

3013
CRTD Vol. 52

An ASME Report



ASME International

Low NOx Measurement: Gas Turbine Plants

Final Report on Review of Current Measuring and Monitoring Practices

January 11, 1999

Report No. 9855-4
by Vaught Engineering Incorporated
29996 North 78th Place
Scottsdale, AZ 85262
602/473-9823

PERMA PURE INC.
P.O. BOX 2105
8 EXECUTIVE DRIVE
TOMS RIVER, NJ 08754

ABBREVIATIONS

| | |
|------------------|---|
| BACT | Best available control technology |
| CEMS | Continuous emission monitoring system |
| CL | Chemiluminescent |
| CO | Carbon monoxide |
| CO ₂ | Carbon dioxide |
| DLN | Dry low NO _x emission system |
| dscfm | Dry standard cubic feet per minute |
| FTIR | Fourier transform infrared |
| HAPS | Hazardous air pollutants |
| H ₂ O | Water |
| IC | Reciprocating internal combustion engines |
| IR | Infrared |
| LAER | Lowest achievable emission rate |
| MmB/h | Millions of BTU per hour |
| MW | Megawatt |
| Nafion® | Permeation type dryer tubing |
| NH ₃ | Ammonia |
| Nm | Nanometers |
| NO | Nitric oxide |
| NO ₂ | Nitrogen dioxide |
| NO _x | Sum of nitric oxide and nitrogen dioxide |
| ppb | Parts per billion |
| ppm | Parts per million |
| ppmdv | Parts per million volume dry exhaust |
| RA | Relative accuracy |
| RATA | Relative accuracy test audit |
| RM | Reference method |
| SCONOX® | NO _x reduction process, Goal Line Environmental Technology |
| SCR | Selective catalytic reduction |
| TDL | Tunable diode laser instrument |
| USEPA | US Environmental Protection Agency |
| UV | Ultraviolet |
| UVDOAS | Ultraviolet dispersion absorption spectrometer |

Recently the South Coast Air Quality Management District (Los Angeles) has proposed to promulgate an emission control standard for gas turbines limiting emissions to approximately 2 ppm_{dv} corrected to 15% O₂. At this level of control standard, measurement variability once viewed as a small part of the allowed emissions, becomes an appreciable part of the total. The following example illustrates this point.

One agency, in establishing their control standard, has estimated the total measurement variability for NO_x to be ± 1 ppm. A similar estimate made by an engine manufacturer places this value at ± 1.5 ppm. Table 1.1 assesses these levels from a compliance viewpoint and illustrates the seriousness of the measurement problem and the difficulty of meeting very low levels of control when measurement variability accounts for an appreciable part of the allowable value of the standard. The values given in Table 1.1 are estimates and are not corroborated by this report.

Table 1.1 Estimated Compliance with Low NO_x Standard

| | Estimated measurement variation ± 1 ppm | Estimated measurement variation ± 1.5 ppm |
|--|---|---|
| Level of standard, ppm | 2.0 | 2.0 |
| Measurement variability, ppm | 1.0 | 1.5 |
| Maximum control level to insure compliance, ppm | 1.0 | 0.5 |

Approach

The American Society of Mechanical Engineers, Codes and Standards Committee B133, Subcommittee 2 (SC2) produces environmental standards for industrial gas turbines. SC2 members as well as specialists in government and industry are concerned that current measurement technology and protocols will not produce the required precision for source testing and monitoring at the very low levels being promulgated. (Specifically 1 to 5 ppm_{dv}, corrected to 15% oxygen.)

To provide understanding of present capabilities on which engineering and regulation can be based, SC2 developed a review program to determine the state-of-the-art in the practice of measuring low concentrations. As currently planned, this effort is divided into three phases:

- Phase I: NO_x Measurement Practices and Capabilities
- Phase II: CO and VOC Measurement Practices and Capabilities
- Phase III: Preparation of a Measurement Standard

2.0 GAS TURBINE SITE TESTING

Source test reports and RATA reports from ten gas turbine installations were reviewed and analyzed to determine test parameters used and NO_x measurement values obtained. These reports are summarized in Table 2.1 below.

Site Selection

Initially, sites were selected from the BACT/LAER permit listings of the USEPA and California Air Resources Board. Permitting agencies were contacted and the selections were reviewed to determine if these sites were constructed and tested. With agency assistance ten sites were selected that had tested to or below a NO_x level of 5 ppm_{dv}, corrected to 15% O₂. Source test and relative accuracy test audit reports were supplied by the agencies for the sites selected. These reports are listed in the References section of this report (San Diego APCD; Am Test-Air Quality, LLC; Carnot; Best Environmental, Inc.; CEMS Services, Inc.; Cisco Custom Instrumentation Services Corporation; Delta Air Quality Services, Incorporated; Environmental Laboratories, Inc.; Radian Corporation; Steiner Environmental, Inc.).

Plant Description

The gas turbine plants selected were located in the Northeast or on the West Coast. Plant sizes ranged from a single engine plant rated at 23 MW to a four-engine plant rated at 1044 MW. All power plants reviewed had the similar characteristics listed below.

- All operated on natural gas fuel. One plant supplemented natural gas with biogas.
- All plants were combined cycle. One plant also had peaking capability.
- All plants had catalytic reduction of NO_x in addition to engine controls.
- One site used a new catalyst system "SCONOX." All others used SCR.
- Two sites used "Dry Low NO_x" combustors. The rest used water or steam injection.

Items Reviewed

In the review of these tests, a number of items were singled out that affected the measurement accuracy of the extremely low NO_x values.

Traverse and representative sampling. All except one of the sites reviewed had tall stacks that provided for good mixing. The EPA protocols given in Method 20 (USEPA, Title 40) establish procedures for obtaining a representative sample. However, no means is given for determining how representative the sample actually is or must be. In Method

Table 2.1 (Con't) Source Test and Relative Accuracy Test Audit Summary

| SITE | D | E | F |
|--|--|--|--|
| Test date | Sep-97 | Jul-98 | Nov-97, Jan-98 |
| No. of units | 2 (4 engines) | 2 | 2 |
| Engine | GE MS7001FA | Siemens V 84.2 (2) | GE LM6000 |
| Size | | 121MW ea | 95MW (plant) |
| Load | 100% | 90% | 100% |
| Application | Comb. Cycle (1044MW) | Comb. Cycle, 286MW | Comb. Cycle and Peaking |
| Fuel rate, mmB/h | | 1032 and 1053 | 420 ng and 90 digester gas |
| Total mass flow, dscfm | | | |
| Water/steam injection | steam | steam | water |
| Catalyst | SCR | SCR-Foster Wheeler | SCR-Graseby/STI |
| SOURCE TEST/RM | | Sep-96 | Nov-97, Jan-98 |
| NO _x , ppm, 15% O ₂ | 3.6-4.2 | 2.2 and 1.8 | 3.90 and 3.96 |
| CO ₂ | | 3.3 and 3.2 | |
| O ₂ | 12.8-13.3 | 15.3 and 15.2 | 14.02 and 15.08 |
| H ₂ O | | 7.5 and 7.0 | |
| NH ₃ | 0.1-0.7 | >0.1 and 1.9 | 4.69 and 7.56 |
| CO | 2.0-3.0 | 0.27 and 1.1 | 32.6 and 0.07 |
| Protocol | EPA Meth. 1,2,3A,4,6C,7E,10 Ref Meth. 2 | EPA Meth. 1,3A,4,7E,10,19, PS,2,3,4 NYSDEC RATA for CEMS | EPA Meth. 1,2,19,20 CARB Meth. 1,4 |
| NO _x analyzer (oper. princ.) | Thermo Electron 42 (CL) | Thermo Electron 10A (CL) | Thermo Electron 10AR (CL) |
| Analyzer Range, ppmv | 0-25 | Not stated | 0-2.5, 0-10, 0-25, 0-100 |
| Water removal | 3 Thermo electric conds. | Condenser | Ice bath at stack, 35-40F Chiller after pump, 38F |
| TRAVERSE TEST | | | |
| Method | EPA RM-1 | Method 20, O ₂ traverse | Method 20, O ₂ traverse |
| Average concentration | 12.9 | Lowest 8 pts. of 48 | Repeat lowest 8 pts. |
| Stratification, % | Not stated | Not stated | Not stated |
| Mixing length | 2.1 dia. | 7.6 dia | Not stated |
| RATA | | | |
| CEMS NO _x analyzer (oper. princ.) | Rosemount 951C (CL) | Rosemount 951C (CL) | Thermo. Environ. Mod 42 (CL) |
| Range, ppm | 0-10, 0-100 | 0-10, 0-250 | 0-25, 0-125 |
| NO _x RM ppm _{dv} | 3.6-4.3 | 2.2 and 1.8 | 3.90 and 3.96 |
| NO _x CEMS, ppm _{dv} | 3.6-4.1 | 2.0 and 2.4 | |
| NO _x Relative accuracy, % | 1.3-6 | 5-9 | 10.9 and 18.4 |
| NO ₂ Converter efficiency | Meets Method 20 | | |
| O ₂ Relative accuracy, % | 1.0-3.0 | 2 and 2 | 1.6 and 2.1 |
| CALIBRATION GASES | | | |
| NO _x , ppm | 11.6, 20.58 | 5.6, 10.3, 24.7 | 0, 6, 12, 23 |
| CO, ppm | 7.21, 11.89 | | 0, 10, 17 |
| O ₂ , % | 11.0, 20.9 | | 0, 14, 20.9 |
| CO ₂ , % | | 9.9, 18.0 | 0, 3.5, 10 |

Table 2.1 (Con't) Source Test and Relative Accuracy Test Audit Summary

| SITE | J | K | L |
|--|--|--|--|
| Test date | Nov-97 | Jul-96 | Jul-97 |
| No. of units | 1 | 2 | 2 |
| Engine | GE 7FA | GE 7FA | GE 7FA |
| Size | 165 | | |
| Load | 100% | 100% | 100% |
| Application | Comb. Cycle | Comb. Cycle | Comb. Cycle |
| Fuel rate, mmB/h | 1,720 | 1580 | 1580 |
| Total mass flow, dscfm | | | |
| Water/steam injection | Dry Low NOx-II Comb. | Dry Low NOx Comb. | Dry Low NOx Comb. |
| Catalyst | SCR | SCR | SCR |
| SOURCE TEST/RM | | | |
| NO _x , ppm, 15% O ₂ | 3.6 | 4.1 and 3.8 | 4.2 and 3.5 |
| CO ₂ | 4 | | |
| O ₂ | 14.02 | | 13.9 and 13.9 |
| H ₂ O | | | |
| NH ₃ | | | |
| CO | 3.9 | 5.07 | |
| Protocol | EPA. 1,2,3A,3B,4,19,20, PS-2,3,4,6 | EPA. 1,2,3A,3B,4,19,20, PS-2,3,4,6 | EPA. 1,2,3A,3B,4,19,20, PS-2,3,4,6 |
| NO _x analyzer (oper. princ.): analyzer Range, ppmv | Thermo Environm. 42H (CL) 0-10, 20, 50, 100 | Thermo Environm. 42H (CL) 0-10, 20, 50, 100 | Thermo Environm. 42H (CL) 0-10, 20, 50, 100 |
| Water removal | refrigeration | refrigeration | refrigeration |
| TRAVERSE TEST | | | |
| Method | Method 20, O ₂ traverse | Method 20, O ₂ traverse | 3 pt. O ₂ Traverse |
| Average concentration | 14 | 13.98 and 14.0 | 13.9 |
| Stratification, % | Not stated | Not stated | Flat |
| Mixing length | 7.9 | 6.2 | 6.2 |
| RATA | | | |
| CEMS NO _x Analyzer (oper. princ.) | Rosemount 951C (CL) | Rosemount 951C (CL) | Rosemount 951C (CL) |
| Range, ppm | 0-10 | 0-10 | 0-10 |
| NO _x RM ppm _{dv} | 3.57 | 3.42 and 3.9 | 4.21 and 3.66 |
| NO _x CEMS, ppm _{dv} | 3.32 | 3.42 and 3.94 | 4.015 and 3.52 |
| NO _x Relative accuracy, % | 9.5 | 1.9 and 2.2 | 5.86 and 5.3 |
| NO ₂ Converter efficiency | 90 plus | 90 plus | 90 plus |
| O ₂ Relative accuracy, % | 1 | 0.5 and 0 | 0.7 and 0 |
| CALIBRATION GASES | | | |
| NO _x , ppm | 4.77, 8.94 | 4.98, 8.96, 9.14 | 4.98, 8.94, 17.9 |
| CO, ppm | 29.8, 60.9, 95.8 | 27.4, 57.6, 88.8 | 29.9, 57.6, 90.7 |
| O ₂ , % | 12.2, 22.29 | 6.03, 20.0 | 12.0, 22.7 |
| CO ₂ , % | 12.0, 21.94 | 3.96, 8.98 | 11.9 and 27 |
| Gas divider | | yes, type not stated | |

Table 2.2 Spiking Test Results

| | |
|--------------------------------------|------------------|
| NO _x analyzer range, ppm | 0-12 |
| NO recovery | 83% at 1.7ppmdv |
| NO ₂ recovery | 59% at 1.6 ppmdv |
| NO ₂ converter efficiency | 85.4% |

Other Variations

The site test reports include multiple tests that provide information on the variation from unit to unit and the variation encountered in succeeding annual tests.

Unit-to-unit variation Six sites contained multiple engines that were measured individually. These engines were measured in succession by the same reference method using the same equipment. Variations shown in Table 2.3 include:

- Differences in engine, HRSG, SCR, and control equipment
- Differences in operating set point
- Minor differences in RM test set up and traverse
- Variability in measurement

Table 2.3. Variation in measured NO_x values from unit-to-unit

| Site | No. of Units | Measured NO _x at 15% O ₂ | | | |
|------|--------------|--|------|------------|--------------|
| | | High | Low | Difference | % Difference |
| C | 5 | 6.7 | 5.7 | 1.0 | 17.5 |
| D | 4 | 4.2 | 3.6 | 0.6 | 16.6 |
| E | 2 | 2.2 | 1.8 | 0.4 | 22.0 |
| F | 2 | 3.96 | 3.90 | 0.006 | 1.5 |
| H | 2 | 4.07 | 4.01 | 0.08 | 2.0 |

Table 2.3 shows that considerable variation in NO_x can exist from unit to unit at the same site when using the same test protocol.

A similar review of the measured oxygen shows variation from 0 to 7.6% of the measured value. This is less variability than shown by oxides of nitrogen measurements. No direct correlation was observed between NO_x and O₂ variability.

3.0 MEASURING INSTRUMENTS

Introduction

The measurement of oxides of nitrogen from gas turbines and other engines is no longer limited to the use of chemiluminescent analyzers and chemical cells. Instrument manufacturers have developed research analyzers into practical, multifunctional source and monitoring instruments. Further, the development of microprocessors has provided an economical means to control and process complex functions and signals. Three of these advanced instruments are reviewed below in addition to chemiluminescent and chemical analyzers. A number of other instruments operating on a variety of principles are being developed for testing and monitoring applications (Rising and Buzard, 1998, Spellacy, 1993).

Chemiluminescent (CL) Analyzers

Chemiluminescence, the emission of light by the products of a chemical reaction, is one of the most widely used methods of measurement of stack gases. All source test and relative accuracy test data obtained in this review of gas turbine site testing used chemiluminescent analyzers to measure NO_x. Because of their sensitivity, which allows measurements in parts per billion (ppb), CL analyzers are frequently used to measure and monitor ambient air.

Operating principle CL instruments operate on the principle that reacting NO gas with ozone forms light that is transformed by a photomultiplier tube into an electrical signal proportional to the concentration of NO. Suitable electronics are supplied to provide amplification and signal conditioning to meet many output requirements. A detailed discussion of the operation and construction of CL analyzers is given by Kita in ISA's text in *Analytical Instrumentation* (1996).

Calibration CL instruments are calibrated using a gas of certified NO concentration. For application to low NO_x measurement, the calibrating gas must be no greater in concentration than the measured value and certified to $\pm 1\%$.

NO₂ converter NO_x in the exhaust of gas turbines requires a catalytic converter to change the NO₂ component in the exhaust to NO so that it can be detected by the CL analyzer. Stainless steel converters operate at temperatures in excess of 1200°F and are the most durable. However, in order not to oxidize the NH₃ that is also present in the exhaust of SCR systems, a low temperature converter, usually molybdenum, is required.

subject to temperature drift. A sensor's performance at low concentration depends on baseline drift, degassing of the interference filter, and signal-to-noise ratio.

Typical performance Analyzers using chemical cells are not available that measure NO_x with acceptable accuracy in the concentration range of 0 to 5 ppm. Commercial instruments are able to measure NO_x with an accuracy of approximately ± 1 ppmv over a range of 0 to 50 ppmv. Typical performance is shown in Table 3.2.

Table 3.2 Typical performance of electrochemical analyzers

| Parameter | Min. full scale range, ppm | Max. full scale range, ppm | Accuracy, % of measurement range final value | Response time, seconds |
|-----------------|----------------------------|----------------------------|--|------------------------|
| NO | 0 to 100 | 0 to 3000 | ≥2.8 | 30 |
| NO ₂ | 0 to 100 | 0 to 500 | ≥1.0 | 80 |
| NO _x | 0 to 200 | 0 to 3500 | ≥3.8 | 80 |

Ongoing electrochemical sensor development will provide cells that are capable of accurately measuring single digit NO_x values.

Calibration Chemical cells require a reference gas for calibration.

Fourier Transform Infrared (FTIR) Analyzers

The range of application of FTIR instruments is extremely broad, including many process instruments and those that measure pollutants in air and water. Fourier transform infrared spectroscopy was originally a laboratory instrument, but with microprocessors it is currently being used for stack measurements. Because of the ability of these instruments to measure a number of components simultaneously, their use is expected to grow, particularly for those applications that require monitoring of hazardous air pollutants.

Operating principle FTIR instruments operate on the principle that the chemical compounds (pollutants) of interest absorb infrared radiation in a repeatable and specific way. An infrared interference pattern (interferogram) is created by passing an IR beam from an interferometer through the sample and returning it to the instrument for analysis. The resulting interferogram must be interpreted using a Fourier transform analysis, which converts the output from a time base to a frequency base. The resultant signal is an absorption spectrum of the sample gas that is compared with a library of known spectra for analysis. These known

Ultraviolet (UV) Analyzers

Analyzers employing the UV range of light have been used for process and emissions monitoring for many years. The higher energy shorter wavelength of UV systems provides improved detection over IR instruments (Saltzman, 1996).

Recently, ultraviolet dispersive absorption spectrometers (UVDOAS) have been applied to CEMS monitoring gas turbines. These UVDOAS analyzers are capable of simultaneously monitoring a large number of exhaust components, including NO and NO₂, at concentrations below 1 ppm. UVDOAS systems can be designed to have no moving parts. They can be applied as in situ instruments measuring exhaust directly by the use of fiber-optic couplings between the source and the sample, and the sample and the spectrometer. Extractive applications that allow measurement cell temperatures as high as 250°C are available.

An installation of a UVDOAS at a gas turbine powered cogeneration plant was made in Los Angeles. The system continuously monitored NO_x and NH₃ at levels below 3-5 ppm and had sensitivity below 500 ppb (Baum and Lord, 1996; Baum, 1996).

Operating principle A photo diode array detector composed of 128 to 4000 diodes in conjunction with a diffraction grating is used to provide a spectrum for the analysis of exhaust pollutants. A pulsed xenon arc, mercury vapor, or quartz halogen lamp provides a source of UV light in a suitable spectral range (wave length 200 nm to 1000 nm). The pulsed xenon arc eliminates the need for a chopper. Gratings or interference filters are used to provide wavelength isolation. By selecting the proper high-dispersion grating, a high-resolution spectra is produced. The absorption peak strength of the source and the spectral gratings are selected for the measurement application. Selection of this grating is most important because of the potential for interference. The light source is attenuated by passing UV light through the sample cell or stack and measuring the absorption. Differential absorption at different frequencies using a multi-element charge coupled device (CCD) array detector provides a signal that is a function of the concentrations of the samples being measured. All wavelengths are measured simultaneously. The detector output is coupled to a data acquisition system that provides digital output in real time that can be used to generate a spectral scan for analysis and control of the operation being monitored (Air Instruments and Measurements, Inc., 1997).

Accuracy Measurement accuracy depends on sample path or sample cell length, on the design choice of the spectral grating, and on the maintenance of the optics. UVDOAS systems have demonstrated repeated accuracy and the ability to operate unattended for several months. The lower threshold of measurement for a 20-inch sample cell is below 500 ppb. A UVDOAS analyzer will monitor NO and NO₂ in typical scale ranges shown below.

Table 3.4 Sensitivity of TDL Systems

| Pollutant | Stack Monitor 100m path length | Extraction cell 12 m path length | Extraction cell 50 m path length |
|-----------------|-----------------------------------|-------------------------------------|-------------------------------------|
| NO | 0.50 ppm | 0.1 ppm | 60 ppb |
| NO ₂ | 0.125 ppm | 0.5 ppm | 15 ppb |
| NH ₃ | 0.025-ppm | 2.0 ppm | 3 ppb |

- The final mixing length before sampling
- The emission and flow characteristics of the equipment following the engine (HRSG, SCR)
- Sealing of the exhaust system from leakage

Sampling problems Most of the ten gas turbine site tests reviewed in Section 2 had tall stacks and relatively flat profiles. One exception is Site B, Table 2.1, where the stack is short and the concentration profile is non-uniform and varies with time. These conditions have caused the measurements from this site to have high variability.

In this and similar cases, single point sampling, three point sampling, or traversing the stack is not an adequate way of obtaining a representative sample. A more precise method is to use a multi-holed sampling probe or rake that takes a more representative sample by extracting exhaust from across the entire duct.

Representative sampling Proof that the sample is representative of the engine exhaust can be established by a carbon balance that compares CO₂ measured in the exhaust with CO₂ computed from measured fuel flow and fuel analysis. This procedure is described more fully in ASME Exhaust Measurement Standard B133.9 (American Society of Mechanical Engineers, 1994).

In cases where catalyst after treatment is used, there is no assurance that the NO_x exit profile is related to CO₂ from the engine. However, if the multi-holed averaging probe is designed correctly, it will obtain an average sample despite profiles that vary with time and space. In the case of SCR systems, NH₃ concentration and a material balance provide a basis for verifying the average NO_x concentration.

Sample Transport and Conditioning

The exhaust sample must be brought from the probe to the measuring system in such a way that it remains representative. Sample lines, valves, and pumps must be heated to prevent water vapor condensation and be of non-reactive material such as Teflon or stainless steel as defined in Method 20 (USEPA, Title 40).

Water vapor removal Means to eliminate the interference effect of water vapor in most NO_x measuring instruments is required. Conventionally this is done through a condenser as recommended in Method 20. However, since exhaust gas from turbines with DLN systems can contain 40% NO₂, which is soluble in water, additional effort is required to prevent loss of NO₂ during the condensation of water vapor. One test company provides a water vapor trap at the top of the stack just

5.0 SUMMARY AND RECOMMENDATIONS

Summary

1. A review of NO_x measurement data contained in the source test and RATA reports from ten gas turbine plants showed a variety of measurement problems. All installations were permitted to and operated with very low NO_x emissions in the range of 1 to 5 ppm_{dv} at 15% O₂. All used an after treatment catalyst to achieve this low value. The findings are summarized below.
 - a) Most installations have tall exhaust stacks with long mixing lengths that provide for a uniform sample at the sampling plane.
 - b) All testing used state, federal, and/or local agency measurement protocols.
 - c) One installation (Site B) has a short mixing length and showed 37% variation in traverse, a high loss of NO₂ (41%) in the measurement system, and low NO₂ converter efficiency.
 - d) NO_x measurement variability, as evidenced by RATA testing, showed relative accuracy values ranging from 1.3 to 34%.
 - e) Tests of sites with multiple units showed that NO_x variability on units of the same design ranged from 1.5 to 22%.
 - f) No estimate was made of the total absolute variability of NO_x measurement.
 - g) All measurement systems (CEMS and RM) used chemiluminescent analyzers and NO₂ converters. Many of the converters were tested to Method 20 requirements. Inherently CL instruments produce lower readings of NO₂ compared with other methods, such as UV, that do not require NO₂ to NO converters.
 - h) In all tests condensers were used to remove water vapor from sample gas before introducing it into the analyzer. These condensers varied in design and location. The efficiency of these water removal systems was not measured during testing.
 - i) Some tests used CEMS and RM instruments with scale factors over five times greater than the measured value. Similarly, some calibrating gases were used that were several times greater than the measured values.

hydrocarbons, NH₃, and other parameters that affect compliance of fuel flow, fuel analysis, and oxygen measurement.

2. High NO₂ content exhausts are expected to become more prevalent. Perform research into the absorption of low concentration NO₂ in operating gas turbine engine sampling systems to provide guidelines for designing and operating water vapor removal equipment that does not allow washing away nitrogen dioxide.
3. A special protocol for measuring low concentrations of oxides of nitrogen from gas turbine plants is required since the current protocols are inadequate. This new protocol should address the following issues:
 - a) Proof of representative sampling.
 - b) Use of multi-holed sampling probes.
 - c) Removal of water vapor to eliminate washing out NO₂.
 - d) Qualification testing of NO₂ converters at each test to insure higher performance levels. Correcting data for converter efficiency loss.
 - e) Requiring that NO and NO₂ values be measured and recorded.
 - f) Stipulating measurement instrument thresholds, scale factors, and calibrating gas values that are appropriate to the measurement level.

ACKNOWLEDGEMENTS

The organizations listed below were contacted during the research for this review project. The author and the ASME Codes and Standards Committee B133, SC2 express our appreciation for the cooperation and interest shown by these organizations and their staff members in providing information and guidance.

Agencies

California Air Resources Board
New Jersey Department of Environmental Protection
New York State Department of Environmental Conservation
Oregon Department of Environmental Quality
Sacramento Metropolitan Air Pollution Control District
San Diego County Air Pollution Control District
San Joaquin Valley Unified Air Pollution Control District
South Coast Air Quality Management District
Texas Natural Resources Conservation Commission
US Environmental Protection Agency

Corporations

Air Instrument and Measurement Inc.
Air Tech Environmental
Allied Signal Engines
Bovar Western Research
CAE Express
California Analytical Instruments, Inc.
Cubics Corporation
General Electric Company
Monitor Labs, Inc.
Perma Pure Inc.
Praxair Technology, Inc.
Radian International
Siemens Power Corporation
Solar Turbines Incorporated
Testo, Inc.
Thermo Environmental Instruments Inc.
Unisearch Associates Incorporated
Westinghouse Electric Company

Sponsors

US Environmental Protection Agency
International Gas Turbine Institute of ASME