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Project Summary

Hitachi Zosen NO_x Flue Gas Treatment Process: Volume 2. Independent Evaluation

J. M. Burke

Nitrogen oxide (NO_x) emissions from stationary sources may be reduced by 80 - 90% by applying selective catalytic reduction (SCR) of NO_x with ammonia. In the interest of furthering the development of this technology, EPA sponsored pilot scale tests of two SCR processes treating flue gas slipstreams from coal-fired boilers. One of the processes was the Hitachi Zosen (HZ) process. An independent evaluation of the pilot plant tests of the HZ process shows that the process can reduce NO_x emissions from a coal-fired boiler by 90%. Initial tests resulted in plugging of the catalyst. But a new catalyst with larger gas passages was tested: it operated for 5500 hours without any signs of plugging. An energy analysis indicates that the HZ process energy requirements equal 0.3% of the boiler's capacity. Process costs were estimated based on the pilot plant test results. Estimated capital investment and annual revenue requirements for the HZ process are $44/kW and 2.91 mills/kWh, respectively. These costs are slightly lower than previous estimates for the process.

This Project Summary was developed by EPA's Industrial Environmental 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

Selective catalytic reduction (SCR) of NO_x with NH_3 can reduce NO_x emissions by 80% or more. As such, SCR represents the most effective process available for controlling stationary source NO_x emissions. For a utility application of SCR, a catalytic reactor is located between the economizer and air preheater sections of the boiler. At this location the flue gas temperature is 300 - 400°C (570-750°F), which is optimum for the catalytic activity. Ammonia is injected into the flue gas upstream of the catalyst and reacts with NO_x on the catalyst surface to form elemental nitrogen and water.

Most SCR processes were developed and are being operated commercially in Japan, primarily on gas- and oil-fired sources. However, in the U.S., SCR systems are now being installed on a limited basis. The most notable application is a demonstration system that is being constructed to treat half of the flue gas from Southern California Edison's 215 MWe Huntington Beach Unit No. 2 (an oil-fired boiler). Operation of this system is expected to establish

SCR as a commercially available technology for oil- and gas-fired sources in the U.S.

In Japan, development efforts are currently aimed at applying SCR to coal-fired sources. To date, most of the SCR process vendors in Japan have operated pilot units on slipstreams from coal-fired boilers. In addition, there are now four full-scale SCR systems treating flue gas from coal-fired boilers; eight other units are scheduled for start-up in 1982 and 1983. These development efforts are rapidly establishing SCR as commercially available for controlling NO_x emissions from coal-fired sources in Japan.

The transfer of SCR technology from Japan to the U.S. for coal-fired applications presents a potentially significant problem. Since most coal-fired boilers in the U.S. operate electrostatic precipitators (ESPs) downstream of the air preheater, a typical SCR application would expose the catalyst in the reactor to the full particulate concentration from the boiler. Although tests have been conducted in Japan in which the catalyst was exposed to high particulate concentrations with no adverse effects, the differences in the composition of particulates from U.S. and Japanese coals could impact SCR operation.

To further the development of SCR technology and to determine how differences between Japanese and U.S. coal/particulate properties impact the performance of SCR processes, EPA sponsored pilot scale (0.5 MW equivalent) tests of two SCR systems. One of the SCR systems was the Hitachi Zosen (HZ) process. The HZ pilot plant processed a flue gas slipstream from a coal-fired boiler. The contractor responsible for the design and operation of the pilot plant was Chemico Air Pollution Control Corp. (now General Electric Environmental Services Corp.), the North American licensee for the HZ process. Chemico was also responsible for collection, evaluation, and reporting of the test data.

Primary objectives of the pilot plant test program sponsored by EPA were: (1) to demonstrate the ability of the HZ process to achieve a 90% reduction in NO_x emissions, and (2) to determine the long-term impacts on catalyst performance which result from processing flue gas from a coal-fired utility boiler.

In conjunction with the pilot plant test program, EPA contracted with Radian Corp. to independently evaluate the processes tested based on the pilot plant results. This document summarizes the results of the independent evaluation of the HZ process. It includes a discussion of the results of tests conducted by both Chemico and Radian and the results of Radian's independent evaluation of the HZ process. A separate report (Volume I) covering the detailed results of the pilot plant test program has been prepared by HZ.

Program Objectives and Approach

The independent evaluation of the HZ pilot plant test program conducted by Radian Corp. had three major objectives: (1) to provide independent validation of the process measurements made by Chemico; (2) to quantify changes in the emission rates of secondary pollutants (pollutants other than NO_x) across the pilot plant reactor; and (3) to complete a technical and economic evaluation of the HZ process including identification of areas which require further development or investigation.

To validate the measurements made by Chemico, a quality assurance program was implemented. This program used EPA reference methods and other standard measurement techniques to make independent audits of critical process parameters; e.g., flue gas flowrate and NH_3 injection rate. In conjunction with the quality assurance program, the continuous NO_x monitors were subjected to certification tests designed to determine their ability to make accurate repeatable measurements. These certification tests included measurement of the continuous monitors relative to accuracy, drift, calibration error, and response time.

Concurrent with the quality assurance program, a stack sampling program was conducted to measure changes in secondary process emissions across the SCR reactor. This approach required simultaneous sampling of the reactor inlet and outlet for the species of interest. The samples were then analyzed and differences between inlet and outlet concentrations determined.

Based on the results of the quality assurance program, the stack sampling program, and the test data collected by Chemico, an evaluation of the HZ process was completed. This evaluation consisted of several steps. First, the test data were analyzed and reduced to a form which could be used to predict process performance for a specified set of operating conditions. Then, using the reduced test data and the results of the stack sampling program, material and energy balance calculations were completed for a 500 MWe coal-fired application of the HZ process. The basis for these calculations was identical to that used by TVA in developing cost estimates for the HZ process and presented in "Preliminary Economic Analysis of NO_x Flue Gas Treatment Processes."[1] The results of the material and energy balance calculations were then used to develop a modified estimate of total capital investment and annual revenue requirements for a 500 MW coal-fired application of the HZ process. Finally, the test data were reviewed and areas requiring further investigation/quantification were identified.

Results

Several areas which influence the technical and economic feasibility of the HZ process were examined as part of this study:

- Pilot plant test results.
- Results of Radian's independent tests.
- Results of a 500 MW conceptual design of the HZ process.
- Material balance calculations for a 500 MW process application.
- Energy balance calculation for a 500 MW process application.
- Estimated capital investment and annual revenue requirements for a 500 MW HZ process application.

The following discussion summarizes the results of the evaluation of each of these areas. Overall conclusions on the technical and economic feasibility of applying the HZ process to a coal-fired boiler are presented later.

Pilot Plant Test Results

The test program at the HZ pilot plant was initiated in June 1979, and was completed in January 1981. During this period, the pilot plant processed a flue gas slipstream from between the economizer and the air preheater of the coal-fired Unit 3 at Georgia Power Co.'s Plant Mitchell Station. Design flue gas flowrate to the pilot unit was 1700 Nm^3/hr (1060 scfm), and flue gas was processed for about 10,000 hours.

The pilot plant test program involved examination of three charges of catalyst material under a variety of test conditions. In general, these tests were divided into two categories: optimization tests and demonstration or long-term tests. The objective of the optimization tests was to identify operating conditions which would reduce NO_x emissions by 90% at a minimum cost for operating the process. The major objective of the demonstration tests was to document the ability of the process to achieve a 90% reduction in NO_x emissions for 90 days.

The objectives of the pilot plant tests conducted by Chemico were exceeded. The NO_x reduction efficiency of the plant averaged over 90% during the 90 day demonstration test; the average was 89.8% over 5 months of operation. This included several test periods during which the NH_3/NO_x ratio was varied to determine its effect on NO_x reduction efficiency. If these test periods are excluded from the averages, the NO_x reduction efficiency during the 5 months of operation would be greater than 90%.

Other significant results of the test program showed that neither temperature nor flowrate has any significant effect on NO_x reduction efficiency within a range about the design level. These results indicate that process performance should not be impaired at boiler loads below the design level. As a result, no temperature or flow control would be required for a full-scale application of the HZ process.

During the test program, three catalyst charges were examined: two of these (NOXNON 500) experienced severe plugging problems after about 2000 hours of operation. When replaced with the NOXNON 600 catalyst, which has larger gas passages, no further plugging problems were observed. The original plugging was believed to be due to the adhesiveness of the fly ash. At high temperatures, fly ash samples collected from the power plant were found to agglomerate.

Tests with the NOXNON 500 catalyst did not last long enough to get a good measure of catalyst activity, but results of the NOXNON 600 tests showed a gradual decline in catalyst activity with time. After 5500 hours of operation, activity of the NOXNON 600 had dropped slightly, but it was still possible to achieve 90% NO_x reduction. Since 5500 hours is nearly 1 year of operation (~7000 hours), a catalyst life of 1 year seems reasonable, based on test results. In fact, catalyst life may be extended well beyond 1 year based on the results of the in-situ regeneration test conducted at the conclusion of the test program. These tests showed that catalyst activity had been restored to the level of essentially new catalyst. Unfortunately, since the regeneration test was conducted during the final week of the test program, it is uncertain how long the effects of regeneration would last.

Overall, the results of the pilot plant tests indicate that application of the HZ process to a coal-fired boiler is technically feasible. The tests demonstrated the ability of the process to achieve 90% NO_x reduction for over 90 days and also demonstrated a stable catalyst life of nearly 1 year.

Independent Evaluation Test Program Results

The independent evaluation test program conducted by Radian had two primary objectives: to ensure the quality of the data collected at the HZ pilot plant and to quantify changes in the concentrations of certain pollutants across the HZ reactor. Data quality was determined by quality assurance (QA) audits and continuous monitor certification tests; changes in pollutant concentrations were determined by a secondary emissions sampling program. The results of each element of the independent evaluation program are summarized below.

Quality Assurance Audits

The QA audits conducted by Radian were designed to ensure that the process data which are required to characterize the operation of the HZ pilot plant were accurate. Radian used reference methods for auditing process operating parameters which were measured on a continuous or routine basis by Chemico. One exception to this was the measurement of NH_3 emissions which were not routinely monitored by Chemico, although the original design of the pilot unit included an analyzer intended to determine NH_3 emissions.

The results of the NH_3 emissions sampling conducted by Radian indicated an average NH_3 concentration at the reactor outlet of about 50 ppm under operating conditions which result in 90% NO_x reduction. The NH_3 concentration at the reactor outlet was much higher than expected (previous work in Japan indicated NH_3 concentrations of about 10 ppm). The relatively high NH_3 concentrations are expected to have an impact on equipment downstream of the catalytic reactor for a commercial application of the HZ process. This is discussed in more detail later.

The results of the QA audits conducted by Radian are summarized in Table 1. As shown, all but the SO_2 concentration measurements were within 10% of the values recorded by Chemico. This indicates that, except for the SO_2 monitor, the process data collected by Chemico accurately characterize the operation of the HZ pilot plant.

In the case of the flue gas SO_2 concentration at the HZ pilot plant, the audit results were determined to be correct, and the SO_2 monitor was in error. This error is characteristic of the type of SO_2 monitor used (pulsed fluorescence) when the instrument is calibrated with standard gases composed of SO_2 in nitrogen.

Secondary Emissions Sampling

The secondary emissions sampling program was conducted by Radian during July and August 1980, concurrent with the demonstration test conducted by Chemico. The objective was to quantify changes in the emission rates of pollutants other than NO_x. For the most part, these tests were conducted during tests in which steady state NO_x reduction efficiency was maintained at 90%.

Table 2 summarizes the results of the secondary emissions sampling program at the HZ pilot plant. As shown, concentrations of hydrocarbons, CO, hydrogen cyanide (HCN), and nitrosoamines at the reactor outlet were below the detection limits of the analytical techniques employed. For hydrocarbons and CO, no conclusions can be drawn concerning the impacts of the HZ process. For HCN, the analytical detection limit is equivalent to 10 ppbv and for

Table 1. *Results of QA Audits at the Hitachi Zosen Pilot Plant*

Measurement Audited	*Relative Error[a], %*
SO_2 Concentration	*-19.8*
Flue Gas Flowrate	*- 0.3*
NH_3 Injection Rate	*- 6.0*
Reactor Pressure Drop	*4.5*
Reactor Temperature	*4.8*

[a] *Relative Error* $= \frac{\text{Monitor Reading - Audit Measurement}}{\text{Audit Measurement}} \times 100\%$

N-Nitrosodimethylamine, 2 ppbv. In both cases, these concentrations are at levels which are considered safe for emission sources.

Table 2 shows an increase in SO_3 concentration across the HZ reactor. This is due to oxidation of SO_2 in the reactor and was not unexpected since the catalyst contains vanadium pentoxide which is the catalyst used in manufacturing sulfuric acid. The apparent change in particulate concentration shown in Table 2 is believed to be due to unaccounted for stratification in the ducts. Note that no results for nitrous oxide (N_2O) are presented. This is due to the fact that the analytical technique used to measure N_2O was unsatisfactory for use in a flue gas stream.

In addition to measuring the concentration of particulates in the flue gas, an elemental analysis of the particulates was completed in an attempt to determine if erosion of the catalyst has a measurable effect on the concentration of vanadium (V) and titanium (Ti) in the particulates. Table 3 gives results of the elemental analysis of the particulates collected at the HZ pilot plant. As shown, an apparent increase in all elements occurs across the reactor, but the relative concentrations on V and Ti remain constant. This indicates that there is no measurable change in the concentration of V or Ti in the particulates exiting the reactor.

Continuous Monitor Certification Tests

Certification tests were conducted for the SO_2 and NO_x monitors used to measure flue gas concentrations of pollutants at the inlet and outlet of the reactor. These tests were included in the independent evaluation program to ensure the quality of the pilot plant performance data being collected by Chemico. Certification of continuous emission monitors involves a formal procedure, developed by EPA to ensure the accuracy of monitors measuring emissions from sources which must comply with new source performance standard emission limitations. For a continuous emission monitor (CEM) to be certified, it must be subjected to and pass a number of performance tests, including:

- Calibration error.
- Response time.
- Drift.
- Relative accuracy.

Table 2. *Stack Sampling Results at HZ Pilot Unit*

Flue Gas Component	*Reactor Inlet Concentration*[a]	*Reactor Outlet Concentration*[a]
Nitrosoamines (μg/dscm[b]*)*	*5*	*5*
Hydrogen Cyanide (mg/dscm)	*0.01*	*0.01*
Ammonia (ppmv-dry basis)	*Not measured*	*54.8*
Sulfur Trioxide (ppmv-dry basis)	*8.4*	*20.7*
Hydrocarbons[c] *(C_1-C_6) (ppmv)*	*1.0*	*1.0*
Carbon Monoxide[c] *(%)*	*0.017*	*0.017*
Particulate Loading (g/dscm)	*7.1*	*7.7*
Nitrous Oxide	–	–

[a]Average of three or more tests.
[b]dscm - dry standard cubic meter.
[c]Below the detection limit.

Table 3. *Results of Particulate Analysis at the HZ Pilot Plant*[a]

Component	*In*	*Out*	*Out/In*
Al	*10.7%*	*13.0%*	*1.21*
Ca	*8200 ppm*	*9900 ppm*	*1.21*
Fe	*4.9%*	*6.0%*	*1.22*
K	*2.0%*	*2.5%*	*1.25*
Mg	*6300 ppm*	*7800 ppm*	*1.24*
Mn	*190 ppm*	*240 ppm*	*1.26*
Sn	*490 ppm*	*680 ppm*	*1.40*
Na	*4200 ppm*	*4700 ppm*	*1.12*
Si	*18%*	*23%*	*1.28*
Zn	*190 ppm*	*250 ppm*	*1.32*
Cu	*150 ppm*	*170 ppm*	*1.13*
Ti	*5800 ppm*	*6900 ppm*	*1.19*
V	*270 ppm*	*330 ppm*	*1.22*

[a]Concentrations are on a mass fraction basis.

The performance specifications for each of the above certification tests are shown in Table 4, along with results of the tests. The performance specifications are those contained in the Federal Register, Vol. 44, No. 197, Wednesday, October 10, 1979 - "Proposed Rules: Standards of Performance for New Stationary Sources; Continuous Monitoring Performance Specifications".[2]

As shown in Table 4, the test results for both the NO_x continuous monitors met the performances specifications. These data indicate that continuous monitors were making accurate measurements of flue gas NO_x concentrations.

Results of the Conceptual Design of a 500 MW HZ Process

A conceptual design of a 500 MW HZ process was prepared based on the pilot plant test results. This conceptual design served as a basis for material and energy balance calculations and for a cost estimate for a 500 MW application of the HZ process.

Table 5 summarizes the results of the conceptual design for a 500 MW application of an HZ process. As shown, the key design variable levels are

Table 4. *Continuous Monitor Certification Test Results at the HZ Pilot Plant*

Certification Test	*Performance Specification*	*Inlet NO_x Monitor*	*Outlet NO_x Monitor*
Calibration Error			
-high level, %	≤ 5	*1.40*	*4.70*
-mid level, %	≤ 5	*4.39*	*2.68*
Response Time, min	≤ 15	*1.4*	*1.6*
Zero Drift (2-hour), %	≤ 2	*1.20*	*0.05*
Calibration Drift (2-hour), %	≤ 2	*1.93*	*1.78*
Relative Accuracy, %	≤ 20[a]	*14.1*	*10.5*

[a]*Alternatively, ≤ 10 % of the applicable emissions standard.*

Table 5. *Results of the Conceptual Design for a 500 MW Hitachi Zosen Process*

Design Parameter	*Design Level*
Reactor Design Parameter	
• *Number of Reactors*	*2*
• *Reactor Cross Section, m^2*	*96.5*
• *Catalyst Volume per Reactor, m^3*	*205*
• *Reactor System Pressure Drop, kPa*	*1.28*
• *Soot Blowers per Reactor*	*4*
• *Soot Blowing Frequency*	*3/day*
Air Preheater Design Parameters	
• *Soot Blowers per Preheater*	*6*
• *Soot Blowing Frequency*	*6/day*
• *Element Configuration*	*Combined Intermediate and Low Temperature Zone*
• *Element Construction*	*Corrosion Resistant Material in Intermediate and Low Temperature Zone*

presented for the SCR reactor and the downstream air preheater.

The conceptual design of the HZ process was prepared for a single application of the process; it was based solely on the pilot plant test results. Results of this design indicate that NO_x emission can be reduced by 90%, using the HZ process. In fact, 90% NO_x reduction was possible at space velocities greater than previous estimates indicated (i.e., at a relatively lower catalyst volume per unit volume of flue gas treated). However, the greater space velocities were accompanied by NH_3 emissions which were much higher than previous estimates.

One result of the high NH_3 emissions estimated for the conceptual design was that special modifications to the air preheater are required to mitigate problems associated with the formation of ammonium sulfates downstream of the reactor. These modifications were identified as part of a prior study[3]; they are based on Japanese experience with air preheater operations downstream of an SCR system. Note that modifications specified for the air preheater were expected to minimize problems at relatively low NH_3 and SO_3 concentrations at the reactor exit. Concentrations at the reactor outlet for the conceptual design are much higher than anticipated in previous studies of SCR technology; this could result in operational problems which cannot be minimized by the preheater modifications included in the conceptual design. This represents an area which requires further investigation.

Reactor pressure drop and other design parameters are fairly consistent with previous estimates for the process. The design results also show that the process can operate over a range of temperatures (340 - 410°C) and space velocities (6,500 - 8,900 hr^{-1}) without any significant effect on NO_x reduction efficiency. This indicates the process has good flexibility in processing flue gas under conditions of changing boiler load.

In summary, the conceptual design indicates that the HZ process can reduce NO_x emissions by 90%. This NO_x reduction efficiency can be achieved at a lower catalyst volume per unit of flue gas treated than previous estimates indicated. However, the lower catalyst volume of the conceptual design is accompanied by a significantly higher NH_3 emission rate which can result in severe operational problems in downstream equipment, particularly the air preheater. Further work is required to determine if the effects of these NH_3 emissions can be offset by the air preheater modifications included in the conceptual design.

Results of Material Balance Calculations for a 500 MW HZ Process

Material balance calculations for a 500 MW application of the HZ process were included as part of this study to identify raw material requirements for the process and to serve as a basis for an estimate of capital investment and annual revenue requirements. The material balance was based on the pilot plant and secondary emissions sampling test results and thus reflects those results in the estimated raw material requirements. The most significant results of the material balance calculations include estimation of NH_3 requirements for NO_x reduction, NH_3 and SO_3 emissions from the process, and steam requirements for air preheater soot blowing.

The NH_3 requirements for the process were estimated to be 1.0 mole of NH_3 per mole of NO_x in the flue gas entering the reactor. This requirement was estimated based on the results of approximately 6 months of pilot plant operation. During the 6 months, the NH_3/NO_x injection ratio averaged 0.98, and the NO_x reduction efficiency averaged 89.8%. With an NH_3/NO_x injection ratio of 1.0, estimated NH_3 requirements for the process decreased about 10% for previous estimates.

Estimates of NH_3 and SO_3 emissions from the HZ process were significantly higher than previous estimates indicated. As discussed earlier, this results in the requirements for air preheater modifications and additional soot blowing. The requirement for additional soot blowing results in a sevenfold increase in HZ process steam requirements. This is not very significant from a material balance standpoint, but it is important in terms of its effect on process energy requirements. Note that HZ claims that the NH_3 emission and SO_2 oxidation rates can be reduced with no decrease in process performance by adjusting the composition of the catalyst. However, since this was not demonstrated during the pilot plant tests, it was not considered in preparing the material balances or the conceptual design.

In summary, the material balance calculations showed no significant change in raw material requirements for the HZ process. The most important result was the estimated NH_3 and SO_3 emission rates which were significantly higher than previous estimates indicated.

Results of Energy Balance Calculations for a 500 MW HZ Process

An energy balance was completed as part of the evaluation of the HZ process. This energy balance defined overall process energy requirements and quantified the heat credits associated with the process. The results of the analysis of energy requirements indicated that the HZ process has a net energy consumption equivalent to about 0.3% of the energy input to the boiler.

The individual components of the overall process energy requirements are summarized in Table 6. Each component has been put on the basis of heat input to the boiler. For steam, a thermal efficiency of 88% was used to determine the energy input required to generate one Gcal of steam energy. For electricity, a boiler heat rate of 2.27 Mcal/kWh was used. The heat credit was assumed to replace heat input to the boiler on a 1-to-1 basis.

Results of the Cost Estimate for a 500 MW HZ Process Application

An estimate of total capital investment and annual revenue requirements for a 500 MW application of the HZ process was prepared as part of this evaluation. The estimated costs reflect the results of the pilot plant tests. When compared with the previous estimate prepared by TVA, the modified cost estimates indicate the magnitude of the impact the pilot plant results had on estimated process costs. In addition, comparison of the modified cost estimate with cost estimates for other SCR processes indicates the cost effectiveness of the HZ process as tested in the pilot plant program.

Results of Capital Cost Estimate

Table 7 gives the individual components of and the estimated total capital investment for a 500 MW application of the HZ process. The total capital investment was estimated to be approximately \$22.1 x 10^6 which is equivalent to approximately \$44/kW of generating capacity. When compared to TVA's previous estimate, this represents a slight decrease.

The principal difference between th two estimates is the estimated catalys volume. The required catalyst volum based on the pilot plant tests wa estimated to be about 20% less, thereb decreasing the total capital investment However, the decrease in costs fron reduced catalyst volume requirement

Table 6. *Overall Energy Requirement for a 500 MW Application of the HZ Process*

Energy Area	*Energy Requirement Gcal/hr*	*Percent of Boiler Capacity*
Heat Credit	*(3.15)*	*(0.28)*
Steam	*3.36*	*0.30*
Electricity	*3.50*	*0.31*
Total	*3.71*	*0.33*

Table 7. *Estimated Capital Investment for a 500 MW Application of the Hitachi Zosen Process*[a]

Direct Investment[b]	*Investment, \$*	*% of Total Direct Investment*
NH_3 storage and injection	*645,000*	*5.5*
Reactor section	*8,632,000*	*73.4*
Gas handling	*351,000*	*3.0*
Air preheater modifications	*1,461,000*	*12.4*
Sub-total direct investment (DI)	*11,089,000*	*94.3*
Services, utilities (0.06 x DI)	*665,000*	*5.7*
Total direct investment (TDI)	*11,754,000*	*100.00*
Indirect Investment		
Engineering design and supervision	*274,000*	*2.3*
Architect and engineering contractor	*69,000*	*0.6*
Construction expense $= 0.25\ (TDI \times 10^{-6})^{0.83}$	*1,933,000*	*16.4*
Contractor fees $= 0.096\ (TDI \times 10^{-6})^{0.76}$	*625,000*	*5.3*
Total indirect investment (IDI)	*2,901,000*	*24.6*
Contingency = 0.2·(TDI + IDI)	*2,931,000*	*24.9*
Total fixed investment (TFI)	*17,586,000*	*149.5*
Other Capital Charges		
Allowance for start-up and modifications = (0.1) (TFI)	*1,759,000*	*15.0*
Interest during construction = (0.12) (TFI)	*2,110,000*	*17.9*
Total depreciable investment	*21,455,000*	*182.4*
Land	*5,000*	*-*
Working capital	*336,000*	*2.9*
Royalty fee	*300,000*	*2.6*
TOTAL CAPITAL INVESTMENT	*22,096,000*	*187.9*

[a]*Basis: 500 MW new coal-fired power plant, 3.5% sulfur coal, 90% NO_x removal. Midwest plant location. Represents project beginning mid-1977, ending mid-1980. Average basis for scaling, mid-1979. Investment requirements for fly ash disposal excluded. Construction labor shortages with overtime pay incentive not considered.*

[b]*Each item of direct investment includes total equipment costs plus installation labor, and material costs for electrical, piping, ductwork, foundations, structural, instrumentation, insulation, and site preparation.*

was somewhat offset by the costs of air preheater modifications required to minimize ammonium sulfate deposition problems.

Results of the Annual Revenue Requirement Estimate

Table 8 gives the individual components and the total estimated average annual revenue requirements for a 500 MW application of the HZ process. The average annual revenue requirement was estimated to be approximately $\$10.2 \times 10^6$ which is equivalent to 2.91 mills/kWh. Compared to TVA's previous estimate, this represents a 17% decrease in the annual revenue requirements.

As with capital costs, the principal factor which decreased the annual revenue requirements is the lower quantity of catalyst required in the reactor. Again, this reduction in annual revenue requirements was somewhat offset by the cost of increased air preheater soot blowing.

Cost Comparison and Summary

The capital investment and annual revenue requirements of the HZ process have been estimated based on the results of the test conducted at the EPA-sponsored pilot plant in Albany, GA. These estimates indicate that the capital costs and annual revenue requirements are slightly lower than the estimated costs prior to the test program. A more important comparison, however, is the cost of the HZ process relative to the cost of other SCR processes.

Since the same basis was used in preparing the modified HZ cost estimate and TVA's preliminary economic estimates for other SCR processes, it is possible to make a direct comparison with the costs of the Shell flue gas treating (SFGT) process which were developed under the EPA pilot plant test program. Table 9 gives the estimated annual revenue requirements for two pollution control systems which reduce emissions of particulates, NO_x, and SO_3 by 99.5, 90, and 90%, respectively. As shown, the pollution control systems include flue gas desulfurization capability and have downstream ESPs to put the cost estimates on a common basis.

As shown in Table 9, the estimated costs associated with the HZ processes are 30 percent lower than those of the

Table 8. *Estimated Average Annual Revenue Requirements for a 500 MW Application of the Hitachi Zosen Process*[a]

Item	*Annual Quantity*	*Unit Cost, $*	*Annual Cost, $*	*% of Annual Revenue Required*
Direct Costs				
Raw materials				
NH_3	*5.25×10^6 kg*	*0.165/kg*	*866,300*	*8.47*
Catalyst			*5,125,000*	*50.14*
Total raw materials			*5,991,300*	*58.61*
Conversion costs				
Operating labor and supervision	*8760 labor hr*	*12.50/ labor hr*	*109,500*	*1.07*
Utilities				
Steam	*20,700 Gcal*	*7.94/Gcal*	*164,400*	*1.61*
Electricity	*10,787,000 kWh*	*0.029/kWh*	*312,800*	*3.06*
Heat credit	*22,050 Gcal*	*-7.94/Gcal*	*(175,100)*	*(1.71)*
Maintenance = 0.04 x TDI			*470,200*	*4.60*
Analyses	*2,920 labor hr*	*17.00/ labor hr*	*49,600*	*0.48*
Total conversion costs			*931,400*	*9.11*
Total direct costs			*6,922,700*	*67.72*
Indirect Costs				
Capital charges				
Depreciation = (0.06) (total depreciable investment)			*1,287,300*	*12.59*
Average cost of capital = (0.086) (total capital investment)			*1,900,300*	*18.59*
Overheads				
Plant = (0.5) (conversion costs minus utilities)			*314,700*	*3.08*
Administrative = (0.1) (operating labor costs)			*11,000*	*0.11*
Total indirect costs			*3,513,300*	*34.37*
Spent catalyst disposal			*(214,000)*	*(2.09)*
Total Annual Revenue Requirements			*10,222,000*	*100.00*

[a]*Basis: 500 MW new coal-fired power plant, 3.5% S coal. 90 percent NO_x reduction, 90 percent SO_2 removal. Midwest power plant location, 1980 revenue requirements. Remaining life of power plant = 30 years. Plant on line 7000 hr/yr. Plant heat rate equals 9.5 MI/kWh. Investment and revenue requirement for disposal of fly ash excluded. Total direct investment \$11,754,000; total depreciable investment \$21,455,000; and total capital investment \$22,096,000.*

Table 9. *Estimated Annual Revenue Requirements for Two Pollution Control Systems*[a]

SCR Process	*Annual Revenue Requirements ($ x 10^6)* SCR	FGD	ESP	Overall
SFGT	*33.6*	-	*3.0*	*36.6*
Hitachi Zosen	*10.2*	*14.7*	*2.2*	*27.1*

[a]*All costs except the HZ-SCR and the SFGT-SCR costs are from "Preliminary Economic Analysis of NO_x Flue Gas Treatment Processes." Tennessee Valley Authority - Office of Power. EPA-600/7-80-021, February 1980.*

SFGT process. These results indicate that the HZ process, as tested in the pilot plant and presented in the conceptual design, is the most economical of the two SCR processes tested in EPA's pilot plant program within the constraints of the conceptual design used in this study. Note that the relative costs presented in Table 9 are only valid for one specific application; they could change for other applications.

Overall the results of the modified cost estimate indicate that, for the particular application examined in this study, the HZ process is economically competitive with other SCR processes. This is based on a conceptual design which was representative of operating conditions demonstrated during the pilot plant tests. Note, however, that the costs can be affected by the impacts of high NH_3 and SO_3 emissions whose effects were not examined during the pilot plant tests. Additionally, the estimates presented in this evaluation were based on a 1-year catalyst life which was not demonstrated. But, HZ will guarantee a 1-year catalyst life for coal-fired applications.

Conclusions

The following conclusions are based on the work performed during this study. For the most part, the information obtained during the course of the study is summarized in the full report and serves as background for the conclusions presented here. The major conclusions of this study are:

- The HZ process can reduce NO_x emissions by 90% when applied to a coal-fired boiler. This level of emissions reduction was achieved over a 90-day period at an NH_3/NO_x injection ratio of 1.0 and space velocities greater than previous test work indicated. However, the excellent performance of this pilot plant was accompanied by NH_3 emissions which were much higher than previous estimates indicated.
- The initial tests of the HZ process experienced problems with catalyst plugging which resulted in failure of two charges of NOXNON 500 series catalyst. These problems were eliminated by using NOXNON 600 series catalyst (a catalyst with larger gas passages) and compressed air (as opposed to superheated steam) for reactor soot blowing. It appears likely that the good performance of the NOXNON 600 catalyst was due to the larger gas passages since the fly ash has a tendency to agglomerate in dry environments.
- A gradual decline in catalyst activity was recorded during the test program which resulted in the requirement for increased NH_3/NO_x injection ratios to attain 90% NO_x reduction. Because the test program was terminated after 5500 hours of operation, the catalyst activity after 1 year of operation could not be determined.
- A novel, in situ catalyst regeneration technique was tested as part of the program. This test showed that the regenerated catalyst had activity similar to fresh catalyst and thus reversed some of the decline in activity observed during the test program. Unfortunately, the catalyst regeneration technique was tested toward the end of the pilot plant test program; so it is uncertain how long the effects of the catalyst regeneration will last.
- The independent evaluation test program indicated that emission rates of most pollutants were not affected by the HZ process. However, emission rates of both NH_3 and SO_3 were relatively high and can result in operational problems in the downstream equipment. The severity of any problems in this regard is very site specific and could not be assessed as part of this study. This should, however, be given careful consideration in any planned applications of the HZ process.
- The conceptual design and material balance calculations indicated high NH_3 emission rates which will cause severe operational problems in the air preheater, downstream of the HZ process. The conceptual design included air preheater modifications designed to minimize those problems. But because the estimated NH_3 and SO_3 emission rates are much higher than previous estimates, it is uncertain if the air preheater modifications will be adequate. Further investigation in this area is required.
- The overall energy requirements for the HZ process were estimated to be 0.3% of the boiler's capacity. This is a very small fraction of boiler capacity and does not significantly affect process costs.
- The estimated capital investment and annual revenue requirements for the HZ process were slightly lower than TVA's preliminary estimate. This indicates that the HZ process is economically competitive with other SCR processes when considered for application to a coal-fired boiler. Note that the cost estimates assumed a 1-year catalyst life which was not demonstrated during the pilot plant tests, although it would be guaranteed by HZ. The relative process costs would change if a 1-year catalyst life were not possible.

In conclusion, the pilot plant tests indicate the HZ process is technically suited for application to coal-fired sources. However, the tests did not demonstrate a 1-year catalyst life which is generally considered a minimum for technical feasibility of an SCR process. In reality, a shorter catalyst life would translate into increased annual revenue requirements. In terms of costs, under the conditions of the cost estimate prepared as part of this study, the HZ process is economically competitive with other SCR processes.

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J. M. Burke is with Radian Corporation, Austin, TX 78759.
***J. David Mobley** is the EPA Project Officer (see below).*
The complete report, entitled "Hitachi Zosen NO_x Flue Gas Treatment Process: Volume 2. Independent Evaluation," (Order No. PB 83-113 837; Cost: $19.00, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

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