FINAL REPORT

AMMONIA CEMS BACKGROUND REPORT

FOR

USEPA CONTRACT NO. 68D20029

WORK ASSIGNMENT NO. 1-5

DEVELOPMENT OF AMMONIA CEMS PERFORMANCE SPECIFICATIONS

JUNE 14, 1993

ETS CONTRACT NO. 92-655-C

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1.0 INTRODUCTION

1.1 Background: The use of continuous gas analyzers for measuring ammonia (NH_3) air emissions from process and combustion sources is expected to increase significantly as a result of new rules and regulations. The most significant use of these analyzers has been and probably will continue to be in the measurement of ammonia slip from nitrogen oxides (NO_x) pollution reduction systems. Current regulations require reductions in NO_x emissions from combustion sources. As a result, the industry has seen widespread development and use of Selective Catalytic Reduction (SCR) systems. These systems inject gaseous ammonia into the combustion gases which, in the presence of a catalyst, reduces the nitrogen oxides to nitrogen and water. The measurement of ammonia at the exhaust of such systems is needed not only for process control and optimization, but also to ensure that significant quantities of NH_3, which some feel is more of a pollutant then NO_x, are not released to the atmosphere. Included in the list of facilities which typically employ this technology are gas-turbines, municipal solid waste combustors, and fluidized-bed-boiler facilities.

The continuous measurement of NH_3 in process and combustion gases is a relatively new field. In most cases, it has been addressed by reapplying existing technologies which were developed for the measurement of other gases. In other cases, this application is being used to develop and utilize new technologies.

With any continuous gas analyzer system, the quality of the data that it provides must be ensured by requiring the system to satisfy certain minimum specifications. The U.S. Environmental Protection Agency (EPA) has developed several Performance Specifications which are used to evaluate continuous emissions monitoring systems (CEMS's) for many of the commonly monitored pollutants (e.g. NO_x, SO_2). These Performance Specifications are contained in Appendix B of Part 60, Title 40 of the Code of Federal Regulations (40 CFR 60). Currently, no Performance Specifications for NH_3 CEMS's exist. As the requirements for ammonia monitoring increase, however, Performance Specifications specifically for NH_3 CEMS's will need to be developed.

1.2 Purpose of Work: In order to develop Performance Specifications of NH_3 CEMS's, information concerning the availability, accuracy, reliability, and overall performance of existing systems must be determined. A literature review was conducted in order to provide an overview of the current status of ammonia monitoring and to summarize previous industry and agency experience with NH_3 CEMS's.

1.3 Scope of Work: Four major sources of information were utilized in conducting the review:

(1) General industrial database search using the McIlvaine Library Service abstract search;

(2) Specific abstract and paper searches using the VPI&SU Library Search System;

(3) Consultation with commercial vendors and manufacturers of NH_3 CEMS's.

(4) Consultation with state enforcement personnel who have been involved with previous permitting and certification work of NH_3 CEMS's (e.g. VADAPC, CARB);

The information obtained in this review has been summarized in this report. This report will be used to assist in the development of a program for laboratory and field evaluations of NH_3 CEMS's.

2.0 SUMMARY OF WORK PERFORMED

2.1 McIlvaine Abstract Search: The McIlvaine Library Service (MLS) was used to identify key industrial publications concerning ammonia CEMS. The MLS is a compilation of technical abstracts which is updated monthly. These abstracts can be searched according to subject, industry, company, or keywords.

Ten abstracts specifically relating to NH_3 CEMS's were located through the McIlvaine Library Service. The search included all articles and publications compiled by the service from 1986 through 1992, and was performed according to subject (NH_3 CEMS).

Seven of the ten abstracts cited applications concerning the measurement of ammonia slip from processes using selective catalytic reduction to control NO_x emissions. According to the abstracts, this is the most common application currently requiring continuous ammonia monitoring.

Seven different analyzer technologies were cited in the abstracts:

TECHNOLOGY	NUMBER OF REFERENCES
Chemiluminescent	1
UV Absorption	4
NDIR	1
FTIR	1
IMS	1
FPD	1
Photoacoustic	1

Appendix A contains each of the abstracts found through the MLS search.

2.2 VPI&SU Library Literature Search: A literature search was conducted using the computerized library database on CD-ROM at Virginia Polytechnic Institute and State University (VPI&SU). The system allows abstract searches using subject or keywords as identifiers. The search was performed according to subject (NH_3 monitoring) and keywords (Ammonia, SCR, De-NO_x).

Nineteen abstracts (excluding those recovered from the McIlvaine search) specifically relevant to NH_3 monitoring were identified through the search. Thirteen of these abstracts contained information concerning actual manufactured instruments capable of NH_3 monitoring. The complete papers were obtained for these abstracts. Appendix B contains the abstracts or complete papers recovered from the library search.

Eight different analyzer technologies were cited in the papers and abstracts:

TECHNOLOGY	NUMBER OF REFERENCES
Chemiluminescent	1
UV Absorption	5
NDIR	2
Laser	4
Electrochemical	4
FPD	1
Photoacoustic	1
IMS	1

As with the McIlvaine search, the VPI&SU literature search indicated that ammonia slip from SCR processes was the primary application for continuous ammonia monitoring.

2.3 Manufacturers Survey: Fifty-one different analyzer equipment manufacturers and suppliers were contacted in the manufacturers survey. Of these, 23 indicated that they produce an analyzer suitable for continuous gas monitoring of ammonia in process or flue gas streams. Survey questionnaires were sent to these 23 applicable manufacturers. The survey forms requested information concerning analyzer description, calibration requirements, analyzer performance, and maintenance requirements. Additional commercial literature and equipment brochures were also solicited from these manufacturers. Sixteen of the 23 manufacturers responded to the survey forms. Appendix C contains a list of all of the manufacturers contacted, as well as the available survey forms which were completed and returned. All applicable manufacturers' literature and brochures are included as Appendix D.

Nine fundamentally different approaches to ammonia monitoring were identified. Different variations of several of the approaches were also determined. The approaches ranged from re-application of existing and well-established gas analysis techniques (e.g. ultraviolet spectroscopy) to relatively new technologies for environmental measurement applications (e.g ion mobility spectroscopy). The system configurations for each of the systems provided by the manufacturers are summarized in Table 2-1.

The applicational experience of the manufacturers with ammonia monitoring ranged from developmental-only work to widespread installations in Europe and North America. Relatively few of the manufacturers were able or willing to release actual performance test data for their installed analyzers. Because this application is relatively new, much of the available data has only recently been obtained, and is unavailable for contractual reasons. In general, however, the manufacturers indicated that their analyzers could satisfy the design and operational requiremtns of Performance Specification 2 of 40 CFR 60, Appendix B.

Nearly all of the manufacturers agreed that sample conditioning and transport were the primary problems with ammonia monitoring. Specifically, they cited potential problems with negative bias due to condensation or reaction, and fouling of sampling components from the build-up of ammonia salts. Other concerns mentioned were problems with the availability of reliable calibration gas mixtures in the low concentration (less than 10 ppmv) range, and the lack of an established NH_3 reference method for relative accuracy determinations.

2.4 State Agency Survey: Twelve state or district enforcement agencies were contacted by telephone in the agency survey. The agencies were asked about their present or past experience with NH_3 CEMS's in their region. Table 2-2 lists the agencies which were contacted.

The overall experience of the contacted agencies with ammonia CEMS's was relatively low. Seven of the 12 agencies were unaware of any NH_3 analyzers being operated in their region. Of those which did have experience with NH_3 CEMS's, the majority of the known applications were with ammonia injection NO_x control installations. None of the agencies had existing regulations which required installation and operation of an ammonia CEMS. Those facilities which were required to perform ammonia monitoring were required through their operating permits only. The attitude of the agencies with respect to the performance of NH_3 analyzers in their region was variable. Most agencies having experience with NH_3 CEMS's cited past problems with analyzer accuracy and/or data availability.

TABLE 2-1

AMMONIA CEMS CONFIGURATIONS

Manufacturer	Probe Type	Filter Type	Sample Interface	Moisture Removal System	Sample Line Material	Analyzer Measurement Principle	Analyzer Model No.	Measurement Output Basis
Air Instruments and Measurements	In-Situ	None	None	None	None	NDIR	E-6000	wet
Altech	Heated	Heated	N/A	None	N/A	NDIR/GFC	MCS-100	wet
Ametek	Heated	Heated	N/A	None	Teflon	UV/LPDA	PDA-6000	wet
Dasabi	Heated	Heated	Valve Splitter	Permeation Dryer	Dual Teflon	Dual Chemiluminescent	2109	dry
Environmental Technology Group, Inc.	Dilution	N/A	Dilution Valve Box	None	Unheated Teflon	Ion Mobility Spectroscopy	N/A	wet
Graseby STI	Dilution	N/A	Valve Splitter	None	Dual Teflon	Dual Channel Chemiluminescent	N/A	wet
Horiba	Heated	In-Stack	Valve Splitter	Permeation Dryer	Dual Teflon	Dual Channel Chemiluminescent	ENHA C-9000	dry
KVB	Heated	Heated In-Stack	Valve Splitter	Dual Condensers	Dual Heated Teflon	Dual Chemiluminescent	TECO 10AR	dry
Land Combustion (ADA Tech.)	Dilution	N/A	Dilution Valve Box	None	Heated Teflon	UV/LPDA	N/A	wet
OPSIS AB (Sweden)	In-Situ	None	None	None	None	UV Absorption	AR 602Z	wet
Rosemount	Heated	Heated Ceramic	Valve Box	None	Close Coupled Teflon	UV/Etalon	ETL-9200	wet
Servomex	Heated	Heated Ceramic	N/A	None	316 SS	NDIR	M2500	wet
Tess-Com, Inc.	Heated	Heated	Valve Box	None	N/A	Ion-Specific Electrode	745	wet

H. Woesthoff (Calibrated Instruments, Inc.)	Heated	Heated	Valve Box	None	Teflon	Conductimetric	MIKROGAS Model TE	wet

TABLE 2-2

ENFORCEMENT AGENCY SURVEY CONTACTS

AGENCY NAME	CONTACT NAME	TELEPHONE NUMBER
California/Bay Area AQMD	Gary Find	(415) 771-6000
California/Monterey Bay Unified APCD	Larry Bornelli	(408) 647-9411
California/South Coast AQMD	Dr. Margil Wadley	(909) 396-2167
Connecticut Bureau of Air Management	Carlton Dodge	(203) 566-2690
Maine Bureau of Air Quality Control	Scott Mason	(207) 289-2437
Maryland Department of Environment	George Beerli	(410) 631-3215
Massachusetts Division of Air Quality Control	Walter Sullivan	(617) 292-5610
New Hampshire Dept. of Environmental Services	Leigh Morrail	(603) 271-1370
New York Dept. of Environmental Conservation	Bob Kerr	(518) 457-7230
Pennsylvania Dept. of Environmental Resources	Joe Nazarro	(717) 787-9702

Vermont Agency of Natural Resources	Robert Lacalaid	(802) 244-8731
Virginia Department of Air Pollution Control	Harry Augustine	(804) 786-0597

3.0 ANALYZER TECHNOLOGIES

Many different techniques exist for measuring ammonia in gas streams. However, many of the sources which require NH_3 monitoring typically have gas streams which are hot, dirty, and contain such corrosive gases as sulfur dioxide and hydrogen chloride. Since ammonia gas is very reactive, as well as highly water soluble, it is usually necessary to maintain the gas sample at the source conditions throughout the sample extraction system in order to maintain the sample integrity. Consequently, these harsh conditions eliminate many measurement technologies which are more suited to ambient or laboratory-type sampling conditions.

There are five major categories of analyzers which have been demonstrated successfully in this application. These are:

- Chemiluminescent;
- Ultraviolet Absorption Spectroscopy;
- Infrared Absorption Spectroscopy;
- Ion Mobility Spectroscopy;
- Electrochemical.

Other technologies which have high potential for this application but which are less developed include laser technologies, flame photometric detection, colorimetry, and mass spectrometry.

3.1 Chemiluminescence

3.1.1 Principle of Operation: Analyzers which measure ammonia by chemiluminescence actually determine the ammonia concentration of the gas by comparison of the nitric oxide (NO) concentrations in two gas sample streams. One of the gas sample streams undergoes a conversion which changes the nitric oxide concentration in the gas by an amount proportional to the ammonia concentration originally in the gas. The other gas stream remains unaltered. The amount of nitric oxide in each stream is measured by the well founded principle of chemiluminescence. Comparison of the two nitric oxide concentrations is then an indication of the amount of ammonia in the original gas stream.

This type of system consists of a dual sampling probe, an ammonia converter and one or two chemiluminescent nitric oxide analyzers. In the ammonia converter, the gas stream passes through a reduction catalyst. The NH_3 in the stream is reduced by the catalyst and an amount of NO proportional to the amount of NH_3 in the sample is consumed. The equation of this reduction reaction is given by:

$$NO + NH_3 + 1/4O_2 \rightarrow N_2 + 3/2H_2O$$

Both the converted and unconverted gas streams are then passed through an NO_2-to-NO converter which oxidizes any NO_2 in the samples to NO. Finally, the two streams are introduced separately to a chemiluminescence analyzer which determines the amount of NO present in each sample stream. Two converter/ analyzers can be used, or a single converter/analyzer can be used with a switching valve which alternately samples each gas stream.

The unconverted gas sample retains the original volume of NO. The difference in NO content between the two sample streams represents the content of NH_3 in the stack gas as given by the equation:

$$NO_{UNCONVERTED} - NO_{REDUCED} = NH_{3\ STACK\ GAS}$$

Since nitric oxide is relatively stable and insoluble in water, the chemiluminescent method is one of the few ammonia monitoring techniques which can be used as a dry-based analysis system. Only the gas stream leading up to the ammonia converter must be kept above the dew point to prevent ammonia loss. After this point, the moisture in the stream can be removed without affecting the ammonia measurement.

3.1.2 Chemiluminescent Suppliers and Analyzer Specifications

3.1.2.1 KVB
9342 Jeronimo, Suite #101
Irvine, California 92718

Principal of Operation: Chemiluminescent with sample conversion by reduction
Model Number: TECO Model 10 AR Analyzers (2)

Specifications	
Measurement Range	0-25ppm, 0-100ppm or 0-250ppm
Sensitivity	1 ppm
Selectivity	
Relative Accuracy	< 20%
Calibration Drift (Zero)	1.0% full scale per day
Calibration Drift (Span)	2.0% full scale per day
Response Time (T_{90})	30 seconds (dual NO_x analyzer) 2 minutes (single NO_x analyzer)
Calibration Frequency	once per day
Calibration Duration	15 minutes
Calibration Media	calibration gas
Power Requirements	4 KVA
Dimensions (LxWxH)	36" x 68" x 76"
Weight (lbs)	2200

Interferences

Acceptable co-existing component levels in sample gas:
SO_2 0-5000 ppm
NO_X 0-5000 ppm
CO 0-5000 ppm
CO_2 0-20%
O_2 0-25%
H_2O 0-20%
N_2 BALANCE

3.1.2.2 Horiba Instruments Incorporated
17671 Armstrong Avenue
Irvine, California 92714

Principal of Operation: Chemiluminescent with sample conversion by reduction
Model Number: ENHA C-900

Specifications	
Measurement Range	0-20ppm, 0-50ppm or 0-100ppm
Sensitivity	1 ppm
Selectivity	
Relative Accuracy	15-20%
Calibration Drift (Zero)	1.0% full scale per week
Calibration Drift (Span)	2.0% full scale per week
Response Time (T_{90})	3 minutes
Calibration Frequency	once per day
Calibration Duration	10 minutes
Calibration Media	calibration gas
Power Requirements	300 VA
Dimensions (LxWxH)	32" x 36" x 70"
Weight (lbs)	883

Development and Applications

Twelve current installations - one @ Ocean States Power, NJ. CEM Certification @ Saguaro Power Company, Henderson, Nevada by Engineering-Science, Inc., Irwindale, CA for the Clark County Air Pollution Control District, Las Vegas, Nevada on 9-29-92 thru 10-9-92.

Interferences

None due to "cross flow modulation" design-switches every 0.5 seconds

3.1.2.3 Graseby-STI
P.O. Box B
Waldren, AK 72948

Principal of Operation: Chemiluminescent with sample conversion by reduction
Model Number: Monitor Labs Model

Specifications	
Measurement Range	0-100ppm
Sensitivity	
Selectivity	
Relative Accuracy	< 20%
Calibration Drift (Zero)	< 5% full scale per day
Calibration Drift (Span)	< 5% full scale per day
Response Time (T_{90})	3 minutes
Calibration Frequency	once per day
Calibration Duration	10 minutes
Calibration Media	Nitric oxide calibration gas
Power Requirements	115 VAC
Dimensions (LxWxH)	48" x 36" x 12"
Weight (lbs)	100-150 (approx)

Development and Applications

In service at several coal-fired cogeneration facilities.

Interferences

None stated.

3.1.2.4 Dasibi Environmental Corporation
515 West Colorado Street
Glendale, California 91204

Principal of Operation: Chemiluminescent with sample conversion by reduction

Model Number: 2109

Specifications	
Measurement Range	0-1, 0-10, 0-30, 0-40 or 0-50ppm
Sensitivity	
Selectivity	
Relative Accuracy	1.0% precision
Calibration Drift (Zero)	1 ppm per day
Calibration Drift (Span)	1.0% full scale per day 2.0% full scale per week
Response Time (T_{95})	90 seconds
Calibration Frequency	
Calibration Duration	
Calibration Media	
Power Requirements	
Dimensions (LxWxH)	20" x 17" x 7"
Weight (lbs)	48 (analyzer only)

Development and Applications

One "prototype" provided in recent past - not much market. New NH3 analyzer 2108 w/ NH3 (will be listed as 2109) will be shown in the 1/93 Demo Program, but will not be for sale until later.

Interferences

None stated.

3.2 Ultraviolet (UV) Absorption Spectroscopy

3.2.1 Principle of Operation: Several ammonia analyzers employing the principle of UV absorption have been developed. This principle is well established in measuring a variety of different gases in environmental applications. Recent technological innovations have greatly improved on UV measurements and have made possible the measurement of more difficult gases such as ammonia.

The Beer-Lambert law states that the transmittance of light through an absorptive gas is decreased exponentially and directly proportional to the length of the light path and the concentration of the gas. This relationship is represented mathematically as:

$$T = I/I_o = e^{-acl}$$

where:

T	=	transmittance of light through the gas;
I_o	=	intensity of the light entering the gas;
I	=	intensity of the light exiting the gas;
a	=	molar absorptivity;
c	=	gas concentration;
l	=	distance the light beam travels through the gas.

The molar absorptivity, a, depends on the wavelength of the light and on the characteristics of the gas. It determines how much light energy a gas molecule will absorb at a given wavelength. Normally, this quantity can be determined by calibration and remains a constant for a given instrument and gas.

Many pollutant gases of interest (NH_3 included) have strong and distinct absorption characteristics in the ultraviolet (UV) spectrum. Conventional instruments for applying UV absorption spectroscopy in the laboratory have used scanning monochromatic UV detectors for measuring the amount of absorption in the UV energy range. These instruments, however, have typically not been successful in process environments. Since the detectors measure at only a single wavelength, they are very sensitive to misalignments caused by vibration, temperature, or pressure changes. Their accuracy is also highly sensitive to changes in the reference measurement (I_o) which can change from variations in the light source or distortion in the optics.

One of the more common technologies being used to improve on conventional UV spectrometers is the linear photodiode array

(LPDA) detector. The UV/LPDA consists of a linearly-spaced series of semiconductor photodiodes (pixels) fabricated into a semiconductor chip. The current output of each diode is related to the light intensity striking it. These detectors have a high quantum efficiency and are well suited to measuring in the UV region. Additionally, they are very durable, and can tolerate relatively high temperature, humidity, and vibration.

Another type of UV analyzer has been recently developed based around the Etalon technology. An Etalon is a solid state crystal which is constructed so that its optical properties match the periodic absorption line spacing of ammonia in the UV region between 205 nm and 215 nm. Thus, the Etalon is used as a light filter which has the same absorption characteristics as that of pure ammonia. An ammonia analyzer operating on this principle utilizes an electro-optical assembly constructed of the Etalon crystal, light polarizers, a phase modulator, a UV crystal, and a detector.

When UV light passes through the sample gas and the Etalon crystal, the detector responds to the signal intensity of ammonia absorption. However, when a phase shift induced by the phase modulator is created, it moves the Etalon transmission off the NH_3 absorption lines. As a result, the detector senses the signal intensity without ammonia absorption. The difference in these two responses is used to determine the ammonia concentration in the gas.

3.2.2 UV Absorption Suppliers and Analyzer Specifications

3.2.2.1 Ametek
Process and Analytical Instruments Division
455 Corporate Blvd., Pencader Corporate Center
Newark, Delaware 19702

Principal of Operation: UV Absorption
Model Number: PDA-6000

Specifications	
Measurement Range	0-25ppm
Sensitivity	0.25 to 0.5 ppm
Selectivity	
Relative Accuracy	0.5 ppm for coal fired 1.0 ppm for oil fired 0.25 ppm for gas fired
Calibration Drift (Zero)	1.0% full scale per day
Calibration Drift (Span)	2.0% full scale per day
Response Time (T_{90})	30 seconds
Calibration Frequency	once per day
Calibration Duration	15 minutes
Calibration Media	cal gas or optical filters
Power Requirements	2 KVA
Dimensions (LxWxH)	8" x 60" x 72"
Weight (lbs)	1000

Development and Applications

Ametek has been manufacturing UV monitors for 25-30 years. They have been manufacturing UV analyzers for NH3 for five years. Pilot plant - 1989-WINCO (Westinghouse Idaho Nuclear Company) - test results used in 11/89 paper by Robert Saltzman.

Interferences

Acceptable co-existing component levels in sample gas:
- SO_2 0-500 ppm

3.2.2.2 Land Combustion, Inc.
2525-B Pearl Buck Road
Bristol, PA 19007

Principal of Operation: UV Absorption/LPDA
Model Number: N/A

Specifications	
Measurement Range	0-100 ppm
Sensitivity	1 ppm
Selectivity	
Relative Accuracy	7%-8% full scale
Calibration Drift (Zero)	1.1 ppm per day
Calibration Drift (Span)	1.9 ppm per day
Response Time (T_{90})	4 minutes
Calibration Frequency	once per day
Calibration Duration	10 minutes
Calibration Media	calibration gas
Power Requirements	
Dimensions (LxWxH)	
Weight (lbs)	

Development and Applications

Technology developed by ADA Technologies, Inc., 304 Inverness Way South, Suite 110, Englewood, CO 80112 and licensed to Land. Land is scheduled to start manufacturing the analyzer in late summer '93. ADA field tested prototype in September, 1989 at a gas turbine co-generation facility with ammonia injection upstream of a SCR (data presented in 11/89 paper by M.D.Durham for AWMA). Also, testing done 10-23-91 to 1-92 against South Coast Air Quality Management District (SCAQMD) criteria and presented in 10-9-92 and 11-17-92 papers at AWMA conferences.

Interferences

Interference sensitivity data not available.

3.2.2.3 Rosemount Analytical, Inc.
1201 North Main Street
P.O. Box 901
Orrville, Ohio 44667-0901

Principal of Operation: UV Spectroscopy/Etalon
Model Number: ETL-9200

Specifications	
Measurement Range	0-10 ppm (autorange to 0-200ppm)
Sensitivity	0.1 ppm
Selectivity	
Relative Accuracy	0.1 ppm abs. (1.0% full scale)
Calibration Drift (Zero)	
Calibration Drift (Span)	2.0% full scale per week
Response Time (T_{90})	1 minute
Calibration Frequency	1/day with NH_3 sealed cell 1/quarter with cal gas
Calibration Duration	
Calibration Media	sealed ammonia cell or 0-50 ppm cal gas (diluted)
Power Requirements	
Dimensions (LxWxH)	20" x 21" x 30"
Weight (lbs)	

Development and Applications

Southern Cal Edison tested ETL-9200 for 6 months using two types of reference methods. Results should be issued shortly. EPA @ RTP (George Gillis) will evaluate ETL-9200 shortly.

Interferences

High SO2 conc. requires electronic compensation.

3.2.2.4 Air Instruments and Measurements, Inc.
13111 Brooks Drive, Suite D
Baldwin Park, California 91706-1460

Principal of Operation: UV Absorption (in-situ)
Model Number: E-6000

Specifications	
Measurement Range	(depends on stack diameter)
Sensitivity	2.0% full scale
Selectivity	
Relative Accuracy	2.0% full scale
Calibration Drift (Zero)	1.0% full scale/month
Calibration Drift (Span)	1.0% full scale/month
Response Time (T_{90})	0.5 seconds
Calibration Frequency	once per day
Calibration Duration	5-10 minutes for cal gas 30 seconds for optical filters
Calibration Media	cal gas or optical filters
Power Requirements	
Dimensions (LxWxH)	
Weight (lbs)	

Development and Applications

San Diego Gas and Electric, San Diego, CA
utility boiler/denox scrubber
estimated start-up 9/92
(2 installations at this location)

Southern Cal Edison (Mandaiay Plant)
Camarillo, CA
DeNox scrubber and NH3 injection
est. start-up 1/93
(this is a test project using Air Inst.& Meas. analyzers)

Interferences

None reported at wavelength used.

3.2.2.5 OPSIS AB
Furuland, Sweden

Principal of Operation: UV Absorption
Model Number: AR 602 Z

Specifications	
Measurement Range	0 - 1400 ppm
Sensitivity	0.7 ppm
Selectivity	
Relative Accuracy	
Calibration Drift (Zero)	1.5 ppm/month
Calibration Drift (Span)	1.0% full scale/month
Response Time (max)	30 seconds
Calibration Frequency	once per day
Calibration Duration	
Calibration Media	cal gas or optical filters
Power Requirements	
Dimensions (LxWxH)	
Weight (lbs)	

Development and Applications

Monitor performance has been evaluated by the Swedish Institute for Environmental Protection and Power Engineering. Results are included in March 30, 1992 report: "Report on the Performance Test of the Mult-Component Emission Measuring System OPSIS AR 602Z for NH_3 of OPSIS AB, Lund/Sweden, in the Purified Gas of Furnaces". According to this paper, the system met or exceeded all CEMS requirements.

Interferences

The following have been shown to be acceptable co-existing component levels in sample gas:
SO_2 0-435 mg/m^3
NO_X 0-885 mg/m^3
CO 0-1%
CO_2 0-14.9%

H_20 0-20%
N_2 BALANCE

3.3 Infrared (IR) Absorption Spectroscopy

3.3.1 Principle of Operation: Most gases exhibit a tendency to absorb energy at specific wavelengths in the infrared spectrum. The basic principles described for UV absorption also apply to IR absorption. One problem that has limited IR absorption spectroscopy in the past has been the interference effects caused by two gases commonly found in most flue gases - water vapor (H_2O) and carbon dioxide (CO_2). Both of these compounds absorb IR energy at several different wavelengths, and are typically at relatively high concentrations relative to the pollutants being monitored. However, many recent innovations in IR spectroscopy have significantly reduced these interference effects, and have made this a viable and common technique for monitoring many pollutants.

Several different types of IR absorption spectrometers have been developed based primarily on different methods of IR detection. Two of the most common which have utility in the NH_3 application are the Gas Filter Correlation (GFC) technique and the Fourier Transform technique.

Gas Filter Correlation involves the use of a gas-filled cell (filter) containing the pure gas of interest. This cell is placed in front of the IR beam between the gas sample and the IR detector alternately with a cell containing no absorption characteristics. The resulting response from the IR detector represents two energy levels - one missing the energy absorbed by the gas filter cell and one containing all of the energy source. This technique allows highly selective measurement of any gas that presents adjacent harmonic absorption lines in the IR spectrum, including ammonia.

A relatively new but potentially successful technique which is still in the developmental stages uses the Fourier Transform Infrared Analysis (FTIR) technology. FTIR takes advantage of recent breakthroughs in computer processing technology and mathematically analyzes the IR signal for spectral information characteristic solely to the gas of interest. A key advantage of the FTIR approach is the ability to simultaneously monitor several different gases with one instrument. It also eliminates instrument error and provides higher sensitivity than conventional IR analyzers. Unfortunately, it remains in the developmental stages at this time.

3.3.2 IR Spectroscopy Suppliers and Analyzer Specifications

3.3.2.1 Altech Systems Corporation
5345 Commerce Avenue
Moorpark, California 93021

Principal of Operation: IR Spectroscopy/GFC
Model Number: MSC-100

Specifications	
Measurement Range	0-100 ppm (minimum)
Sensitivity	0.5 ppm
Selectivity	
Relative Accuracy	< 20%
Calibration Drift (Zero)	
Calibration Drift (Span)	< 2.5% full scale
Response Time (T_{90})	5 minutes
Calibration Frequency	once per day
Calibration Duration	15 minutes
Calibration Media	calibration gas
Power Requirements	5 KVA
Dimensions (LxWxH)	60" x 36" x 78"
Weight (lbs)	2000

Development and Applications

Primarily MSW Gas Turbine Coal fired utilities

Interferences

None reported.

3.3.2.2 Servomex Company
90 Kerry Place
Norwood, Massachusetts 02062

Principal of Operation: IR Spectroscopy
Model Number: 2500

Specifications	
Measurement Range	0-400 ppm (minimum)
Sensitivity	1 ppm
Selectivity	> 1%
Relative Accuracy	1.0% full scale
Calibration Drift (Zero)	1.0% full scale/week
Calibration Drift (Span)	1.0% full scale/week
Response Time (T_{90})	1 minute
Calibration Frequency	once per month
Calibration Duration	10 minutes
Calibration Media	cal gas or liquid
Power Requirements	30-150 VA
Dimensions (LxWxH)	13.19" x 5.67" x 5.67"
Weight (lbs)	40 (analyzer only)

Development and Applications

Approximately 20 sold to chemical and fertilizer plants.

Interferences

None reported.

3.4 Ion Mobility Spectrometry (IMS)

3.4.1 Principle of Operation: Ion-Mobility Spectrometry (IMS) has existed as a research tool for over 30 years. Recent technological advances have made it applicable to environmental analyzers, including ammonia monitoring.

The IMS method of ammonia detection utilizes a teflon membrane sample cell, a radioactive source to ionize the sample, and a sample detector and microprocessor to evaluate the sample concentration.

The stack gas sample is drawn into the sample cell, diluted and conditioned, and drawn across a teflon membrane. The membrane provides a means in which to increase selectivity to block out particulates, and to limit the effects of humidity and other interferences. Dry, purified instrument air (carrier gas) moves the sample from the inside surface of the membrane to the reaction region where the sample is ionized by a weak plasma from a Nickel-63 radioactive source. A dopant may be utilized in this ionization reaction to enhance the ionization effect and increase specificity.

The sample molecules (ions) are then moved through the cell under the influence of an electric field and are periodically allowed into a drift tube by a electronic shutter. The sample ions separate based on mass, shape, size and charge, and move through the drift tube towards a detector. The ions create a current as they strike the detector which is amplified and measured as a spectrum of voltage verses time. Each ion arrives at the detector at a unique "drift time" based on the mass, shape and size of the ion as well as the drift length, temperature, pressure and strength of the electric field in the sample cell.

A microprocessor is utilized to calculate the ammonia concentration of the sample by comparing spectrum data generated by the sample detector to a look-up table stored in microprocessor memory.

The data combines both instantaneous peak measurements and change-of-height tracking of the spectrum generated. Peak heights are determined for the reaction ion and for the sample at one-second intervals, and the ratio of sample ion peak heights to reaction ion peak height is generated and stored. A difference of current ratio to previous ratio is generated and saved as a table of ratio differences over the past sixty (60) second time period. A running sum of this table is generated, summed with the current ratio, and compared with a reference look-up table to determine the concentration of the sample.

3.4.2 Ion-Mobility Spectroscopy Supplier and Analyzer Specs.

Environmental Technologies Group, Inc.
Industrial Products Division
1400 Taylor Avenue
P.O. Box 9840
Baltimore, Maryland 21284-9840

Principal of Operation: Ion-Mobility Spectroscopy
Model Number: N/A

Specifications	
Measurement Range	0-20 ppm
Sensitivity	1.0 ppm (without dilution probe)
Selectivity	
Relative Accuracy	3% full scale
Calibration Drift (Zero)	< 4.0% full scale per month
Calibration Drift (Span)	< 4.0% full scale per month
Response Time (T_{90})	< 10 minutes
Calibration Frequency	as required
Calibration Duration	20 minutes for zero 20 minutes for span
Calibration Media	calibration gas
Power Requirements	
Dimensions (LxWxH)	19.5" x 31.6" x 19.5" (analyzer)
Weight (lbs)	

Development and Applications

IMS technology tested in 1989 at major oil refinery (referenced in 6/91 Chem. Eng. Progress article).

Interferences

None stated.

3.5 Electrochemical

There are several different methods of ammonia measurement which follow electrochemical techniques. These are traditionally wet-chemistry based approaches. Two different electrochemical techniques are conductimetric and ion specific electrode. The development of both of these techniques for ammonia analysis has been somewhat limited to date.

3.5.1 Conductimetric - Principle of Operation: Analyzers which determine ammonia concentrations conductimetrically measure the change in conductivity of a solution after it reacts with ammonia in the sample gas. The sample gas is first extracted from the flue or process stream through a heated probe, particulate filter, and sample line. In some cases, an alkaline scrubbing solution is circulated through the probe to remove acid gases (e.g. SO_2, NO_2, HCl, HF, etc.) from the gas. Acid gases can be interferents in the analyzer.

At the analyzer, precise amounts of the gas sample and the reacting reagent are mixed together in a mixing chamber. Normally, a dilute solution of sulfuric acid is used as the reagent. Upon mixing, the ammonia reacts with the acid to form ammonium sulfate:

$$2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$$

The conductivity of the resulting solution is measured and compared with that of the pure reagent. The difference in these two measurements are proportional to the amount of ammonia in the original gas stream. The concentration measurement is on a wet volumetric basis (e.g. ppmwv).

3.5.2 Ion Specific Electrode - Principle of Operation: This technique employs an electrical conductivity measurement using an ammonium-ion specific electrode.

The sample gas is first extracted from the flue or process stream through a heated probe, particulate filter, and sample line. At the analyzer, the gas sample enters a scrubber where an aerosol mist of deionized water absorbs the ammonia from the gas. This resulting solution is then mixed with a buffering reagent which adjusts the solution pH, fixes the ionic activity of the solution, and eliminates interfering ions. The sample then flows through a thermoelectrically cooled temperature block and past the surfaces of the ion-specific measuring electrode and a reference electrode. The two electrodes develop a potential difference which corresponds to the amount of ammonium ion in the solution. The resulting measurement is on a wet concentration basis (e.g. ppmwv).

3.5.3 Electrochemical Suppliers and Analyzer Specifications

3.5.3.1 H. Woesthoff, GmbH
U.S. Representative - Calibrated Instruments, Inc.
200 Saw Mill River Road
Hawthorne, NY 10532

Principal of Operation: Conductimetric
Model Number: MIKROGAS Model MS

Specifications	
Measurement Range	0 - 250 ppm (multiple ranges)
Sensitivity	0.05 ppm
Selectivity	
Relative Accuracy	3% full scale
Calibration Drift (Zero)	3.0% full scale per month
Calibration Drift (Span)	3.0% full scale per month
Response Time (T_{90})	100-200 seconds
Calibration Frequency	once per day
Calibration Duration	
Calibration Media	calibration gas
Power Requirements	110V/60Hz or 220V/50Hz
Dimensions (LxWxH)	
Weight (lbs)	

Development and Applications

None stated.

Interferences

Acid gases are an interference and must be removed prior to analysis.

3.5.3.2 Tess-Com, Inc.
Analytical Instruments
P.O. Box 600
Clairton, PA 15025

Principal of Operation: Ion Specific Electrode
Model Number: 745

Specifications	
Measurement Range	0-100 ppb, 0-100 ppm
Sensitivity	0.1 ppb
Selectivity	
Relative Accuracy	5% (low end scale) 3% (high end scale)
Calibration Drift (Zero)	2%
Calibration Drift (Span)	2%
Response Time (T_{90})	2 minutes
Calibration Frequency	once per day
Calibration Duration	40-60 minutes (ppb scale) 15-30 minutes (ppm scale)
Calibration Media	calibration gas
Power Requirements	15-20 amps
Dimensions (LxWxH)	18" x 18" x 28" (analyzer)
Weight (lbs)	30 (analyzer only)

Development and Applications

None stated.

Interferences

No data available.

3.6 Other Potential Technologies

The literature searches and manufacturers survey identified several other methods of ammonia measurement which have been proven in principle but have not been fully developed for environmental measurements. For various technical or economic reasons, some of these approaches may be more suitable for process stream measurement applications or as toxic gas detectors rather than as combustion flue gas analyzers. These technologies include the following:

- **Flame Photometric Detection** - This approach utilizes the reaction between ammonia and a sulfuric acid aerosol to form ammonium sulfate. A highly sensitive flame photometric detector (FPD) is then used to quantify the ammonium sulfate formed.

- **Colorimetric** - This technique has found some use in toxic gas detectors and in single-point process stream monitors. The detector utilizes a chemically treated solid substrate which changes color when exposed to ammonia. The sample gas is contacted with the substrate and the substrate darkens in direct proportion to the amount of ammonia in the gas. This darkening attenuates a light beam passing through the substrate, which then gives an indication of the ammonia concentration in the gas stream.

- **Laser Measurements** - There are several different technologies which employ lasers to photochemically excite the gas stream and cause a characteristic emission spectrum. Special detectors sensitive to the characteristic emissions spectrums are then used to quantify the ammonia concentration. Detectors employed in this technique include IR, UV, and photoacoustic detectors.

- **Mass Spectrometry** - Mass spectrometers are commonly used in measuring process streams. These spectrometers are based on the principle that an ionized molecule develops a characteristic mass spectrum consisting of molecular and fragment ions with various mass-to-charge ratios. The concentration of ammonia is determined by measuring the intensity of the ions specific to ammonia ionization.

4.0 SAMPLING AND CONDITIONING SYSTEMS

Regardless of the type of analyzer used to measure ammonia concentrations in a flue gas, the accuracy and reliability of this measurement will depend very strongly on the success of the sample conditioning system in delivering a representative gas sample to the analyzer. Indeed, the problem of maintaining sample integrity is regarded as one of the most difficult aspects of continuous ammonia monitoring.

The sampling and conditioning system comprises all of the hardware components necessary to extract a gas sample from a duct or stack, deliver this gas to the analyzer, and condition this gas such that the analyzer is not damaged by contact with the gas.

Since ammonia is highly soluble in water, any condensation of flue gas moisture during sample transport or analysis may result in a negative measurement bias. Consequently, many analyzing systems are designed to analyze the gas on a hot basis with the flue gas moisture still in the sample in the vapor state. Many sources such as municipal waste combustors require additional elevation in sample temperature due to formation of ammonia salts (e.g. ammonium chloride, ammonium sulfite) by the reaction of ammonia with HCl or SO_2. Because of the high reactivity of ammonia with most compounds, it takes longer for ammonia to reach equilibrium to the surfaces of an extraction system than it does for most other pollutants. Therefore, the response time for ammonia extraction and measurement systems is generally longer than it is for most other compounds.

The following sampling and conditioning systems are used with various different NH_3 analyzers:

- In-Situ
- Hot/Wet
- Cold/Dry
- Cold/Wet (Dilution)

The systems are defined by the relative temperature (hot or cold) in which the gas is transported and delivered to the analyzer and by the relative condition of the gas with respect to flue gas moisture (wet or dry) retained during its transport.

4.1 In-Situ Systems: In-situ analyzers utilize the simplest type of sampling system. Essentially, the gas is analyzed inside the stack or duct by the analyzer, thus eliminating any need for sample transport and conditioning. The gas is at the same temperature and moisture condition as the actual flue gas. Therefore, the measurement is on a hot and wet basis.

In-situ systems are limited by the fact that the entire analyzer must be capable of withstanding the environment at the sampling location. Generally, they operate on either a UV or IR absorption principle.

4.2 Hot/Wet Systems: A hot/wet system generally consists of a heated extraction probe, a particulate filter (in-situ and/or heated/external), heated sample lines (usually Teflon), and a heated sampling pump. The entire system, including all valves and fittings, must be heat-traced to eliminate any possibility of moisture condensation. In many applications (e.g. MSW combustors) it is necessary to heat the gas higher than normally needed for condensation prevention to ensure that ammonium salts do not form within the system. Temperatures as high as 230^{o}C (450^{o}F) may be required in some cases. It is important when designing the heating system to ensure that every inch of the system is heat-traced, and that the system will maintain the desired temperatures in all anticipated climates. All components exposed to the gas sample must be constructed of a corrosion-resistant material such as 316 stainless steel or Teflon. More corrosive gases may require such materials as Hastelloy C-276 steel or Inconel.

Generally, the closer the analyzer is to the source, and therefore the shorter the length of heated sample line required, the better the overall performance of the system. Ammonia systems typically have long response times, and also tend to have a slightly negative bias. Minimization of the distance from the sample probe to the analyzer can significantly improve on these problems.

4.3 Cold/Dry Systems: A cold/dry system utilizes a chiller-condenser system to cool the sample gas below its dew point and condense the flue gas moisture. Obviously, this system cannot be used for direct measurement systems, since condensation of the water would also remove the NH_3 in the sample. It can be used for indirect measurement systems, however, such as the chemiluminescent systems which convert ammonia to the more stable nitric oxide.

A cold/dry system consists of a heated probe and either a heated particulate filter or in-situ filter. The gas leaving the probe is split into an ammonia stream and a NO_x stream. The NO_x stream is transported through a heated sample line to a chiller-condenser for moisture removal. The ammonia stream is transported through heated sample line first to a catalytic converter which converts the ammonia to NO_x. The gases leaving the converter then pass through a chiller-condenser. Both dry streams may be transported to the analyzers through heated or unheated sample lines.

4.4 Cold/Wet (Dilution) Systems: The dilution system lowers the dewpoint of the gas sample by diluting the sample with a large quantity of dry purified air. Dilution ratios of 10 or 20 parts air to one part sample are typical. Since the moisture is not actually removed from the sample, the analysis is on a wet basis.

A dilution system utilizes a special probe called a dilution probe for sample withdrawal. The probe is equipped with a critical orifice to simplify metering of the dilution air. By diluting the sample, the concentration of water in the gas is lowered enough so that it will not condense at ambient temperatures. Therefore, unheated sample lines can often be used for sample transport. In some climates, however, heated sample lines may still be necessary.

Since dilution of the sample lowers the concentration of ammonia in the gas, the analyzer must be sensitive enough to measure these low concentrations. Fractional-ppm or ppt ranges are required.

5.0 PERFORMANCE DATA

Table 5-1 summarizes available information for relative accuracy, calibration error, and calibration drift for several different types of ammonia analyzers. All of the information in Table 5-1 was supplied by the respective instrument manufacturers.

The availability of reliable performance data for NH_3 CEMS's is relatively poor. The majority of applicable installations use NH_3 CEMS's for monitoring of ammonia slip from SCR systems. Most of these installations are not required to certify the instruments, since they are normally not used for actual NH_3 compliance. Those systems which have undergone certification tests normally have abided by Performance Specification 2 requirements.

Several recent studies have been conducted by independent contractors examining the performance of NH_3 CEMS's. However, not all of this data has been published yet. One recent study of interest which has been published examined the performance of four different NH_3 CEMS's utilizing three different technologies (UV/LPDA, NDIR/GFC, and chemiluminescence). This work was presented at the October 1992 Air and Waste Management Association CEM conference. The document describing this work, entitled "Field Evaluation Study of Ammonia Continuous Emissions Monitoring Systems", is included in Appendix B of this report.

Results of this field evaluation indicate that the relative accuracy values reported in Table 5-1 may be considerably lower than actual in-service relative accuracy values. System maintenance and proper sample conditioning were cited in the paper as two of the most important factors governing monitor performance.

The Electric Power Research Institute (EPRI) is currently conducting a project concerning the development of a CEMS equipment specification and procurement manual. This project will include information on NH_3 CEMS's, and will address available performance data and maintenance information. This report is scheduled to be published by EPRI in October, 1993.

TABLE 5-1

MANUFACTURER-SUPPLIED PERFORMANCE DATA

COMPANY	MODEL NUMBER	MEASUREMENT PRINCIPLE	PERFORMANCE DATA		
			ACCURACY	CALIBRATION ERROR	CALIBRATION DRIFT
KVB	N/A	Chemiluminescent	< 20% relative	1% fs	2% /day
Horiba	ENHA C-900	Chemiluminescent	15-20% relative	1%	2% /week
Dasibi	2109	Chemiluminescent	N/A	N/A	1% /day 2% /week
Ametek	PDA-6000	UV Absorption/ LPDA	1 ppm absolute	0.5%	N/A
Land/ADA	N/A	UV Absorption/ LPDA	7% to 8% relative	1.33%	2%
Altech	MSC-100	UV Absorption	< 20% relative	N/A	2.5%
Air Instruments and Measurements	E-6000	UV Absorption	2% fs	1%	1% /month
Rosemount	ETl-9200	UV/Etalon	1% fs	N/A	2% /week
Servomex	2500	NDIR	1% fs	0.5%	1% /week
Environmental Technology Group	N/A	Ion Mobility Spectroscopy	3% fs	3%	4% /month
H.Woesthoff GmbH (Cal. Inst.)	MS	Electro-conductivity	3% fs	N/A	3% /month
Tess-Com	745	Ion Specific Electrode	5% fs	N/A	2%

6.0 AGENCY SURVEY

The following pages summarize the responses to the agency survey. Twelve agencies were contacted by telephone. Each agency representative was asked seven specific questions concerning the use of NH_3 CEMS's in their region.

AGENCY CONTACT QUESTIONS

AGENCY NAME: California/Bay Area AQMD

PERSON CONTACTED: Gary Find

TELEPHONE #: 415/771-6000

1a. Are you aware of any continuous ammonia analyzers being used to monitor process or combustion emissions in your region or state?

YES

1b. If yes, can you give names and type of application (e.g. MSW incinerator, gas-fired boiler with SCR) of any locations?

United Airlines Gas Turbine with SCR (San Francisco)
Coke Burning Boiler Utility

1c. If yes, are you aware of the general performance of these analyzers?

- Reliability (EXCELLENT/SATISFACTORY/VARIABLE/POOR):

Satisfactory/Variable

- Accuracy and Drift (within Perf.Spec. 2 requirements?):

No knowledge

2a. Are there currently any regulations requiring installation and operation of ammonia CEMS in your state?

No current regulations - required through individual permits only.

2b. If yes, what are they (e.g. what industries are affected, specific regulatory requirements)?

N/A

3a. Does your agency have plans to adopt new or additional regulations concerning ammonia CEMS in the near future?

No knowledge

3b. If yes, what type of scope and on what time scale.

N/A

AGENCY CONTACT QUESTIONS

AGENCY NAME: California/Monterey Bay

PERSON CONTACTED: Larry Bornelli

TELEPHONE #: 408/647-9411

1a. Are you aware of any continuous ammonia analyzers being used to monitor process or combustion emissions in your region or state?

No. Use wet methods (EPA 350.3 and Bay Area ST-1B) for compliance determinations.

1b. If yes, can you give names and type of application (e.g. MSW incinerator, gas-fired boiler with SCR) of any locations?

N/A (compliance tests performed on cogeneration and cement plants)

1c. If yes, are you aware of the general performance of these analyzers?

- Reliability (EXCELLENT/SATISFACTORY/VARIABLE/POOR):

N/A

- Accuracy and Drift (within Perf.Spec. 2 requirements?):

N/A

2a. Are there currently any regulations requiring installation and operation of ammonia CEMS in your state?

No.

2b. If yes, what are they (e.g. what industries are affected, specific regulatory requirements)?

N/A

3a. Does your agency have plans to adopt new or additional regulations concerning ammonia CEMS in the near future?

No

3b. If yes, what type of scope and on what time scale.

N/A

AGENCY CONTACT QUESTIONS

AGENCY NAME: California/South Coast AQMD

PERSON CONTACTED: Dr. Margil Wadley

TELEPHONE #: 909/396-2167

1a. Are you aware of any continuous ammonia analyzers being used to monitor process or combustion emissions in your region or state?

No

1b. If yes, can you give names and type of application (e.g. MSW incinerator, gas-fired boiler with SCR) of any locations?

N/A

1c. If yes, are you aware of the general performance of these analyzers?

- Reliability (EXCELLENT/SATISFACTORY/VARIABLE/POOR):

N/A

- Accuracy and Drift (within Perf.Spec. 2 requirements?):

N/A

2a. Are there currently any regulations requiring installation and operation of ammonia CEMS in your state?

No

2b. If yes, what are they (e.g. what industries are affected, specific regulatory requirements)?

N/A

3a. Does your agency have plans to adopt new or additional regulations concerning ammonia CEMS in the near future?

No knowledge.

3b. If yes, what type of scope and on what time scale.

N/A

AGENCY CONTACT QUESTIONS

AGENCY NAME: Connecticut Bureau of Air Management

PERSON CONTACTED: Carlton Dodge

TELEPHONE #: 203/566-2690

1a. Are you aware of any continuous ammonia analyzers being used to monitor process or combustion emissions in your region or state?

No

1b. If yes, can you give names and type of application (e.g. MSW incinerator, gas-fired boiler with SCR) of any locations?

N/A

1c. If yes, are you aware of the general performance of these analyzers?

- Reliability (EXCELLENT/SATISFACTORY/VARIABLE/POOR):

N/A

- Accuracy and Drift (within Perf.Spec. 2 requirements?):

N/A

2a. Are there currently any regulations requiring installation and operation of ammonia CEMS in your state?

No

2b. If yes, what are they (e.g. what industries are affected, specific regulatory requirements)?

N/A

3a. Does your agency have plans to adopt new or additional regulations concerning ammonia CEMS in the near future?

No

3b. If yes, what type of scope and on what time scale.

Waiting on Federal EPA guidelines.

AGENCY CONTACT QUESTIONS

AGENCY NAME: Maine Bureau of Air Quality Control

PERSON CONTACTED: Scott Mason

TELEPHONE #: 207/289-2437

1a. Are you aware of any continuous ammonia analyzers being used to monitor process or combustion emissions in your region or state?

No

1b. If yes, can you give names and type of application (e.g. MSW incinerator, gas-fired boiler with SCR) of any locations?

N/A

1c. If yes, are you aware of the general performance of these analyzers?

- Reliability (EXCELLENT/SATISFACTORY/VARIABLE/POOR):

N/A

- Accuracy and Drift (within Perf.Spec. 2 requirements?):

N/A

2a. Are there currently any regulations requiring installation and operation of ammonia CEMS in your state?

No

2b. If yes, what are they (e.g. what industries are affected, specific regulatory requirements)?

N/A

3a. Does your agency have plans to adopt new or additional regulations concerning ammonia CEMS in the near future?

No knowledge.

3b. If yes, what type of scope and on what time scale.

N/A

AGENCY CONTACT QUESTIONS

AGENCY NAME: Maryland Department of the Environment

PERSON CONTACTED: George Beerli

TELEPHONE #: 410/631-3215

1a. Are you aware of any continuous ammonia analyzers being used to monitor process or combustion emissions in your region or state?

No

1b. If yes, can you give names and type of application (e.g. MSW incinerator, gas-fired boiler with SCR) of any locations?

N/A

1c. If yes, are you aware of the general performance of these analyzers?

- Reliability (EXCELLENT/SATISFACTORY/VARIABLE/POOR):

N/A

- Accuracy and Drift (within Perf.Spec. 2 requirements?):

N/A

2a. Are there currently any regulations requiring installation and operation of ammonia CEMS in your state?

No

2b. If yes, what are they (e.g. what industries are affected, specific regulatory requirements)?

N/A

3a. Does your agency have plans to adopt new or additional regulations concerning ammonia CEMS in the near future?

No knowledge.

3b. If yes, what type of scope and on what time scale.

N/A

AGENCY CONTACT QUESTIONS

AGENCY NAME: Massachusetts Division of Air Quality Control

PERSON CONTACTED: Walter Sullivan

TELEPHONE #: 617/292-5610

1a. Are you aware of any continuous ammonia analyzers being used to monitor process or combustion emissions in your region or state?

YES

1b. If yes, can you give names and type of application (e.g. MSW incinerator, gas-fired boiler with SCR) of any locations?

Several coal burning and gas turbine power generators with ammonia injection. Also one woodburning unit.

1c. If yes, are you aware of the general performance of these analyzers?

- Reliability (EXCELLENT/SATISFACTORY/VARIABLE/POOR):

No knowledge.

- Accuracy and Drift (within Perf.Spec. 2 requirements?):

No knowledge.

2a. Are there currently any regulations requiring installation and operation of ammonia CEMS in your state?

No - Issue standards on a permit basis. Generally require B.A.T. requirement of < 10 ppm.

2b. If yes, what are they (e.g. what industries are affected, specific regulatory requirements)?

N/A

3a. Does your agency have plans to adopt new or additional regulations concerning ammonia CEMS in the near future?

No

3b. If yes, what type of scope and on what time scale.

N/A

AGENCY CONTACT QUESTIONS

AGENCY NAME: New Hampshire Department of Environmental Services

PERSON CONTACTED: Leigh Morrail

TELEPHONE #: 603/271-1370

1a. Are you aware of any continuous ammonia analyzers being used to monitor process or combustion emissions in your region or state?

No

1b. If yes, can you give names and type of application (e.g. MSW incinerator, gas-fired boiler with SCR) of any locations?

N/A

1c. If yes, are you aware of the general performance of these analyzers?

- Reliability (EXCELLENT/SATISFACTORY/VARIABLE/POOR):

N/A

- Accuracy and Drift (within Perf.Spec. 2 requirements?):

N/A

2a. Are there currently any regulations requiring installation and operation of ammonia CEMS in your state?

No

2b. If yes, what are they (e.g. what industries are affected, specific regulatory requirements)?

N/A

3a. Does your agency have plans to adopt new or additional regulations concerning ammonia CEMS in the near future?

Not at this time.

3b. If yes, what type of scope and on what time scale.

N/A

AGENCY CONTACT QUESTIONS

AGENCY NAME: New York Department of Environmental Conservation

PERSON CONTACTED: Bob Kerr

TELEPHONE #: 518/457-7230

1a. Are you aware of any continuous ammonia analyzers being used to monitor process or combustion emissions in your region or state?

YES

1b. If yes, can you give names and type of application (e.g. MSW incinerator, gas-fired boiler with SCR) of any locations?

MSW incinerator with SCR.

1c. If yes, are you aware of the general performance of these analyzers?

- Reliability (EXCELLENT/SATISFACTORY/VARIABLE/POOR):

Uses a modified NO_x system. Believes it works OK.

- Accuracy and Drift (within Perf.Spec. 2 requirements?):

No knowledge.

2a. Are there currently any regulations requiring installation and operation of ammonia CEMS in your state?

No

2b. If yes, what are they (e.g. what industries are affected, specific regulatory requirements)?

N/A

3a. Does your agency have plans to adopt new or additional regulations concerning ammonia CEMS in the near future?

No

3b. If yes, what type of scope and on what time scale.

N/A

AGENCY CONTACT QUESTIONS

AGENCY NAME: Pennsylvania Department of Environmental Resources

PERSON CONTACTED: Joe Nazarro

TELEPHONE #: 717/787-9702

1a. Are you aware of any continuous ammonia analyzers being used to monitor process or combustion emissions in your region or state?

No

1b. If yes, can you give names and type of application (e.g. MSW incinerator, gas-fired boiler with SCR) of any locations?

N/A

1c. If yes, are you aware of the general performance of these analyzers?

- Reliability (EXCELLENT/SATISFACTORY/VARIABLE/POOR):

N/A

- Accuracy and Drift (within Perf.Spec. 2 requirements?):

N/A

2a. Are there currently any regulations requiring installation and operation of ammonia CEMS in your state?

No

2b. If yes, what are they (e.g. what industries are affected, specific regulatory requirements)?

N/A

3a. Does your agency have plans to adopt new or additional regulations concerning ammonia CEMS in the near future?

No

3b. If yes, what type of scope and on what time scale.

N/A

AGENCY CONTACT QUESTIONS

AGENCY NAME: Vermont Agency of Natural Resources

PERSON CONTACTED: Robert Lacalaid

TELEPHONE #: 802/244-8731

1a. Are you aware of any continuous ammonia analyzers being used to monitor process or combustion emissions in your region or state?

YES

1b. If yes, can you give names and type of application (e.g. MSW incinerator, gas-fired boiler with SCR) of any locations?

Wood-fired power plant (300 MMBtu, 20 MW)
Uses a Monitor Labs Model 8841 NO_x analyzer with NH_3 to NO converter.

1c. If yes, are you aware of the general performance of these analyzers?

- Reliability (EXCELLENT/SATISFACTORY/VARIABLE/POOR):

New unit - not enough experience yet

- Accuracy and Drift (within Perf.Spec. 2 requirements?):

Initial performance tests exceeded RA limit of 20% as recommended in PS2 - actual value obtained near 90-100% relative accuracy. Changed wording in permit from "must meet 20% RA" to "should meet 20% RA".

2a. Are there currently any regulations requiring installation and operation of ammonia CEMS in your state?

No - by permit only.

2b. If yes, what are they (e.g. what industries are affected, specific regulatory requirements)?

N/A

3a. Does your agency have plans to adopt new or additional regulations concerning ammonia CEMS in the near future?

No

3b. If yes, what type of scope and on what time scale.
N/A

AGENCY CONTACT QUESTIONS

AGENCY NAME: Virginia Department of Air Pollution Control

PERSON CONTACTED: Harry Augustine

TELEPHONE #: 804/786-0597

1a. Are you aware of any continuous ammonia analyzers being used to monitor process or combustion emissions in your region or state?
YES

1b. If yes, can you give names and type of application (e.g. MSW incinerator, gas-fired boiler with SCR) of any locations?

Currently know of 19 analyzers:

Location	# Monitors	Source Description
Hadson 13	**2**	**Coal Cogen. Boiler w/SCR**
Hadson 14	**2**	**Coal Cogen. Boiler w/SCR**
Cogentrix Richmond	**8**	**Coal Cogen. Boiler w/SCR**
Cogentrix Dinwddle	**4 (prop.)**	**Coal Cogen. Boiler w/SCR**
Multitrade-Hurt	**3 (prop.)**	**Wood Cogen. Boiler w/SCR**

1c. If yes, are you aware of the general performance of these analyzers?

- Reliability (EXCELLENT/SATISFACTORY/VARIABLE/POOR):
Variable - Hadson monitors poor performance. Cogentrix Richmond very good.

- Accuracy and Drift (within Perf.Spec. 2 requirements?):
N/A

2a. Are there currently any regulations requiring installation and operation of ammonia CEMS in your state?

No - by permit only for cogeneration units. These sources have been asked to get monitors working and demonstrate to the state. More detailed requirements have not been set.

2b. If yes, what are they (e.g. what industries are affected, specific regulatory requirements)?
N/A

3a. Does your agency have plans to adopt new or additional regulations concerning ammonia CEMS in the near future?

Possibly

3b. If yes, what type of scope and on what time scale.
Waiting on Federal EPA

APPENDIX A

ABSTRACTS FROM McILVAINE LIBRARY SERVICE SEARCH

LIST OF ABSTRACTS

"The Development of a Continuous Real-Time In-Situ Ammonia Monitor"
Al-Sunaid, A.A.; Huntzicker, James J.
Proceedings of the Seventh World Clean Air Congress, Volume 5, Sydney Australia, 8/86, 3 pages

"Development of an Ammonia Slip Monitor for Process Control of NH_3 based NO_x Control Technologies"
Durham, Michael D.; Ebner, Timothy G.; Burkhardt, Mark R.; Sagan, Frand J.
ADA Technologies, Englewood, CA
(presented at the) Proceedings of the A&WMA Speciality Conference, 11/89

"Slip into NO_x Control with Ammonia Emissions Monitor"
Cermenaro, John; Kline, Mike
KVB, Inc., Irvine, CA
ASME/IEEE Conference, Dallas, TX, 10/22-10/26/89
ASME paper #EC13 (8 pages)

"Comparison of Measurement of Atmospheric Ammonia by Filter Packs, Transition-Flow Reactors, Simple and Annular Denuders and Fourier Transform Infrared Spectroscopy"
Wiebe, H.A.; Anlauf, K.G.; Tuazon, E.C.; Winer, A.M.; Biermann, H.W.
Atmospheric Environment, 22, 1517, 1988)

"Development of Low Level NH_3 Measuring Method"
Nakabayashi, Yasuyuki; Abe, Rikiya; Izumi, Takusuke
presented at EPA/EPRI 1987 Joint Symposium on Stationary Combustion NO_x Control, New Orleans, LA, 3/87, 27 pages

"Remote Sensing for Emission Monitoring: Photoacoustic Detection of NH_3 in Power Plant Emission"
Storgaard, M.A.; Rasmussen, O.S.
FLS airlog a/s, Copenhagen, Denmark

"Evaluation of the ADA Continuous Ammonia Slip Monitor"
Durham, Burkhardt, Sagan, Anderson (? can't read all names)
ADA Technologies, Englewood, CA
18 pages

"Field Testing of the ADA Continuous Ammonia Slip Monitor"
Durham, Michael D.; Schlager, Richard J.; Anderson, Gary L.
ADA Technologies, Englewood, CA
16 pages

"Ion Mobility Spectrometry: A New Method of Monitoring for Hydrogen Fluoride, Ammonia and Other Industrial Gases"
Bacon, Allan T.
Environmental Technologies Group, Baltimore, MD
13 pages

"Second Generation-Analyzer Cross Flow Modulation Techniques-Precision, Sensitivity, Continuous Measurements"
Vogelsang, Robert F.
Horiba Instruments, Inc., Irvine, CA
Instrument Society of America, v42, part 1, 1987, 9 pages

APPENDIX B

ABSTRACTS AND PAPERS FROM VPI&SU CD-ROM LITERATURE SEARCH

LIST OF PAPERS

"Field Evaluation Study of Ammonia Continuous Emissions Monitoring Systems"
Haythornthwaite, Shelia M. & Finken, Robert A.
Carnot
Tustin, CA
(presented at the) Proceedings of the A&WMA International Conference on Continuous Emissions Monitoring, Chicago, IL, 10/92
(test date 3/91 thru 7/91)

"A Process UV/VIS Diode Array Analyzer for Source Monitoring"
Saltzman, Robert S.
E.I. du Pont Nemoure & Co., Newark, DE
(presented at the) Proceedings of the A&WMA Speciality Conference, 11/89

"Development of an Ammonia Slip Monitor for Process Control of NH_3 based NO_x Control Technologies"
Durham, Michael D.; Ebner, Timothy G.; Burkhardt, Mark R.; Sagan, Frand J.
ADA Technologies, Englewood, CA
(presented at the) Proceedings of the A&WMA Speciality Conference, 11/89

"Performance of a Continuous Analyzer for Monitoring Nitric Oxide and Ammonia Slip from Advanced NO_x Control Systems"
Schlager, Richard J.; Durham, Michael D.; Anderson, Gary L.
ADA Technologies, Englewood, CA
(presented at the) Proceedings of the A&WMA International Conference on Continuous Emissions Monitoring, Chicago, IL, 10/92

"Evaluation of Power Plant NO_x Control Systems Using a Continuous Nitric Oxide and Ammonia Slip Monitor"
Schlager, Richard J.; Durham, Michael D.
ADA Technologies, Englewood, CA
(presented at the) Proceedings of the POWER-GEN Conference, Orlando, FL, 11/92

"Computerized Control and Signal Processing for Infrared Analyzers"
Dillehay, David L.
Altech Systems Corporation
Moorpark, California
(presented at the) Proceedings of the A&WMA Speciality Conference, 11/89

"Ion Mobility Spectroscopy Applications for Continuous Emission Monitoring"
Bacon, Allan T.; Reategui, Julio
ETG, Inc.
Baltimore, Maryland

"Move Towards Process Control for CEM Natural But Slow"
Makansi, Jason
Power, 8/89, pages 9-16

"Continuous Emission Monitoring by Infrared Photoacoustic Spectroscopy"
Jalenak, Wayne
Bruel & Kjaer Instruments, Inc., Marlborough, MA
(presented at the) Proceedings of the A&WMA Specialty Conference, 11/89

"Diode Laser Measurements of Trace Concentrations of Ammonia in an Entrained-Flow Coal Reactor"
Silver, Joel A.; Bomse, David S.; Stanton, Alan C.
Southwest Sciences, Inc.
Sante Fe, NM
Applied Optics, v30, n12, 4/20/91, pages 1505-1511

"Ammonia-Gas-Selective Optical Sensors Based on Neutral Ionophores"
Ozawa, Satoshi; Hauser, Peter C.; Seiler, Kurt; Tan, Susie S.; Morf, Werner E.; Simon, Wilhelm
Analytical Chemistry, v63 n6, 3/15/91, pages 640-644

"A Combined $Ca(OH)_2/NH_3$ Flue Gas Desulfurization Process for High Sulfur Coal; Results of a Pilot Plant Study"
Pakrasi, Arijit; Davis, Wayne T.; Reed, Gregory D.; Keener, Timothy C.
Journal of Air and Waste Management, v40 n7, 7/90, pages 987-992

"Response of the Flame-Photometric Detector to Ammonia"
Fowler, William K.
Analytical Chemistry, v63 n23, 12/1/91, pages 2798-2800

"Excimer Laser Photolysis Study of NH_3 in the Presence of NO at 193 nm"
Ikeda, Tetsuya; Danno, Minoru; Makihara, Hiroshi
Advanced Technology Research Center, Mitsubishi Heavy Industries, Ltd., Yokohama, Japan
Journal of Applied Physics, v67 n10, 5/15/90, pages 6527-6528

LIST OF ABSTRACTS

"Continuous NH_3 Analyzer Tested in California"
ANON
Gas Industries (magazine), Park Ridge, IL
v34 n5 3/90 pages 20-22

"Applications of the ZrO_2 Sensor in Determination of Pollutant Gases"
Haefele, E.; Kaltenmaier, K.; Schoenauer, U.
(German proceedings of) Euro-Sensors IV
Sensors and Actuators, B: Chemical
v B4 n 3-4, 6/91, pages 525-527

"Measurement of NH_3 with the Solidox NH_3 System"
Haefele, E.; Kaltenmaier, K.; Schoenauer, U.
(German proceedings of) Euro-Sensoes IV
Sensors and Actuators, B: Chemical
v B4 n 3-4, 6/91, pages 529-531

"Selective NH_3 Sensor"
Moseley, P.T.; Williams, D.E.
Sensors and Actuators, B: Chemical
v B1 n 1-6, 1991, pages 113-115

"In-situ Measurement of NH_3 with a $^{13}CO_2$ Wavelength Laser System"
Meienburg, W.; Neckel, H.; Wolfrum, J.
Journal of Applied Physics
v B51, ISS 2, pages 94-98, 8/90

"Ammonia in Power Plant Emission"
Hammerich, Mads; Hanningsen, Jes; Olafsson, Ari
presented at conference in Hague, Neth; 3/14-3/15/90
International Society for Optical Engineering, Bellingham,WA
v1269 pages 21-27

"Slip into NO_x Control with Ammonia Emissions Monitor"
Cermenaro, John; Kline, Mike
KVB, Inc., Irvine, CA
ASME/IEEE Conference, Dallas, TX, 10/22-10/26/89
ASME paper #EC13 (8 pages)

APPENDIX C

MANUFACTURER SURVEY INFORMATION

MANUFACTURERS CONTACTED FOR NH_3 ANALYZER INFORMATION

(*) Indicates firm was identified as a NH_3 CEMS manufacturer or supplier and participated in survey.

(**x**) Indicates firm was identified as a NH_3 CEMS manufacturer or supplier but did not respond to survey.

***** ADA Technologies, Inc.
304 Inverness Way South, Suite 110
Englewood, CO 80112
303/792-5615
contacts: Ms. Jeanne Kurtz and Mr. Richard Schlager

***** Air Instruments and Measurements, Inc.
13111 Brooks Drive, Suite D
Baldwin Park, California 91706-2200
800/969-4246
contact: Mr. Owen Brooks

***** Altech Systems Corporation
5345 Commerce Avenue
Moorpark, California 93021
805/529-9955
contact: Ms. Cheryl Calon

***** Ametek
Process and Analytical Instruments Division
455 Corporate Blvd., Pencader Corporate Center
Newark, Delaware 19702
contact: Mr. Brian Reed

x Anarad Inc.
534 East Ortega
Santa Barbara, CA 93103
805/963-6583
contact: Mr. Jeff Davis

***** Calibrated Instruments, Inc.
200 Saw Mill Road
Hawthorne, New York 10532

914/741-5700
(repersentative for H.Woesthoff, GmbH)

ANALYZER MANUFACTURERS CONTACTED - continued

CDS Analytical, Inc.
Box 277
Oxford, PA 19363-0277
215/932-3636

CEA Instruments
16 Chestnut Street
Emerson, NJ 07630
201/967-5660
contact: Mr. Steve Adelman

Clean Air Engineering
500 West Wood Street
Palatine, Illinois 60067
800/627-0033

Columbia Scientific Industries Corporation
Box 203190
Austin, TX 78720-3190
800/531-5003

Control Instruments Corporation
25 Law Drive
Fairfield, New Jersey 07004
201/575-9114

Cosmos Gas Detection Systems
1140 Northwest 46th Street
Box 70498
Seattle, Washington 98107
206/789-5410

* Dasibi Environmental Corporation
515 West Colorado Street
Glendale, California 91204
818/247-7601
contact: Mr. Keith Gosselin

Datatest, Inc.
6850 Hibbs Lane

Levittown, PA 19057
215/943-0668
contact: Mr. Julian Saltz

Delphain Corporation
220 Pagasus Avenue
Northvale, NJ 07647
800/288-3647

Dynamation Inc.
3784 Plaza Drive
Ann Arbor, MI 48108
313/769-0573

Environmental Systems Corporation
200 Tech Center Drive
Knoxville, TN 37912-7930
615/688-7900

* Environmental Technologies Group, Inc.
Industrial Products Division
1400 Taylor Avenue
P.O. Box 9840
Baltimore, Maryland 21284-9840
410/321-5200
contact: Mr. Allen Bacon

x Enviroplan
3 Becker Farm Road
Roseland, NJ 07068
201/994-2300
contact: Mr. Robert Feingold

* Extrel Corporation
Extrel Mass Spectromety
575 Epsilon Drive
Pittsburgh, PA 15238-2838
412/963-7530
contact: Mr. Tony Slapikas

Fischer and Porter Company
Box 3355
Warminster, PA 18974
800/829-6001

ANALYZER MANUFACTURERS CONTACTED - continued

ANALYZER MANUFACTURERS CONTACTED - continued

Foxboro Company
Bristol Park
Foxboro, MA 02035
800/521-0451

Gow Mac Instruments Company
Keary Street, Building 26E
Bridgewater, New Jersey 08807
908/560-0600

Graseby-Nutech-RTL
4022 Stirrup Creek Drive
Durham, North Carolina 27703
800/637-6312

* Graseby-STI
PO Box B
Waldren, Arkansas 72948
501/637-2687

* Horiba Instruments Incorporated
17671 Armstrong Avenue
Irvine, California 92714
800/446-7422
contact: Mr. Robert Gollett

Infrared Analysis, Inc.
1424 North Central Park Avenue
Anaheim, CA 92802-1418
714/535-7667
contact: Mr. Steve Hanst

Kurz Instruments, Inc.
2411 Garden Road
Monterey, California 93940
800/424-7356

* KVB
9342 Jeronimo, Suite #101
Irvine, California 92718

ANALYZER MANUFACTURERS CONTACTED - continued

800/722-3047
contact: Joanne

Lamotte Company
Box 329
Chestertown, Maryland 21620
800/344-3100

* Land Combustion, Inc.
2525-B Pearl Buck Road
Bristol, PA 19007
800/922-9679
contact: Dr. Ken West

x Lear Siegler Measurement Controls
74 Inverness Drive, East
Englewood CO 80112
800/422-1499
contact: Mr. Clark Doran

x McNeill International
37914 Euclid Avenue
Willoughby, Ohio 44094
800/626-3455
contact: Damir

* MDA Scientific, Inc.
405 Barclay Blvd.
Lincolnshire, Illinos 60069
800/323-2000
contacts: Mr. Les Wolf, Ms. Karla Reisch and Mr. Ron Walczak

x Measurement Technologies
3485 Sacramento Drive, Suite F
San Luis Obispo, CA 93401
805/549-0595
contact: Mr. Will Whalen

Metrosonics, Inc.
Box 23075
Rochester, New York 14692
716/334-7300

ANALYZER MANUFACTURERS CONTACTED - continued

ANALYZER MANUFACTURERS CONTACTED - continued

x Midac Corporation
1599 Superior Avenue, Suite B-3926
Costa Mesa, CA 92627-3625
714/645-4096

Nicolet Instrument Corporation
Analytical Division
5225-1 Verona Road
Madison, WI 53711
800/356-8088

x Phoenix Instruments, Inc.
65 North Plains Industrial Road
Wallington, CT 06492
203/269-4331
contact: Mr. James Jordan

Radiometer America, Inc.
811 Sharon Drive
Cleveland, Ohio 44145
800/736-0600

* Rosemount Analytical, Inc.
1201 North Main Street
P.O. Box 901
Orrville, Ohio 44667-0901
216/684-4418
contact: Mr. Gary Lang

Sensidyne
16333 Bay Vista Drive
Clearwater, FL 34620
800/451-9444
contact: Cavalier (Sensidyne representative)
804/271-5226
Mr. Mike Pausic

* Seromex Company
90 Kerry Place
Norwood, Massachusetts 02062
800/862-0200

contact: Mr. Kevin Geary

Siemens Industrial Automation, Inc.
100 Technology Drive
Alpharetta, Georgia 30202
404/740-3933
contact: Mr. Harold Henry

Sierra Instruments, Inc.
5 Harris Court, Building L
Monterey, CA 93940-5700
800/866-0200
contact: Mr. Kieth Grant

Sierra Monitor Corporation
1991 Tarob Court
Milpitas, CA 95035
408/262-6611

Teledyne Analytical Instruments
16830 Chestnut Street
City of Industry, CA 91749
818/961-9221

* Tess-Com, Inc.
Analytical Instruments
P.O. Box 600
Clairton, PA 15025
412/233-5782
contact: Mr. Lou Colonna

Thermo Environmental Instruments, Inc.
8 West Forge Parkway
Franklin, MA 02038
508/520-0430

Universal Sensors and Devices, Inc.
9205 Alabama Avenue, Unit C
Chatsworth, CA 91311
800/899-7121

Viking Instruments Corporation

12007 Sunrise Valley Drive
Reston, Virginia 22091
703/758-9339

APPENDIX D

MANUFACTURERS' LITERATURE

The following manufacturers supplied information for this section (in order as they appear):

KVB
Horiba
Dasibi Environmental
Ametek
Rosemount
Air Instruments and Measurements, Inc.
Servomex
Environmental Technologies Group, Inc.
Calibrated Instruments, Inc.
Tess-Com, Inc.
Extrel
MDA Scientific