyclone-Fired Boilers

Feasibility of Reburning for Cyclone Boiler NO_x Control

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This paper gives results of an engineering and economic feasibility study of reburning as a potential retrofit NO_x reduction method for coal-fired cyclone boilers. Results indicate that most cyclone boilers are suitable for retrofit from the standpoint of available furnace residence time, a key parameter in applying the technology. Heat transfer analysis for a 200 MW cyclone boiler case study predicts insignificant increases in furnace exit gas temperatures; thus, no conve tive pass or sootblowing modificatio would be required. No technical fact were identified that would preclu retrofit of reburning to most of t cyclone boiler generating capacity. N reductions predicted for 200 and 700 M boilers were 50 and 60%, respectiv without derating. These predictions based on the units' available furn residence times. Capital and 10-y levelized busbar power cost estima ranged from $15 to $34/kW and 1.6 to mills/kWh, depending on the reburr fuel selected. A follow-on pilot reburi project on a 6 x 10^6 Btu/hr cyclc equipped test furnace is also describe

NO_x Control Options for Coal-Fired Cyclone Utility Boilers

R. E. Thompson, R. M. Himes, an G. R. Offen

The implementation of stringent regulations in Japan and West Gerr has increased the probability of control provisions in acid rain legisl in the U.S. The economic impact o proposed legislation is a serious co to utilities with cyclone units bec they have high NO_x emissions and few cost-effective retrofit options. paper highlights an EPRI study dir at evaluating NO_x control options ra from conventional and advanced bustion modifications to low-NO_x sla combustors, reburn technology, an gas treatment. The first phase study included a review of cyclon emission characteristics, their d dence on boiler design and ope parameters, and a comparison to unit designs. Prior attempts to redu clone NO_x emissions by means o bustion modifications were eva and constraints to low-NO_x op identified. These design and op constraints included reduced com gas temperature, slag capture a cosity control, high temperatur rosion, and carbon burnout. The NO_x reduction potential and op constraints of several potential NO_x control concepts were the pared on a preliminary basis to de which concepts exhibited th promise. A more detailed evalu these concepts in continuing, i brief technical and economi parisons to alternative NO_x cor tions for cyclone units.

TRW Coal Combustor—NO_x Emissions

Donald J. Frey

TRW has developed an atmospheric, entrained-coal combustor with significant support from DOE/PETC which can either be retrofitted to existing units or integrated with new steam generating equipment. The concept consists of a water-cooled main combustor in which pulverized coal is burned in suspension at heat release rates approaching 10^6 Btu/hr-ft^3 of combustor volume. Combustion occurs at sub-stoichiometric conditions in order to control NO_x formation. More than 90% of the ash is removed from the combustors as molten slag. The flue gas exiting the combustor is at a temperature near 1650°C, contains almost no carbon, only 10% of the ash, and CO and H_2 (amounting to about 15% of the original heat input). These gaseous combustibles must be burned in the host boiler, and the final air, termed secondary air, is injected into the furnace through a conventional windbox/burner arrangement. TRW has conducted many tests at its Capistrano test facilities to minimize NO_x formation. The earlier determinations were made on a 10 x 10^6 Btu/hr combustor, firing Utah, Wyoming, and Montana coals. The secondary air was admitted through fixed pipes, and final combustion occurred in an uninsulated water-cooled chamber. Later tests were performed in a 50 x 10^6 Btu/hr combustor, also at Capistrano. These results supported most of the earlier conclusions and provided additional insight regarding the beneficial effects on NO_x formation of controlled mixing and burning in the secondary combustion stage.

Session VIIa: Oil- and Gas-Fired Boilers

Methanol Dual-Fuel Combustion

Alexander Weir, Jr., Leslie J. Radak, Edward A. Danko, Ray A. Lewis, and Harry W. Buchanan

Dual-fuel combustion is a technique invented to lower emissions of NO_x from boilers. This paper presents experimental data using this technique in a utility boiler at a level of 35 MW. Tests with low sulfur (0.21% S) oil/natural gas, low sulfur oil/methanol, and natural gas/methanol were performed, and the NO_x emission data were compared with NO_x emissions of 100% low sulfur oil, gas, and methanol. Tests with a mixture of 70% natural gas/30% methanol revealed that the NO_x emissions level using the dual-fuel technique was lower than those obtained with either 100% gas or 100% methanol. The NO_x level was about 25% of the level obtained with natural gas fired in a conventional combustion mode or about 50% of the NO_x level obtained with natural gas fired in a "staged" combustion or "burners-out-of-service" mode, a state-of-the-art combustion modification technique used to lower NO_x emissions.

Application of Fuel Biasing for NO_x Emission Reductions in Gas-Fired Utility Boiler

Greg C. Quartucy, M. N. Mansour, and James N. Nylander

The effectiveness of fuel biasing in reducing NO_x emissions from gas-fired utility boilers has been evaluated by the San Diego Gas & Electric Company (SDG&E). The unit chosen for this evaluation, South Bay Unit 1, is a 150 MW face-fired unit which currently meets local NO_x emissions limits by operating with burners-out-of-service (BOOS). This operating mode results in CO emissions of greater than 2000 ppm and an O_2 imbalance. Fuel biasing offers a reduction in NO_x emission by controlling combustion stoichiometry in two discrete combustion stages: the first operated fuel-rich to limit the formation of thermal NO_x; and the second operated fuel-rich or fuel-lean. The primary advantage of fuel biasing is that it provides better control of combustion stoichiometry, which reduces O_2 imbalances and increased CO emissions which may accompany BOOS operation. The effect of fuel bias ratio, air register position, and excess oxygen level on unit emissions and performance was evaluated. The use of fuel biasing allowed the unit to meet local NO_x regulations, while decreasing the O_2 imbalance and reducing CO emissions to less than 500 ppm. Additionally, improvements in unit operating efficiency were measured when using the fuel biasing firing mode.

NO_x Inventory and Retrofit Assessment

Dominick J. Mormile, Stephen E. Kerho, Skillman C. Hunter, and Peter E. Coffey

The Empire State Electric Energy Research Corp. (ESEERCO) has funded a program to develop a model for estimating NO_x emissions from the New York Power Pool (NYPP) electric system for different generation dispatch scenarios. Baseline emission levels for each boiler and for the entire system were calculated. In addition, the technical feasibility, NO_x reduction potential, and cost of commercially available NO_x control technologies were evaluated for each boiler. Besides quantifying annual NO_x emission rates for NYPP fossil-fuel-fired power plants, the model enables ESEERCO to evaluate the effectiveness and costs of alternative NO_x reduction strategies.

Full Scale Evaluation of Urea Injection for NO Removal

M. N. Mansour, Sam N. Nahas, Greg C. Quartucy, James N. Nylander, Harold A. Kerry, Les J. Radak, David Eskinazi, and T. S. Behrens

An engineering evaluation was performed by San Diego Gas and Electric (SDG&E) to assess the use of urea injection for NO emissions control on gas- and oil-fired utility boilers. This evaluation consisted of a field assessment of the technology on Unit 2 at SDG&E Encina Generating Station and an evaluation of technology economics. The program was co-funded by Southern California Edison Company (SCE) and the Electric Power Research Institute (EPRI). Fuel Tech, Inc. (FT) co-sponsored the field assessment. The program represented the first application of urea technology to a utility boiler. Urea injection for NO emissions control was developed in 1976 by KVB under EPRI sponsorship. It involves spraying urea as an aqueous solution into the products of combustion where the urea reacts with NO in the gas phase to produce molecular nitrogen and water. The process depends on combustion gas temperature with a reduction in emissions achieved between 760 and 1090°C. The results of the field assessment showed that urea is effective in reducing NO emissions from natural-gas- and fuel-oil-fired utility boilers. NO removals ranged from 30 to 70%. Variables identified as influencing the performance of the process included the urea to NO mole ratio, injection variable, initial NO concentration, and urea solution concentration. The economic assessment has shown that the cost of urea injection is sensitive to the level of NO removal achieved, plant size, and plant capacity factor. The total

levelized costs for the process were estimated based on the performance of the system currently undergoing evaluation. The cost of the technology was estimated for plants ranging from 100 to 500 MW in size and operating over a broad range of initial NO concentrations. For the case studied, the levelized cost of the technology ranged from $700 to $3500/ton of NO removed with the lower cost obtained from the largest plant operating at high initial NO (600 ppm @ 3% O_2). Future work includes optimizing the performance of the urea injection system to improve reagent utilization and level of NO removal achieved. Future work will also define the control logic for a fully automated urea injection system as well as establish the effects on boiler operation of long-term urea injection.

Retrofit Combustion Controls for Gas/Oil-Fired Utility Boilers

Wesley W. Pepper, Ronald F. Balingit, Dan V. Giovanni, and Donald P. Teixeira

The NO_x Reduction Program, a voluntary undertaking by the City of Los Angeles, Department of Water and Power (LADWP), was initiated after determining that utility boilers in the Los Angeles Basin are becoming targets for additional NO_x controls and that Rule 1135.1 NO_x settlement limits may be exceeded in the future under certain dispatch and fuel use scenarios. The program is based on two objectives: (1) to implement measures that will ensure continued compliance with the Rule 1135.1 NO_x settlement emission limits, which could be exceeded in the 1990s under certain resource scenarios such as unavailability of natural gas or hydroelectric import energy; and (2) to evaluate advanced low-NO_x combustion technology capabilities systems as an alternative to postcombustion treatment for retrofit on existing low capacity factor utility boilers. Combustion controls appear to be significantly more cost effective than postcombustion treatment, and their installation could be incorporated with other compatible boiler modifications that would improve boiler reliability and thermal performance. The LADWP NO_x Reduction Program is designed to accomplish these overall objectives through a three-phase approach: Phase 1 was an engineering evaluation of advanced combustion NO_x control techniques applicable to LADWP oil/gas-fired boilers; Phase 2 involves the design, fabrication, and installation of a low-NO_x demonstration system on one LADWP boiler; and Phase 3 will be the test, evaluation, and demonstration of the installed low-NO_x technology. Tasks performed to accomplish the Phase 1 objective were: (1) to identify and screen applicable NO_x control alternatives; (2) to assess commercial experience with advanced low-NO_x combustion technology in Japan; (3) to solicit preliminary technical/budgetary proposals from Babcock & Wilcox (B&W) and Combustion Engineering (C-E) which provide estimates of NO_x emissions control capabilities for the LADWP units; (4) to analyze the information from Japanese installations and the boiler manufacturer's proposals; and (5) to select a boiler and NO_x control technology for consideration in Phase 2. The work was performed jointly by LADWP and its consultants, Electric Power Technologies (EPT) and Electric Power Services International, Inc. This paper summarizes the results of Phase 1 and plans for Phases 2 and 3.

Session VIIb: Industrial and Commercial Applications

Pilot-Scale Tests of a Multistaged Burner Designed for Low NO_x Emission and High Combustion Efficiency

James A. Mulholland and R. K. Srivastava

A multistaged combustion burner design is being evaluated on a 0.6 MW package boiler simulator for in-furnace NO_x control and high combustion efficiency. An adiabatic precombustion chamber burner has been reduced in size by about a factor of two. Natural gas, doped with ammonia to yield a 5.8% fuel nitrogen content, was used to simulate a high nitrogen content fuel/waste mixture. A burner baseline NO emission of 315 ppm (measured dry, corrected to 0% O_2) was measured, compared with an emission of over 1000 ppm estimated for a conventional, unstaged burner. Both deep air staging, resulting in a three-stage configuration, and fuel staging with undoped natural gas, yielding four stoichiometric zones, reduced the baseline NO emission by about 50% (to 160 ppm), meeting the program goal. However, deep air staging resulted in the entire front end of the broiler being fuel-rich and required penetrations into the boiler for staged air injection. Fuel staging, on the other hand, required no boiler penetrations (staged fuel and air were injected from the boiler front wall) and only a small fuel-rich flame core in the boiler (produced aerodynamically). Furthermore, sufficient air for complete oxidation of the primary combustion products was provided at the burner exit (prior to staged fuel and air injection into the boiler) in the fuel staging tests. Thus the four-stage configuration appears to be the most promising approach for minimizing NO emissions and maximizing primary fuel/waste destruction. Further testing is ongoing with pyridine and fuel oil mixtures to better characterize surrogate fuel/waste destruction efficiency.

Diesel Engine NO_x Control: Selective Catalytic Reduction and Methanol Emulsion

John H. Wasser and Richard B. Perry

EPA's Air and Energy Engineering Research Laboratory has recently conducted two diesel engine NO_x reductio studies: one a long term evaluation of selective catalytic reduction (SCR) system, and the other an evaluation c methanol emulsion fuel. The SCR projec established the NO_x reductio performance of a catalytic unit over 4000-hour period. NO_x reductions range between 98 and 69% during the test, wit periodic (approximately every 130 hours) dry cleaning required to mainta activity. Measurements of other pollutan (CO and particulate matter) indicated th the catalyst and/or ammonia addition h no effect on these emissions. No adver operational problems were encounter on the engine system during the te program. The methanol proje established the performance of this f modification. The diesel system w equipped with a fuel emulsification u capable of delivering methanol/fuel-oil water/fuel-oil mixtures to the engine's f supply line. NO_x emission reductions 20-25% were measured when firi methanol/fuel-oil emulsions compared fuel-oil firing only. However, substan increases in CO (from 30 to 70 ppm) hydrocarbon (from 4 to 200 ppm) en sions were also recorded. The meth ol/oil emulsion results are also compa to water/oil emulsion results on the s engine.

The Control of NO_x Emissions From Municipal Solid Waste Incinerators

M. P. Heap, W. S. Lanier, and W. R. Seeker

Disposal of municipal solid waste is a growing problem because of the declining capacity of landfills and restrictions on their use. Incineration provides a cost effective solution: the bulk of material requiring landfilling is reduced, the material can be landfilled with minimal restrictions, and the energy in the waste is converted to usable heat and/or power. Incineration cannot be accomplished without due consideration to the generation and control of atmospheric pollutants. Of major concern are trace quantities of potentially toxic hydrocarbons. The emission of these species can be minimized by appropriate design and operation of the combustion systems; unfortunately, these measures tend to increase rather than decrease emissions of NO_x. This paper discusses the types of municipal waste combustion devices and the types of pollutants generated during waste combustion. Four methods of NO_x control are discussed: Combustion Zone Control, Selective Non-Catalytic, Selective Catalytic, and Hybrid Processes.

Nitrogen Oxide Emissions Reduced from Cement Kiln Exhaust Gases by Process Modification

M. S. May, R. MacMann, J. C. Phillips, and G. L. Young

In January 1982 the South Coast Air Quality Management District (SCAQMD), El Monte, CA, adopted a rule to reduce emissions of NO_x from the exhaust gases of portland cement kilns in the South Coast Air Basin. The rule was drafted to allow cement manufacturers to demonstrate through research whether or not NO_x could be reduced by modification of the cement manufacturing process. Riverside Cement Company, as a result of review of the literature and pilot studies conducted by KVB, Inc., selected the following four tactics as having potential for reducing NO_x emissions: (1) reduce the quantity of fuel used per ton of clinker; (2) reduce the quantity and temperature of the primary air; (3) control the configuration of the flame; and (4) improve control of the operation of the kiln. The Riverside Cement Company was able to demonstrate with statistical confidence that the NO_x emissions, after the implementation of the four tactics for the cement manufacturing process, were 26% less than the premodification emissions.

NO_x Formation in a Cement Kiln: Regression Analysis

John M. Croom, Mallory S. May, Gerald L. Young, Craig Phillips, and Russ MacMann

NO_x emissions from a cement kiln were analyzed with step-wise linear regression. The goal was to demonstrate which operating variable(s) control the rate of NO_x emissions. Of 14 independent variables in the regression analysis, burning zone temperature of the kiln was the only significant variable; it accounted for 83% of the variability in NO_x emissions. Because the burning zone required for production of acceptable quality clinker averages between 1300 and 1400°C, minimum NO_x emission from a long, dry cement kiln is probably 5-6 lb NO_x/ton of clinker produced.

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