APPENDIX A

STANDARD MEASUREMENT PROCEDURES

Method:	**Continuous Emission Monitoring (CEM) System**
Reference:	SCAQMD 100.1, CARB 100, EPA 7E, 3A, 10, 6C
Principle:	Sample gas is drawn from the stack or duct through a sample conditioning system and is sent through a sample manifold to a series of gas analyzers for measurement of the concentrations of O_2, CO_2, NO_X, CO and SO_2.
Analyzers:	See the description pages for the individual analyzers; those pages follow this description of the sampling system.

The CEM sampling system includes three basic subsystems. These are (1) the sample interface, which includes the probe, connecting tubing, and the sample conditioning and transport system, (2) the gas analyzers and their calibration gases, and (3) the data acquisition system. This section presents a description of the sample interface, the calibration gases, and the data acquisition system. Descriptions of the individual analyzers are provided in following sections.

The sample interface includes components to extract a representative sample from the stack or duct, transport the sample to the analyzers, and remove moisture and particulate material from the sample. The system must also preserve the measured gases and deliver the sample for analysis without significant interference. A diagram of the system is provided in Figure 1. The sample interface system includes the following components.

- Probe – the probe is usually heated to prevent condensation of moisture. In some cases the probe may be unheated, depending on the dynamics of the stack environment (i.e. the temperature is high enough to prevent condensation without heating) and the gases to be measured for the testing program. The probe liner or tubing may be constructed of glass, Teflon, titanium or stainless steel, depending on the stack temperature, the matrix of stack gases and the gases to be measured. The probe length is chosen to provide access to the stack traverse points or sampling point required by the testing methods. When used at sources with significant particulate concentrations, the probe may include a filter either at the tip (in-stack) or in a heated box (out-of-stack).
- Heated line – a short section of flexible, heated Teflon tubing is used to connect the probe to the moisture removal system. The line is less than 6 feet in length except in cases where longer tubing is needed to allow traversing of the stack with a long probe (i.e. for stratification tests).
- Moisture conditioning system – the role of the moisture removal system is to cool the sample gas and condense the moisture for removal, yet to minimize the contact between the sample gas and the condensate. Contact between the sample and condensate may cause scrubbing or other interference with the concentration of some gases, especially the water-soluble gases such as SO_2 and NO_2. The sample must be cooled to 37°F or lower in order to present sufficiently dry sample gas to the analyzers. In most cases, two moisture removal systems are necessary to provide sufficient cooling. The first system includes knockout traps constructed of glass (e.g. "short stem" impingers) or stainless

steel immersed in an ice bath. The second system includes thermoelectrically-cooled knockouts with continuous moisture removal pumps, and sufficient cooling capacity to reduce the sample gas temperature to 37°F or below. The second system may be located at ground level, or on the stack. If the two systems are separated by a connecting line of Teflon tubing, the tubing must be at least 10°F warmer than the temperature of the gas leaving the first conditioner.

- Sample transport – a leak-free diaphragm pump is used to transport sample from the probe and moisture conditioning systems to the analyzers in the mobile lab. The pump may be in the mobile lab as shown in Figure 1, or may be located on the stack platform. In either case, a length of Teflon tubing is used to connect the systems at the sampling location or stack platform to the systems in the mobile lab. The "vacuum side" of the system from the probe to the pump is leak checked before and after the test runs by plugging the tip of the probe and drawing the pump's maximum vacuum (or at least the maximum vacuum recorded during the test runs) on the system and delivering all the sample through a single rotameter. The leak check passes if the total flow is less than 2% of the flow noted during the test runs (usually this means a leak rate below 0.5 scfh).

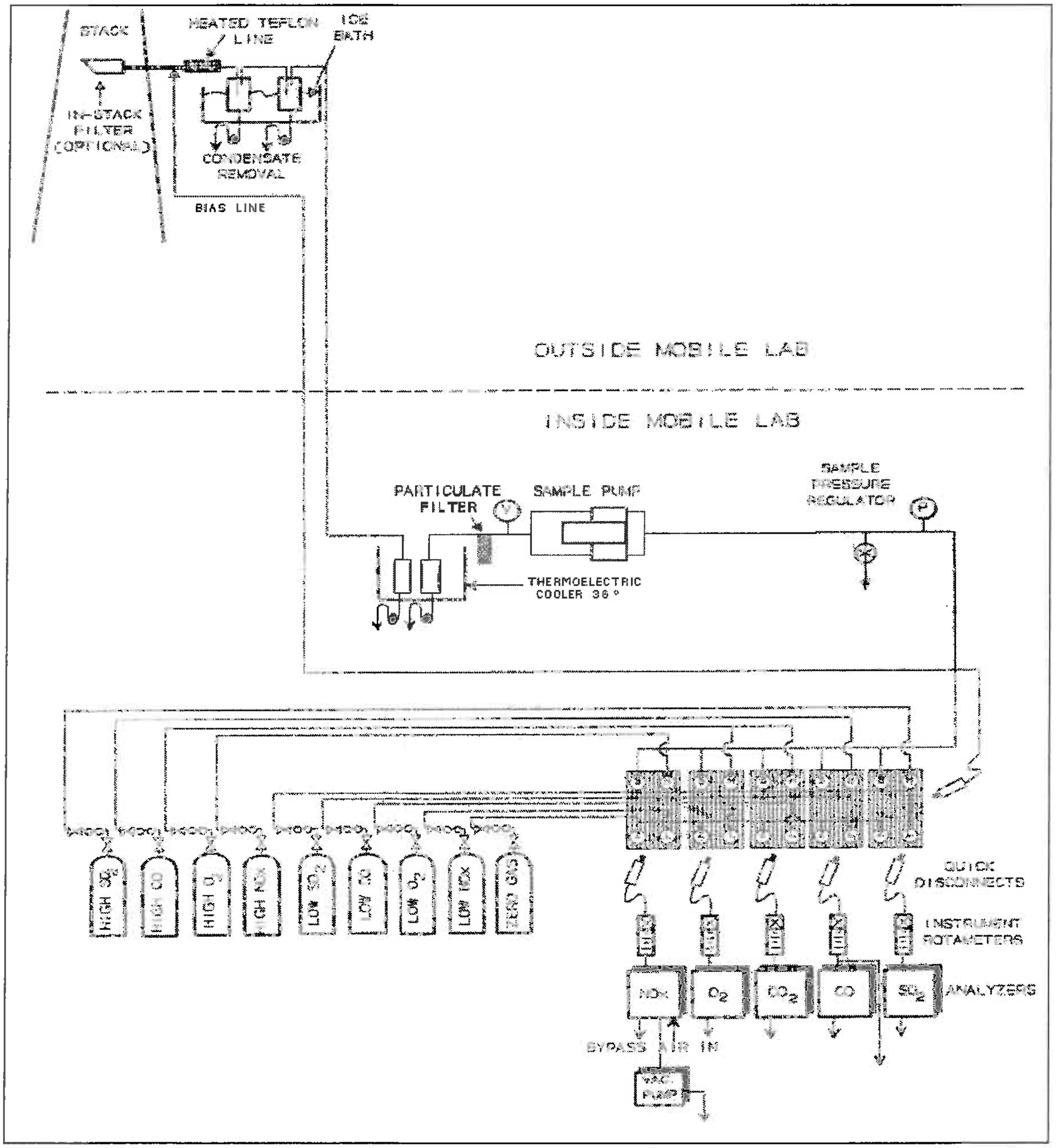
- Sample manifold – the pump delivers sample gas to the analyzers through a manifold system in the mobile lab. The manifold system includes valves for directing sample or calibration gases to any or all analyzers, and for controlling the sample pressure and flow rates. Manifold pressure is modulated using a back-pressure regulator.

- Gas analyzers and calibration gases – the individual gas analyzers are described on separate pages that follow this system description. The gases used for calibration of the analyzers are prepared and analyzed by EPA Protocol and are, at a minimum, certified by the manufacturer to be within 1% of the stated concentration. Each gas cylinder is equipped with a pressure regulator to supply the calibration gas to the analyzer at the same pressure and flow rate as the sample gas. The concentrations of the calibration gases are selected for the range of measurement necessary to determine compliance with emission limits. The gas concentrations necessary are provided in the test method, which must be consulted when choosing the gases to be used for a testing program. The direction of zero, span, or sample gas to each analyzer is accomplished by operation of the sample/calibration selector fittings.

- Calibration error and bias checks – calibration error is determined for each analyzer by directing zero gas, high-range and mid-range gases directly through the manifold to the analyzer. Bias checks are conducted before and after each test run by delivering zero and calibration gases in turn to the "tee" fitting at the back of the sampling probe just prior to the connecting Teflon tubing.

- Data acquisition system – the output of the analyzers is continuously recorded by a digital data acquisition system. The digital system, known as STRATA, provides documentation of the range and calibrations for each analyzer, as well as recording of the output of the analyzer during each calibration error test, bias check and test run. The system also calculates the percent error, percent drift, and the test run results corrected for drift. Results can be provided from "on-site" printouts of one-minute average data, or from text computer files of the data. Where required by regulations, a digital or analog strip chart recorder may also be used to "back-up" the digital data.

Figure 1. CEM System Diagram



Method: **Oxygen (O_2) by Continuous Analyzer**

Reference: EPA 3A, EPA 20, CARB 100, BAAQMD ST-14, SCAQMD 100.1

Principle: A sample is continuously drawn from the flue gas stream, conditioned, and conveyed to the instrument for direct readout of O_2 concentration.

Analyzer: California Analytical 100P, 110P, 200, 300, or Teledyne 320A

Measurement Principle: Paramagnetism

Ranges: 0-5, 0-10, 0-25, 0-100% O_2

Accuracy: 1% of full scale

Output: 0-10 V, linear

Interferences: In comparison to oxygen, other gases have such a minor magnetic susceptibility that most of them are insignificant. Exceptions to this are the nitrogen oxides, which are generally present in ppm concentrations so that their contribution to the measurement is insignificant.

Response Time: 90% <2 seconds

Sampling Procedure: A representative stack gas sample is collected and conditioned using the CEM system described previously. A stratification check traverse is performed at the start of a test program to select single or multiple-point sample locations.

Analytical Procedure: Oxygen is attracted by a magnetic field. This “paramagnetism” is measured in a special cell in which an electric current is produced that is proportional to the concentration of oxygen. This current is measured and conditioned by the instrument’s electronic circuitry to give an output in percent O_2 by volume.

Method: **Carbon Dioxide by (CO_2) by Continuous Analyzer**

Reference: EPA 3A, CARB 100, BAAQMD ST-5, SCAQMD 100.1

Principle: A sample is continuously drawn from the flue gas stream, conditioned, and conveyed to the instrument for direct readout of CO_2 concentration.

Analyzer: California Analytical 100, 200, 300, or Horiba VIA 510

Measurement Principle: Non-dispersive infrared (NDIR)

Accuracy: 1% of full scale

Ranges:: 0-5 minimum, 0-100 maximum

Output: 0-10 V

Interferences: A possible interference includes water. Since the instrument receives dried sample gas, this interference is not significant.

Response Time: 1.2 seconds

Sampling Procedure: A representative stack gas sample is collected and conditioned using the CEM system described previously.

Analytical Procedure: Carbon dioxide concentrations are measured by short path length non-dispersive infrared analyzers. These instruments measure the differential in infrared energy absorbed from energy beams passed through a reference cell (containing a gas selected to have minimal absorption of infrared energy in the wavelength absorbed by the gas component of interest) and a sample cell through which the sample gas flows continuously. The differential absorption appears as a reading on a scale as high as 0 to 100% CO_2.

Method:	**Carbon Monoxide (CO) by NDIR/Gas Filter Correlation**
Reference:	EPA 10, CARB 100, BAAQMD ST-6, SCAQMD 100.1
Principle:	A sample is continuously drawn from the flue gas stream, conditioned, and conveyed to the instrument for direct readout of CO concentration.
Analyzer:	TEI Model 48, 48C, or Teledyne 300EM
Measurement Principle:	NDIR/Gas Filter Correlation
Precision:	0.1% ppm
Ranges:	0-1 ppm minimum to 0-5,000 ppm maximum
Output:	0-10 V
Interferences:	Negligible interference from water and CO_2
Rise/Fall Times (0-95%):	1 minute @ 1 1pm flow, 30 second integration time
Sampling Procedure:	A representative stack gas sample is collected and conditioned using the CEM system described previously. Sample point selection has been described previously.
Analytical Procedure:	Radiation from an infrared source is chopped and then passed through a gas filter which alternates between CO and N_2 due to rotation of a filter wheel. The radiation then passes through a narrow band-pass filter and a multiple optical pass sample cell where absorption by the sample gas occurs. The IR radiation exits the sample cell and falls on a solid state IR detector. The detector outputs from the two gas filters are correlated by a microprocessor for analysis of the CO concentration.

Method: **Nitrogen Oxides (NO/NO_X) by Continuous Analyzer**

Reference: EPA 7E, EPA 20, CARB 100, BAAQMD ST-13A, SCAQMD 100.1

Principle: A sample is continuously drawn from the stack gas stream, conditioned, and conveyed to the instrument for direct readout of NO or NO_X.

Analyzer: EcoPhysics CLD 70E, CLD 70S, California Analytical 600 CLD, or Thermo Scientific 42iHL

Measurement Principle: Chemiluminescence

Ranges: 0-3 ppm minimum to 0-7500 ppm maximum ranges

Output: 0-10 V

Interferences: Compounds containing nitrogen (other than ammonia) may cause interference.

Response Time: 90%, 1.5 seconds (NO mode) and 1.7 seconds (NO_X mode)

Sampling Procedure: A representative stack gas sample is collected and conditioned using the CEM system described previously. If EPA Method 20 is used, that method's specific procedures for selecting sample points are used.

Analytical Procedure: The oxides of nitrogen monitoring instrument is a chemiluminescent nitric oxide analyzer. The operational basis of the instrument is the chemiluminescent reaction of NO and ozone (O_3) to form NO_2 in an excited state. Light emission results when excited NO_2 molecules revert to their ground state. The resulting chemiluminescence is monitored through an optical filter by a high sensitivity photomultiplier tube, the output of which is electronically processed so it is linearly proportional to the NO concentration. The output of the instrument is in ppm volume dry.

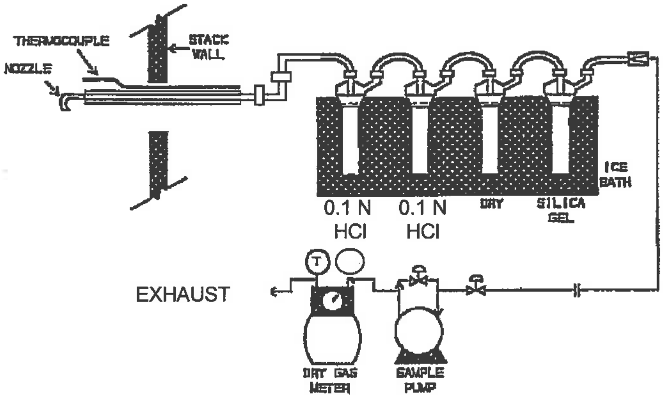
In the NO_X mode, the gas is passed through a converter which converts NO_2 to NO for a measurement of total NO_X concentration. NO_2 can be determined as the difference in readings between the analyzer's NO and NO_X modes. Use of a molybdenum catalytic converter instead of a stainless steel high-temperature converter eliminates conversion of NH_3 to NO.

Method: **Ammonia**

Reference: Bay Area AQMD Method ST-1B; EPA Method 350.3

Principle: Ammonia emissions are determined by collecting a dry, metered volume of flue gas containing ammonia vapor in dilute acid solution. The ammonia concentration of the sample is then determined by ion selective electrode.

Sampling Procedure: The ammonia sampling probe/train arrangement used during the test program is shown schematically in the following figure.



Ammonia sampling probe/train arrangement

A sample is extracted through a Teflon or glass probe fitted with a glass wool plug used to remove particulate matter. The sample is then drawn through four impingers. The first two impingers each contain 100 ml of 0.1 N hydrochloric acid (HCl), the third is empty, and the fourth contains silica gel.

After each sample run, the contents of each of the first two impingers are rinsed with water into a polyethylene sample bottle. The sample bottles are returned to the laboratory for analysis.

Analytical Procedure: The ammonia samples are analyzed by EPA Method 350.3 using an Orion Research Model 940 Microprocessor Ion Analyzer equipped with an ammonia ion selective electrode. The ammonia electrode and reference electrode are mounted behind a gas permeable membrane that separates the sample solution from the internal filling solution. After the addition of sodium hydroxide, ammonia in the sample diffuses across the electrode membrane. The measured pH change in the internal electrode solution is proportional to the concentration of ammonia in the sample solution.

The ammonia concentrations of the sample solutions are measured in units of ppm NH_3 by weight with the specific ion analyzer. By using the NH_3 concentration in ppm by weight, the measured liquid volume of the sample solution, and obtaining the volume of the flue gas sample, the stack flue gas NH_3 concentration in ppm by volume is calculated using the equation:

$$NH_3\ ppmV = 0.049\ \frac{(ppm\ wt\ NH_3\ soln)(liq.\ vol.,\ ml)}{DSCF\ (at\ 60^\circ F)\ of\ sampled\ flue\ gas}$$

Particulate Matter (PM) Emissions

Method: **EPA 5, Amended February 2000; EPA 202, Amended December 2010**
Deviations: **None**
Alternatives: **A field train proof blank was collected on-site instead of baking the glassware for 6 hours**
Pressurized nitrogen purge was used

Tester: The Avogadro Group, LLC
Contact: Ian DeVivi, QSTI

Lab: The Avogadro Group, LLC
Contact: Robert Odell (925) 680-4357, fax (925) 680-4416
Analysis: Gravimetric analysis performed by Avogadro

Test Description: The emissions of total particulate matter (PM) were measured using the procedures and equipment specified in EPA Methods 5 and 202 in conjunction with EPA Methods 1-4. These methods consist of the sampling and analytical methodology necessary to quantify filterable and condensable particulate matter from stationary sources. The quality assurance procedures detailed in the methods were followed.

Triplicate samples were 240 minutes in duration and collected over 120 dscf of flue gas. The sampling was performed isokinetically with a full traverse of the sampling plane. Traverse points were chosen and located according to EPA Method 1.

Sampling Train Setup: The sampling system included a Method 5 nozzle, probe, and heated filter for collection of filterable particulate matter. Sample flowed through the Method 5 apparatus and then through a probe extension of heated Teflon tubing into the Method 202 impinger train. Sample was drawn through the entire system by a leak-free pump and into a calibrated dry gas meter to measure the total sample volume.

The sampling apparatus for filterable particulate matter therefore included a Method 5 nozzle, a heated probe equipped with an S-type pitot tube and thermocouple. The stainless nozzle was connected to the heated probe liner of titanium tubing. The probe was attached to an oven containing a heated filter holder containing a glass-fiber filter on a Teflon support disc. The probe temperature and oven were maintained at 248°F ± 25°F during sampling.

The sampling apparatus for condensable particulate matter (CPM) included the back half of the filter holder, which was connected by a probe extension of heated Teflon tubing to a condenser, an empty condensate dropout impinger (short stem), an empty modified Greenburg Smith impinger and a CPM filter holder. A Teflon membrane filter was loaded into the CPM filter holder. The dropout and impinger were immersed in a water bath, and water was circulated through the condenser, so that the temperature of the sample gas at the CPM filter outlet was maintained between 65 and 85°F (30°C).

The sampling apparatus included a second "cold" section for complete collection of moisture from the sample gas. The CPM filter was followed by two modified Greenburg Smith impingers (the first containing 100 ml of water, and the second containing silica gel) immersed in an ice bath and maintained at or below 68°F (20°C). The impinger train was connected by flexible tubing to the control box, which contained the sampling pump, calibrated dry gas meter, and ancillary temperature and pressure controllers and meters.

Sampling Train Preparation: All glassware parts used to collect and analyze samples were cleaned prior to the test with soap and water, followed by rinses with hot tap water, deionized water, acetone, and hexane, in that order. The impinger trains were assembled in the Avogadro laboratory, and transported to the test site for collection of blanks, final set-up for sampling, etc.

Blanks: A field train proof blank was collected while on-site prior to conducting the first emissions test. The probe extension, condenser, dropout and impinger, connecting glassware, and front half of the CPM filter housing were rinsed twice with water and collected into a clean glass sample container. The water rinses were followed by a single acetone rinse and two hexane rinses of all corresponding glassware, collected into a separate glass sample container. The liquid levels were marked on each sample container.

Following recovery of the first test run, field reagent blanks of 200 mL each were collected directly from the corresponding wash bottles for acetone, water, and hexane and analyzed as described in *Sample Analysis*.

A field train recovery blank was recovered (one per source type at the facility) following the sample recovery from the first or second test run performed. A CPM sampling train was assembled per the *Sampling Train Setup* description, and then purged with nitrogen (with 100 mL of water added to the first impinger) as described in *Sampling Train Operation*. The recovery blank sample was then recovered as described in *Sample Recovery* and analyzed per the description in *Sample Analysis*.

Sampling Train Operation: The sampling train was leak tested once prior to sampling and once following testing. The pre-test leak check was performed at a nominal vacuum to ensure that leakage does not exceed 0.02 cfm. The post-test leak check was performed at a vacuum greater than the highest vacuum recorded during the test to ensure that leakage did not exceed the lesser of a) 4 percent of the average sampling rate, or b) 0.02 cfm. During sampling, the CPM filter was maintained between 65°F and 85°F (20°C and 30°C) while the exit of the silica gel was maintained at or below 68°F (20°C). The sampling rate and nozzle size were chosen to allow isokinetic sampling at 100% ±10%.

Following sampling and the final leak check, the impinger train was moved to the field laboratory, and the impingers were each weighed to determine the mass of moisture collected. The contents of the condenser and dropout were quantitatively transferred with degassed water rinses to the second impinger, and more degassed, deionized ultra-filtered water was added (if necessary) until the tip of the impinger stem was 1 centimeter below the surface of the water. The front section of the impinger train (condenser to CPM filter) was then reassembled and purged with nitrogen through an inline filter at a rate of 14 L/min for 60 minutes. The temperature at the outlet of the CPM filter was maintained between 65 and 85°F during the nitrogen purge.

Sample Recovery: The "front-half" or filterable PM was recovered from the sampling apparatus as described in Method 5. The sample fractions included (1) the acetone rinses of the nozzle, probe liner, and the front-half of the filter holder, and (2) the filter. The acetone rinses were stored in a glass sample container and the liquid level was marked. The filter was placed back into its original Petri dish and sealed.

The "back-half" or condensable PM was recovered from the apparatus as described in Method 202. The sample fractions included (1) aqueous rinses (two rinses with water) of the back-half of the filterable filter holder, probe extension, condenser, impingers, connecting glassware, and the front half of the CPM filter holder, (2) organic rinses (one with acetone and two with hexane) of the same parts, and (3) the CPM filter. The filter was removed from the filter holder and placed into a Petri dish. The liquid levels were marked on each sample container. The third and fourth impingers (cold impinger and silica gel impinger) were also weighed and recorded but not collected as sample. Samples remained upright and were maintained below 85°F (30°C) during transport from the job site to the analytical laboratory.

Sample Analysis: Analyses were performed in Avogadro's in-house laboratory. All liquid sample fractions were measured either volumetrically to ± 1 mL or gravimetrically to ± 0.5 g.

The filterable sample fractions were reduced to dryness and desiccated to a constant weight as described in Method 5.

The CPM filter was extracted with water and with hexane in a sonicator as described in Method 202. The extractions were added to the aqueous and organic rinse containers.

The aqueous back-half sample was extracted three times with 30 mL of hexane in a separatory funnel. The combined hexane extracts were added to the organic rinses from the sampling train recovery, in a clean glass beaker, and evaporated at room temperature down to 10 mL. The organic contents were quantitatively transferred to a clean pre-tared weighing tin, evaporated at room temperature to dryness, and placed into the desiccator.

Following the extraction, the aqueous fraction was transferred to a 500 mL clean glass beaker and evaporated down to 10 mL on a hot plate or in an oven at 221°F (105°C) then allowed to dry at room temperature prior to being placed into the desiccator.

All sample fractions were desiccated for 24 hours in a desiccator containing anhydrous calcium sulfate and weighed at intervals of at least 6 hours to a constant weight following desiccation. The laboratory room temperature was maintained at or below 85°C (30°C) at all times.

If a constant weight was not achieved for the aqueous fraction then the residue was re-hydrated in 100 ml of water, titrated to neutral pH, and dried and reweighed as described in Sections 11.2.2.2 to 11. 2.2.4 of Method 202.

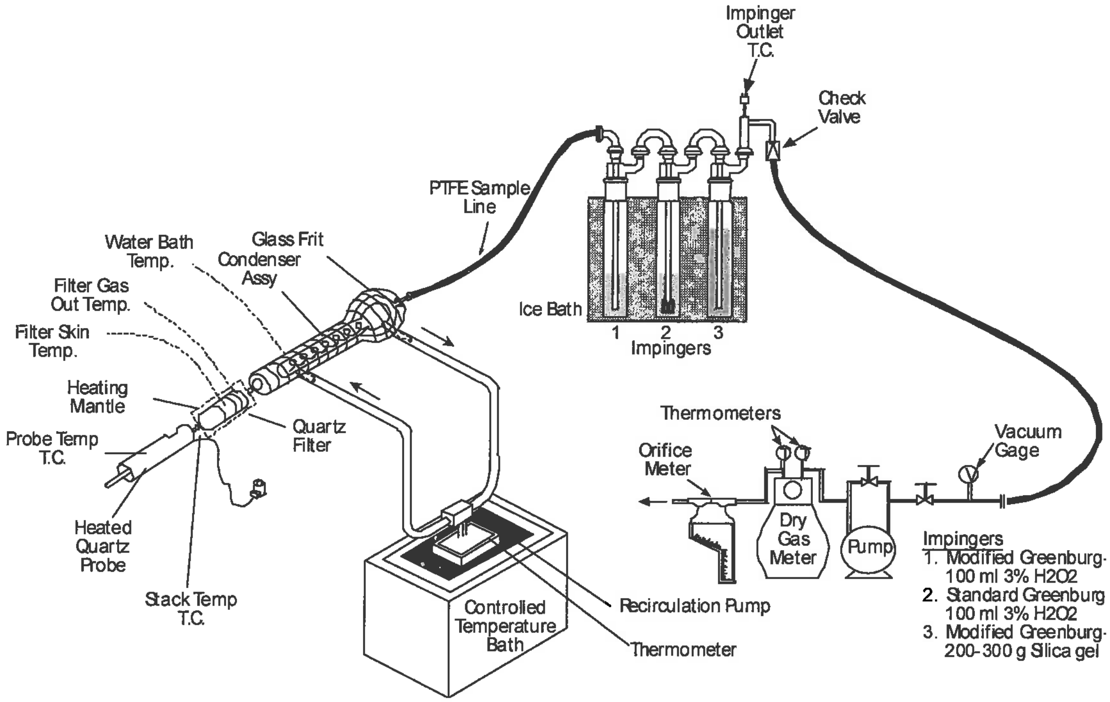
Reporting: The results for each sample fraction are reported to the nearest 0.1 mg. The results were blank-corrected as described in the methods and presented separately as filterable particulate matter, condensable particulate matter and together as total particulate matter.

Method: **Sulfur trioxide and dioxide by controlled condensation**

Applicable Ref. Method: Maddalone, R.F., EPA Office of Research and Development, 1977
EPA Method 6 or 8

Principle: A metered stack gas sample is drawn through a heated probe and filter and through a temperature-controlled condenser followed by a series of impingers.

Sampling Procedure: The sample train used in the tests is shown in the following figure. *(Write-up to be completed).*



Sampling Train for Determination of SO_3 and SO_2 by Controlled Condensation Sampler

CARB or EPA Method 4 (moisture) and Methods 1 and 2 (velocity) are performed in conjunction with the test. Stack velocity is measured during the test to maintain isokinetic sampling and to measure stack flow rate. Moisture concentration is determined by weighing the impingers before and after sampling to determine the amount of moisture collected.

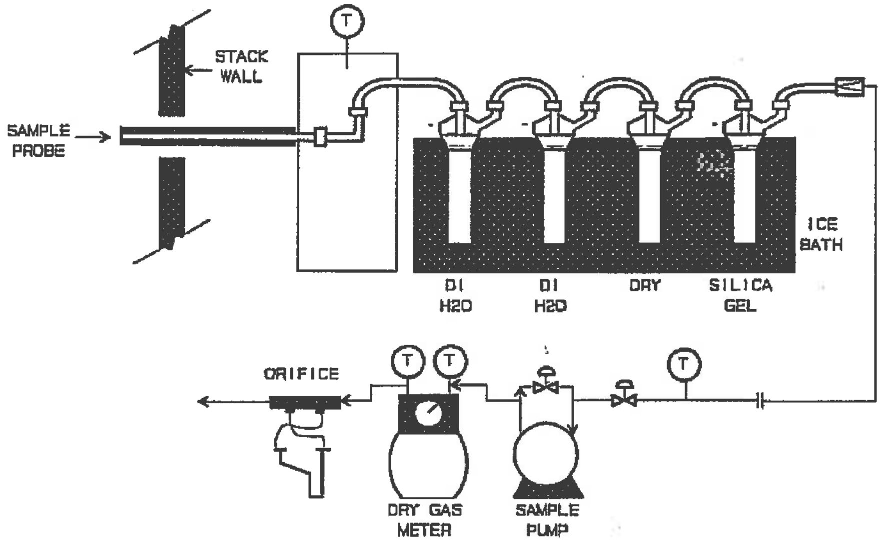
Sample Recovery and Analysis: *(Recovery and analysis procedure to be written).*

Method: **Determination of Moisture in Stack Gases**

Applicable Ref. Methods: EPA 4, ARB 1-4, SCAQMD 4.1

Principle: A gas sample is extracted at a constant rate from the source; moisture is removed from the sample stream and determined volumetrically or gravimetrically.

Sampling Procedure: The sample train used in the tests is shown in the following figure. The sample is drawn at a constant rate through a stainless steel probe. The probe is connected to an impinger train by Teflon tubing. The train consists of two Greenburg-Smith impingers which contain 100 ml water, an empty impinger as a knockout, and an impinger containing silica gel to protect the pump from moisture.



Sample Train for Determination of Moisture by EPA Method 4

Sample Recovery and Analysis: Following testing, moisture content is determined gravimetrically from initial and final impinger weights.

Method: **Stack Gas Velocity and Volumetric Flow Rate**

Reference: EPA Method 2, SCAQMD Method 2.1, ARB Method 2

Principle: The average gas velocity in a stack is determined from the measurement of the gas density and from the measurement of the average velocity head using a Type-S (Stausscheibe) Pitot tube.

Sampling Procedure: The velocity head and temperature are measured at traverse points specified by EPA Method 1 or SCAQMD Method 1.1. The velocity is measured using a Type-S Pitot tube and an inclined water manometer. The flow coefficient of the pitot tube is known. Temperature of the gas is measured using a thermocouple. The stack gas molecular weight is determined from independent measurements of O_2, CO_2, and H_2O concentrations.

Sample Analysis and Recovery: The stack gas velocity is determined from the measured average velocity head, the measured average temperature, the measured average duct static pressure, the measured dry concentrations of O_2 and CO_2, and the measured concentration of H_2O. The velocity is determined from the following set of equations:

$$V_s = 2.90C_p\sqrt{\Delta p T_s\left[\frac{29.92}{P_s}\right]\left[\frac{28.95}{MW_{wet}}\right]} \qquad \text{[ft/s]}$$

Δp = *Velocity/Head, inches* H_2O [in. H_2O]

T_s = *Gas Temperature, degrees R* [R]

P_s = *Absolute Static Pressure* [in Hg]

C_p = *Pitot Flow Coefficient* [unitless]

$$MW_{wet} = [(0.44)(\%CO_2)+(0.32)(\%O_2)+(0.28)(\%N_2)](1-\frac{\%H_2O}{100})+(18)(\frac{\%H_2O}{100})$$

The stack gas volumetric flow rate is determined from the measured stack gas velocity, the area of the stack at the measurement plane, and the measured gas temperature and pressure. The volumetric flow rate is determined from the following set of equations:

$$Q = (V_s)(AREA)(60) \qquad \text{[wacfm]}$$

$$Q_{ws} = Q\left[\frac{T_{ref}}{T_s}\right]\left[\frac{P_s}{29.92}\right] \qquad \text{[wscfm]}$$

$$Q_{sd} = Q_{ws}\left[1-\frac{\%H_2O}{100}\right] \qquad \text{[dscfm]}$$

Method: **Stack Gas Volumetric Flow Rate by Fuel "F" Factor and Heat Input**

Reference: EPA Method 19

Principle: The average stack gas volumetric flow rate is determined from the measurement of the heat input rate, stack concentration of O_2 or CO_2, and either an assigned F Factor or a site specific F Factor as determined from a corresponding fuel analysis.

Measurement Procedure: The metered fuel flow is recorded over the test period and a fuel flow rate is determined in either scf/hr or lb/hr. The average stack diluent concentration of either O_2 or CO_2 is also determined for the test period using EPA Method 3 or 3A. Finally, the use of an assigned F Factor for a given fuel type as provided in Method 19 can be used with the above parameters to calculate stoichiometrically the stack gas volumetric flow rate. Otherwise, a fuel sample may be collected and analyzed for higher heating value (HHV) and composition (CHONS) and a site specific F Factor determined.

Stoichiometric Calculations: The stack gas volumetric flow rate is determined from the following set of equations:

Input Parameters:

Qf = Fuel Flow, scfh (lb/hr)

HHV = Higher Heating Value, Btu/scf (Btu/lb)

O_2 = Exhaust Gas Concentration, %

CO_2 = Exhaust Gas Concentration, %

F_d = F Factor (O_2 Based), dscf/MMBtu

F_c = F Factor (CO_2 Based), dscf/MMBtu

Equations:

$$Q_{sd} = Q_f \; x \; HHV \; x \; F_d \left(\frac{MMBtu}{10^6 \; x \; Btu}\right)\left(\frac{20.9}{20.9 - O_2}\right)$$

or

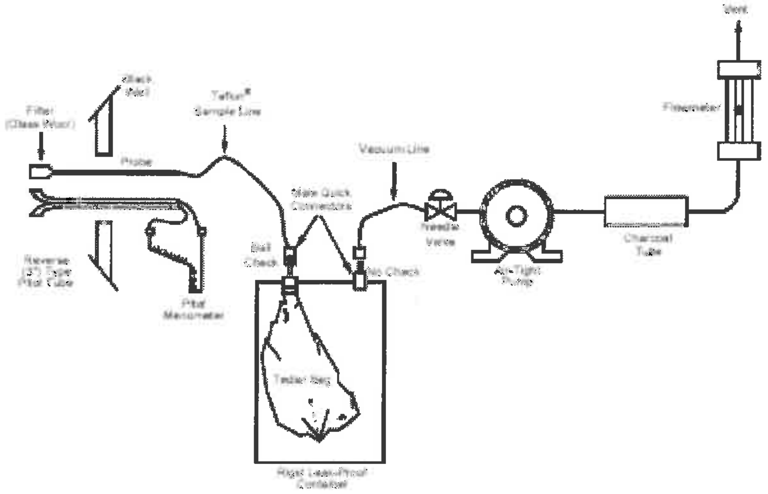
$$Q_{sd} = Q_f \; x \; HHV \; x \; F_c \left(\frac{MMBtu}{10^6 \; x \; Btu}\right)\left(\frac{100}{CO_2}\right)$$

Method: **Volatile Organic Compounds (VOC) by EPA Method 18**

Reference: EPA Method 18

Principle: A Tedlar bag is filled with sample gas at a constant rate. The bag contents are analyzed by gas chromatography–flame ionization detector for concentrations of C_1 through C_6+ hydrocarbons.

Sampling Procedure: A sample is drawn through a probe of Teflon, glass, titanium or stainless steel tubing and through a length of flexible Teflon tubing directly into a Tedlar bag. The displacement or "lung" sampler is shown in the figure. A pump is used to draw or displace air out of the rigid container so that the bag fills with sample.



Apparatus for sampling of stack gas into a Tedlar bag

Analytical Procedure: The bag samples are transported to the laboratory for analysis using a gas chromatograph with a flame ionization detector (GC-FID). The GC-FID is calibrated with certified standard gases containing C_1 through C_6 hydrocarbons. The analysis includes column separation of the C_1 through C_6 compounds, and column backflush for the total compounds $>C_6$. The laboratory results are reported as ppm volume of methane, ethane, ethene, C_3, C_4, C_5, C_6 and $>C_6$ hydrocarbons as their methane equivalents.

Method: **Determination of Volatile Organic Compounds (VOCs) by EPA Compendium Method TO-12 or TO-15**

Reference: EPA Compendium Method TO-12 or TO-15

Principle: An evacuated canister is filled with flue gas at a constant rate. The tank contents are analyzed for VOCs by preconcentration and gas chromatography (TO-12) or by gas chromatography/mass spectrometry (TO-15).

Sampling Procedure: A sample is collected at the source (usually from a stack or vent) into a canister evacuated to 0.05 mm Hg. When the canister is opened to the source containing the VOCs to be sampled, the differential pressure causes the sample to flow into the canister. The flow rate is regulated so that it is constant and the period sampled is one hour if possible. Pitot and temperature measurements of the total stack or vent flow are made.

Analytical Procedure: The canister is shipped immediately after sampling to the laboratory for analysis. For TO-12 analysis, a portion of the gaseous sample is drawn from the canister through a cryogenic trap. The sample is thermally desorbed from the trap and analyzed by GC/FID for low concentrations of organic compounds.

For TO-15 analysis, a portion of the gaseous sample from the canister is drawn through a multisorbent packing. Next, the sample is thermally desorbed from the packing and backflushed from the trap onto a gas chromatographic column to separate the compounds. Compounds of interest are determined by mass spectrometry.

The Avogadro Group, LLC subcontracts TO-12 and TO-15 analysis to qualified local laboratories experienced in the analytical procedures. These laboratories also supply the canisters for sampling.

Method:	**Total Hydrocarbons (THC) by Flame Ionization**
Reference:	EPA 25A, CARB 100
Principle:	A sample is continuously drawn from the flue gas stream through a heated line to the analyzer for direct readout of HC/VOC concentration. Results are reported as ppmV equivalents of calibration gas or as carbon equivalents.
Analyzer(s):	JUM Engineering Models VE-7 and 109A; VIG Model 20
Measurement Principle:	Flame Ionization Detection
Accuracy:	1% of full scale
Ranges:	0-10, 0-100, 0-1000. 0-10,000 ppm wet
Output:	0-10 V, 4-20 mA
Interferences:	High particulate levels, condensed moisture – dealt with by using a heated filter and heated sample line
Response Time:	0.5 seconds
Sampling Procedure:	A sample is continuously drawn from the flue gas stream through a heated line to the analyzer for direct readout of HC/VOC concentration. Results are reported as ppmv equivalents of calibration gas or as carbon equivalents. Exposure of portions of the sample probe or other sample connections to cold temperatures is avoided to prevent moisture condensation. If particulate levels are determined to be significant, an in-stack filter is recommended.
Analytical Procedure:	In the flame ionization detector, the sample gas is injected into the flame which is created by burning hydrogen in air. The hydrogen fuel flows through a metallic capillary tube, and the air flows around it. The flame is positioned between electrodes which have a voltage drop of a few hundred volts between them. When the hydrogen alone is burning, very few ions are formed. When the sample gas containing hydrocarbons is injected into the hydrogen stream, ions are formed in the flame and go to the positive collector electrode. The resulting dc signal produced is proportional to the number of ions formed. The number of ions formed is in turn proportional to the number of carbon atoms in the flame. The FID is sensitive only to the total quantity of hydrocarbons present and does not differentiate between species.