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Instrumentation and Techniques for Exhaust Gas Emissions Measurement

SAE Recommended Practice
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ϕ INSTRUMENTATION AND TECHNIQUES FOR EXHAUST GAS EMISSIONS MEASUREMENT—SAE J254 AUG84

SAE Recommended Practice

Report of the Automotive Emissions and Air Pollution Committee, approved June 1971, completely revised by the Automotive Emissions Committee, Exhaust Emissions Measurement Subcommittee, August 1984.

Scope—This SAE Recommended Practice establishes uniform laboratory techniques for the continuous and bag-sample measurement of various constituents in the exhaust gas of the gasoline engines installed in passenger cars and light-duty trucks. The report concentrates on the measurement of the following components in exhaust gas: hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2), and nitrogen oxides (NO_x). NO_x is the sum of nitric oxide (NO) and nitrogen dioxide (NO_2). Historical techniques still used for some purposes are included in the Appendices. A complete procedure for testing vehicles may be found in SAE Recommended Practice J1094, Constant Volume Sampler System for Exhaust Emissions Measurement.

This recommended practice includes the following sections:

(1) Introduction
(2) Definitions and Terminology
(3) Emissions Sampling Systems
(4) Emissions Analyzers
(5) Data Analysis and Reduction
(6) Associated Test Equipment
(7) Test Procedures
(8) Appendices A, B, and C

1. Introduction—For more than 60 years, automobile and petroleum engineers have been interested in measurements of combustion products from gasoline-powered engines for passenger cars and light-duty trucks. Considerable CO_2, O_2, and CO data at steady-state operating conditions have been obtained using Orsat analysis techniques. These techniques are well known and accurate for concentrations over 1%, but are limited to steady-state or bag sampling methods. With the development of the nondispersive-infrared, flame-ionization, chemiluminescent, and other emissions analyzers, it became possible to sample continuously and to improve accuracy. The purpose of this recommended practice is to describe means for the analysis of exhaust emissions. This procedure has been developed after thorough review and consideration of test techniques in use in laboratories of federal and state governments, and the automobile and petroleum industries.

The resulting SAE procedures reflect the extensive experience gained in these facilities with both techniques and equipment. It is recognized that measurement of exhaust emissions is in a constant state of development. With this in mind, an appendix to the basic document provides information on other methods that have been used. It is intended that the basic document will be subject to continuing review and will be revised as changes in technology and experience warrant. In the meantime, it is felt that the use of this SAE Recommended Practice will assist laboratories in obtaining reproducible and comparable test results without placing undue limitations on the techniques employed.

2. Definitions and Terminology—The following definitions apply to the terms indicated as they are used in this recommended practice.

2.1 Bag Sample—Ambient air or vehicle exhaust collected during various segments of the driving test cycle for analysis.

2.2 Calibrating Gas—A precisely analyzed gas of known concentration, used to determine the response curve of an analytical instrument.

2.3 Chemiluminescence—An analytical method for determining the NO_x concentration in exhaust gas.

2.4 Chassis Dynamometer—A laboratory-power absorption unit, capable of simulating the inertia and road-load power developed by a vehicle.

2.5 Cooler—A device capable of sufficient refrigeration to maintain condenser temperatures in the analytical train at 2 ± 1°C (35 ± 2°F).

2.6 Curb Weight—The weight of the vehicle in operational status, with all standard and commonly-installed optional equipment, and the gas tank filled to nominal capacity.

2.7 Detector—That component in an analytical instrument which responds to a particular exhaust gas constituent.

2.8 Driver's Aid—An instrument intended to guide the vehicle driver in operating the vehicle in accordance with the specified acceleration, idle, deceleration, and cruise operating modes of a specific driving procedure.

2.9 Exhaust Emissions—Any substance (but normally limited to pollutants) emitted to the atmosphere from any opening downstream from the exhaust point of the combusion chamber of an engine.

2.10 Flame Ionization Detection Analyzer (FID)—An analytical instrument used for determining the carbon concentration of hydrocarbons in a gas sample.

2.11 Hang Up—The absorption-desorption of sample (mainly higher molecular weight hydrocarbons) from the surface of the sample system that can cause a delay in instrument response and lower concentration at the analyzer, followed by higher readings in subsequent tests.

2.12 Inertia Weights—A series of rotating weights on a chassis dynamometer, used to simulate the test weight of a vehicle.

2.13 Loaded Vehicle Weight—The manufacturer's estimated weight of a vehicle in operating condition, for the purpose of emission testing, it is the curb weight of a light-duty vehicle plus 300 lb (136 kg).

2.14 LOX-Service Cleaning—Process where sampling system plumbing is cleaned thoroughly prior to flowing liquid oxygen (LOX). Hydrocarbon contamination is removed by rinsing with a solvent that will not generate emission constituents.

2.15 Mode—A particular event (for example, acceleration, deceleration, cruise, or idle) of a test cycle.

2.16 Nondispersive Infrared (NDIR) Analyzer—An analytical instrument currently used to determine CO and CO_2 in exhaust gas.

2.17 Nondispersive Ultraviolet (NDUV) Analyzer—An analytical instrument used to measure NO_2 concentration in exhaust gas.

2.18 Probe—A device inserted into some portion of an engine or vehicle system in order to obtain a representative gas or liquid sample.

2.19 Reference Column—That portion of the NDIR instrument which contains the reference gas for comparison with the sample.

2.20 Response Curve (Calibration Curve)—A line drawn through at least seven points established by calibration gases, which determines the analytical instrument's sensitivity to unknown concentrations.

2.21 Sample Bag—A container made of nonabsorbent material, used to collect ambient and exhaust samples.

2.22 Sample Cell or Sample Chamber—That portion of the analytical instrument through which the sample gas being analyzed passes.

2.23 Sampling—The technique of obtaining an accurate sample of exhaust gas for analysis. Sampling may be by bag, continuous, or proportional method.

2.23.1 SAMPLING, BAG—A technique for collecting a sample of exhaust gas during a period of a test cycle and storing it for future analysis.

2.23.2 SAMPLING, CONTINUOUS—A technique in which a portion of the exhaust is continuously withdrawn for immediate analysis.

2.24 Span Gas—A single calibrating gas blend routinely used in calibration of an instrument such as those used for detecting hydrocarbons, carbon monoxide, and nitric oxide.

2.25 Test Cycle—A sequence of engine or vehicle operating modes, usually designed to simulate road usage of the vehicle.

2.26 Zero Gas (Zero Air)—A pure gas, such as nitrogen or air, used to determine the zero point of an analyzer's response curve.

3. Emissions Sampling Systems

3.1 Continuous (Undiluted Exhaust Gas)—Fig. 1 shows a typical sampling system for the continuous measurement of exhaust-gas products emitted from the tail pipe of a vehicle. Such a system generally consists of sample probes, sample lines, coolers, particulate filters, positive displacement pumps, flow regulators and flow meters, and dessicators.

3.1.1 SAMPLE PROBE—The sample probe is the inlet to the sample system. It is recommended that this probe be constructed of stainless steel tubing, typically 6 mm (0.25 in) OD; it is usually part of a fixture which adapts to the end of the tail pipe of the vehicle. To minimize induction of ambient air, the end of the probe is extended into the tail pipe 30–45 cm (12–18 in) (if possible). The most desirable probe location is parallel to the exhaust flow, facing upstream. The sample probe fixture may slip over the outside of the tail pipe and be used with either a flexible adaptor (silicone rubber) or thermosetting-fiberglass-backed adhesive tape. This arrangement provides a seal which does not allow dilution of the exhaust gas with ambient air. Design of the probe fixture should also allow for unrestricted exit of the remaining exhaust gas (that which is not inducted into the probe) to either an exhausting system or another test apparatus such as a constant volume sampler (see SAE J1094). A valve should be located at or near the tail-pipe fixture to allow purging of the sample probe and the rest of the analysis system with prepurified dry nitrogen

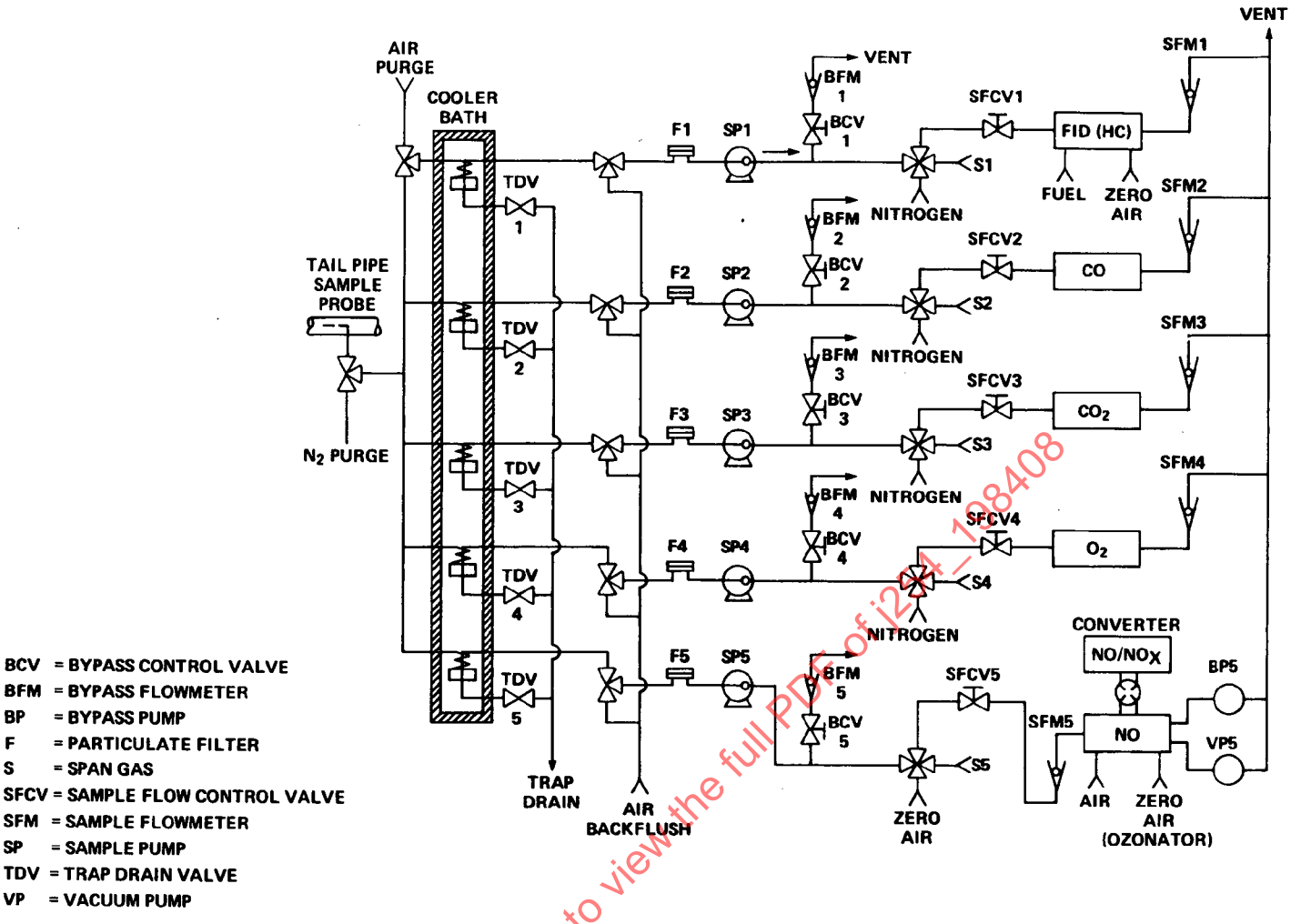


FIG. 1—A CONTINUOUS UNDILUTED EXHAUST GAS ANALYSIS SYSTEM

gas or clean, dry air. The test probe for engine dynamometer testing should be located to approximate the sampling location in an actual exhaust system of the vehicle.

In work with single-cylinder engines, or with the exhaust of a single cylinder of a multicylinder engine operating over a transient duty cycle, the proper probe location is difficult to define because of a varying degree of stratification of the concentrations of the various exhaust products which exist along the length of the exhaust pipe.

3.1.2 Sample Line—The sample line carries the exhaust gas inducted into the sample probe to the condensers which are usually located close to the analysis system. This line is typically 6 mm (0.25 in) OD and should be made of stainless steel or Teflon (or equivalent). Teflon tubing with a flexible outside protective covering is recommended because it practically eliminates the hangup from this part of the sampling system. If the ID is 6 mm (0.25 in), it can easily be joined to 6 mm (0.25 in) OD stainless steel tubing. The length of this sample line should be kept to a minimum, since its length is directly related to the delay time of the entire system; in many cases, it will be found to be responsible for the major portion of the delay time. Excessive delay times usually result when the line from the sample probe to the cooler is too long, or the sample flow rate is too low. Room restrictions may prohibit the use of short sample lines; therefore, other means such as increasing the sample flow rate or simply determining the extent of the delay and accounting for it when processing the data, may have to be used. All tubes connecting the various components of the sampling system should be either stainless steel or Teflon, and should also be as short as possible.

3.1.3 Cooler—The cooler condenses and removes the water contained in the exhaust gas sample. This is required because many analyzers have a strong response to water vapor, and also to prevent condensation of water in the analyzers.

There are a number of acceptable cooler configurations. Two types which have proved effective are the ice-bath cooler and the refrigerated-water bath. Both of these utilize a cooling coil of 6 mm (0.25 in) OD [uncoiled length is approximately 3 m (10 ft)] which empties into a trap with a volume not to exceed 60—80 cm^3 (4—5 in^3) for each leg of the analysis system. (See Fig. 1) A drain and toggle valve are provided to remove the water collected in each trap. The cooling coils are usually clustered in a common, insulated chest which can be filled with ice and water, or a water glycol solution, which can be kept near 2°C (36°F) with an electrically-powered refrigeration system. Keeping the coolant slightly above 0°C (32°F) eliminates water freezing in the trap. A mixer in the coolant helps to maintain a constant temperature.

3.1.4 Sample Filter—Borosilicate glass fiber filters of approximately 7 cm in diameter with an appropriate holding fixture of low internal volume should be used (one in each leg of the sample system, see Fig. 1), to remove any particulate matter which may be present. These filters also tend to stop water droplets which may have passed the cooler. Contaminated filters can result in excessive hangup and should be changed frequently (as often as each test, and if experience indicates the need, even during a test).

3.1.5 Sample Pumps—A pump that supplies a constant flow rate (typically 20 l/m with pump inlet and outlet at atmospheric pressure) can be used in each leg of the analysis system to pull the sample from the probe and then push the sample through the analyzer. Arrangements with a single-sample pump are also possible. To minimize hangup, pumps with stainless steel metal bellows or Teflon coated diaphragms should be used. Carbon vane or piston pumps which may introduce a hydrocarbon lubricant into the sample gas are to be avoided. The pump and motor should be mounted to eliminate the transmission of mechanical vibrations to the connecting sample lines and analyzers. An effective means of accomplishing this is to use short, flexible Teflon tubing (stainless steel braided for safety), to carry the sample gas to and from the pump, and to isolate

the pump and motor with shock mounts. Small mechanical vibration of the analyzers may affect their output.

3.1.6 Flow Control and Measurement—The pump for each analyzer should be allowed to pull as much sample as it can through the sample system to reduce the lag time required to move the sample from the tail pipe to the analyzer. An optional means of increasing the sample flow rate is to use a sample flow bypass. Immediately following each pump, a bypass line allows sample gas to be dumped to a waste system with the remaining 5 l/min proceeding through the analyzer. The bypass flow is regulated by an adjustable needle valve (stainless steel), and monitored with a rotameter-type flowmeter with at least 10 l/m capacity using a stainless steel or inert material float. [High sample rates for raw (undiluted) exhaust analysis should not be used simultaneously with dilute CVS-type analysis, as the raw sample flow will cause an error in the mass emissions obtained from the CVS calculations.]

3.1.7 Extreme care must be taken to assure that all sample system connections are leak free.

3.2 Emissions Sampling Systems—Bag Analysis—These tests yield average emission values for various periods of a complete test by a single measurement of each bag sample. The analysis is simple to perform and can determine whether a vehicle will pass surveillance or compliance tests. SAE Recommended Practice J1094, Constant Volume Sampler System for Exhaust Emissions Measurement, describes this technique. Figs. 2 and 3 show a six-bag sample gathering system and an analytical system, respectively.

In this constant volume (variable dilution) proportional sampling technique, a sampling pump draws a constant volume flow rate, for example, 8.5 m^3/min (300 scfm). This flow consists of the total exhaust of a vehicle with the remainder made up of dilution air. The technique allows for monitoring of continuous emissions on a mass basis and also, with the addition of a second pump, provides an aggregate total mass sample from a vehicle operated through an entire test cycle.

4. Emissions Analyzers

4.1 Nondispersive Infrared Analyzer—NDIR analyzers shown in Fig. 4 are primarily used to determine concentrations of CO and CO_2 in exhaust gas. Although not recommended, NDIR analyzers can also be used to measure NO and HC.

4.1.1 Theory—The NDIR analyzer detects the infrared energy absorption differential between two gas-filled columns. The gas whose concentration is to be determined is flowed through the sample column. The reference column is filled with a nonabsorbing gas such as dry air. In a nondispersive instrument, no attempt is made to separate the infrared energy into discrete wavelengths, but rather to make use of the principle that gas molecules absorb discrete bands of infrared energy.

The infrared radiation is passed through the sample and reference columns into a detector that has two cells which are physically separated by a flexible, metal diaphragm. These two detector cells contain the same gas that is to be analyzed. When the gas in the detector receives infrared energy, the pressure increases in that cell because the absorbed energy heats the gas. With no infrared absorbing gas in the sample column, both cells of the detector receive the same amount of energy and the pressure in the two cells is identical. However, if a gas sample is flowing in the sample column, some of the infrared energy will be absorbed by the gas. This means less energy will arrive at the sample cell side of the detector and the pressure in that cell will be less. This will cause the flexible metal diaphragm to move. The metal diaphragm is used as one plate of a variable plate capacitor in a tuned electric circuit.

To make diaphragm oscillate, thus creating a detector output signal, a chopper blade driven by a synchronous motor is used to periodically interrupt the sample and reference energy beams in the range of 5 to 10 Hz. In some cases, the 5 to 10 Hz signal can modulate a carrier frequency of 10 MHz or so, which is demodulated to obtain a DC signal that is more practical. The amplitude of the oscillating diaphragm, which is a measure of the concentration of the gas, is converted from a variable capacitance into an AC signal, amplified, and synchronously rectified to give a DC output signal.

4.1.2 Interferences—Since exhaust gas is a multi-component gas mixture, several gases in it may have absorption bands that overlap the absorp-

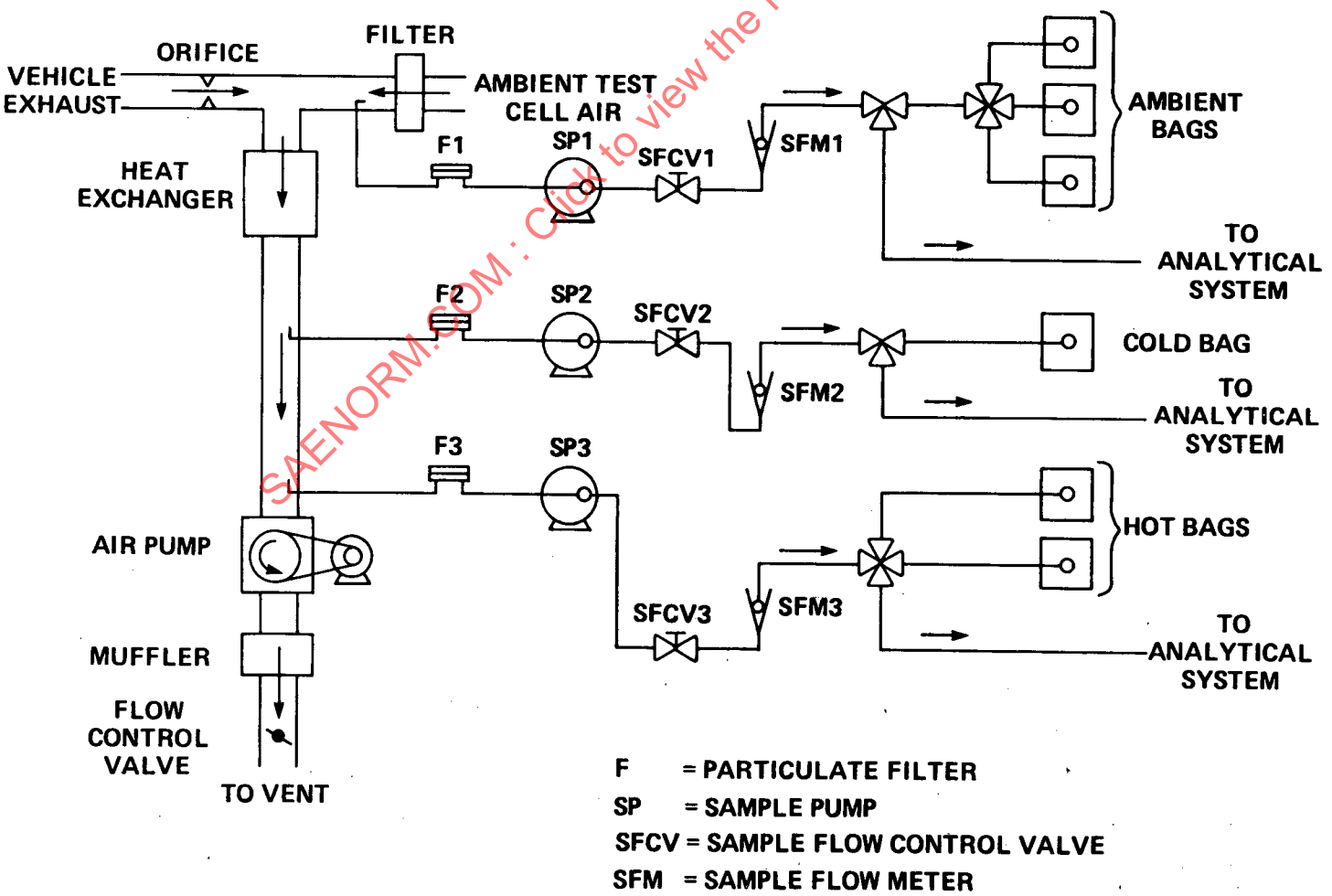
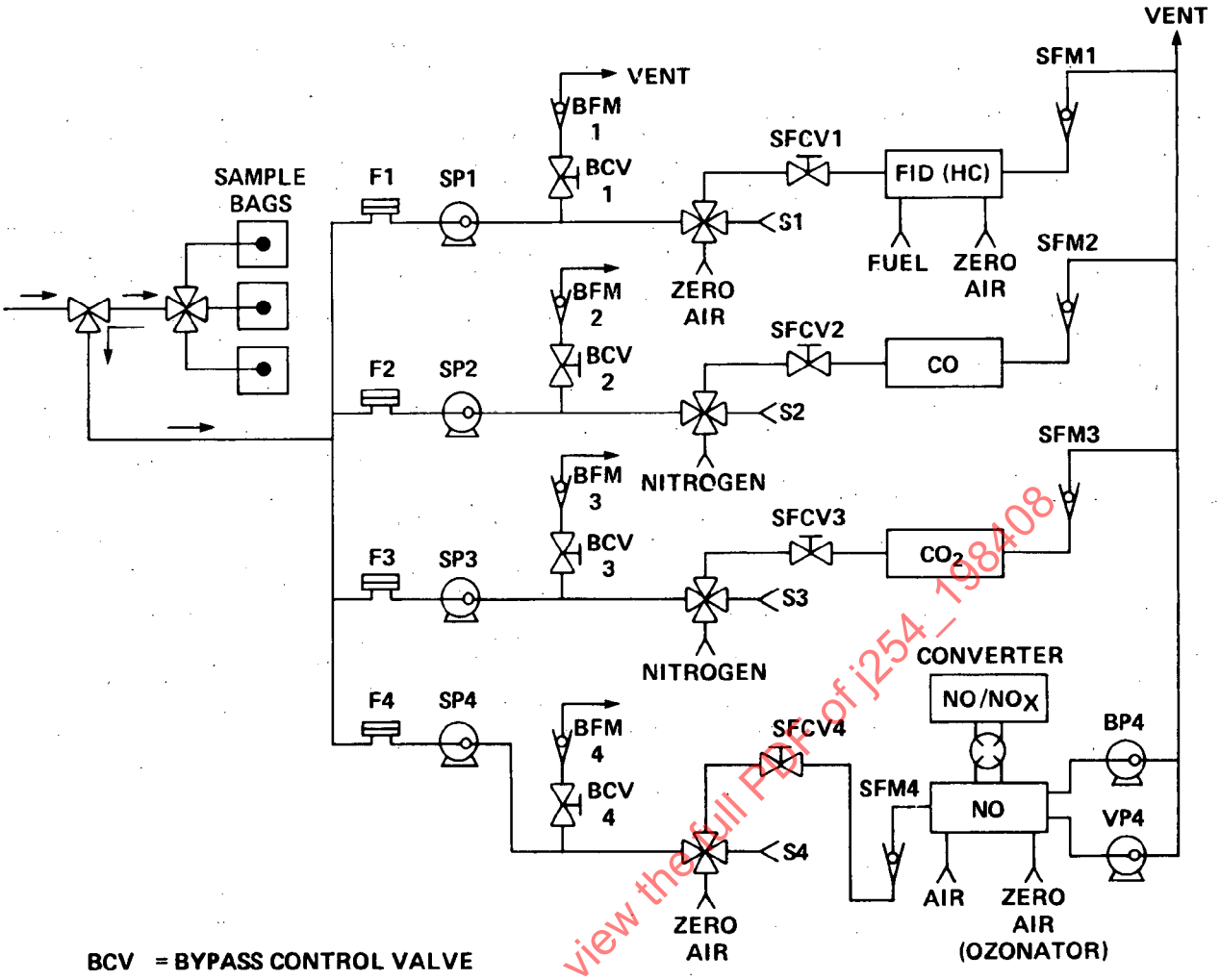


FIG. 2—A REPRESENTATIVE SIX-BAG EMISSIONS SAMPLE GATHERING SYSTEM (CONSTANT VOLUME SAMPLER)



BCV = BYPASS CONTROL VALVE
BFM = BYPASS FLOWMETER
BP = BYPASS PUMP
F = PARTICULATE FILTER
S = SPAN GAS
SFCV = SAMPLE FLOW CONTROL VALVE
SFM = SAMPLE FLOWMETER
SP = SAMPLE PUMP
VP = VACUUM PUMP

FIG. 3—A REPRESENTATIVE ANALYTICAL SYSTEM FOR SAMPLE BAG MEASUREMENT

tion bands for CO and CO_2. To make an NDIR analyzer insensitive to interfering gases, an optical filter, or a cell charged with the interfering gas, may be used to filter out unwanted portions of the infrared absorbing spectra.

Various sample detection system configurations have been used to alleviate undesirable interference signals occurring in the low CO concentration ranges. Individual design variations are described in paragraph 4.1.3.

4.1.3 Analyzer Design Variations—The analyzer shown in Fig. 4A produces infrared radiation from two separate energy sources. This radiation is beamed separately through a chopper. The beams pass through a combination filter cell and optical filter assembly that reduces the interference effects of water vapor and other interfering gases.

The analyzer shown in Fig. 4B has dual collimated infrared light sources. The response of the detector to other infrared absorbing components in the sample stream is minimized by the stacked nature of its construction. The detector has two sets of chambers. The infrared beams enter the first set of chambers, pass through them by means of a transparent bottom into the second set of chambers. The signal detected in the first chamber consists of a large part of the IR absorption signal of the components of interest in the sample stream and a small part of the IR absorption signal of the other components. The second chamber signal provides a much lower-level absorption signal of the component of interest, but approximately the same signal from the interfering components. The interfering gas signal from the lower chamber is electronically subtracted from the upper chamber signal of interest. To further minimize interference, optical filters are placed in front of the detector to cut out those IR beams in the light sources which are not necessary for detecting the IR absorption of the component of interest.

Infrared source imbalance is eliminated through use of a single radiation unit in the CO analyzer shown in Fig. 4C. The two measurement chambers of the detector are in series in the combined ray path and are connected via channels to the detector diaphragm. The absorption spectra of the gases is a band composed of a number of absorption lines. In the shorter, front-measuring chamber of the detector, absorption of the radiation takes place primarily in the center of the absorption band as it does when CO is present in the sample cell. Radiation in the outer edges of the band is absorbed in the longer rear measuring chamber. Since absorption by interfering species falls in both the center and edges of the various

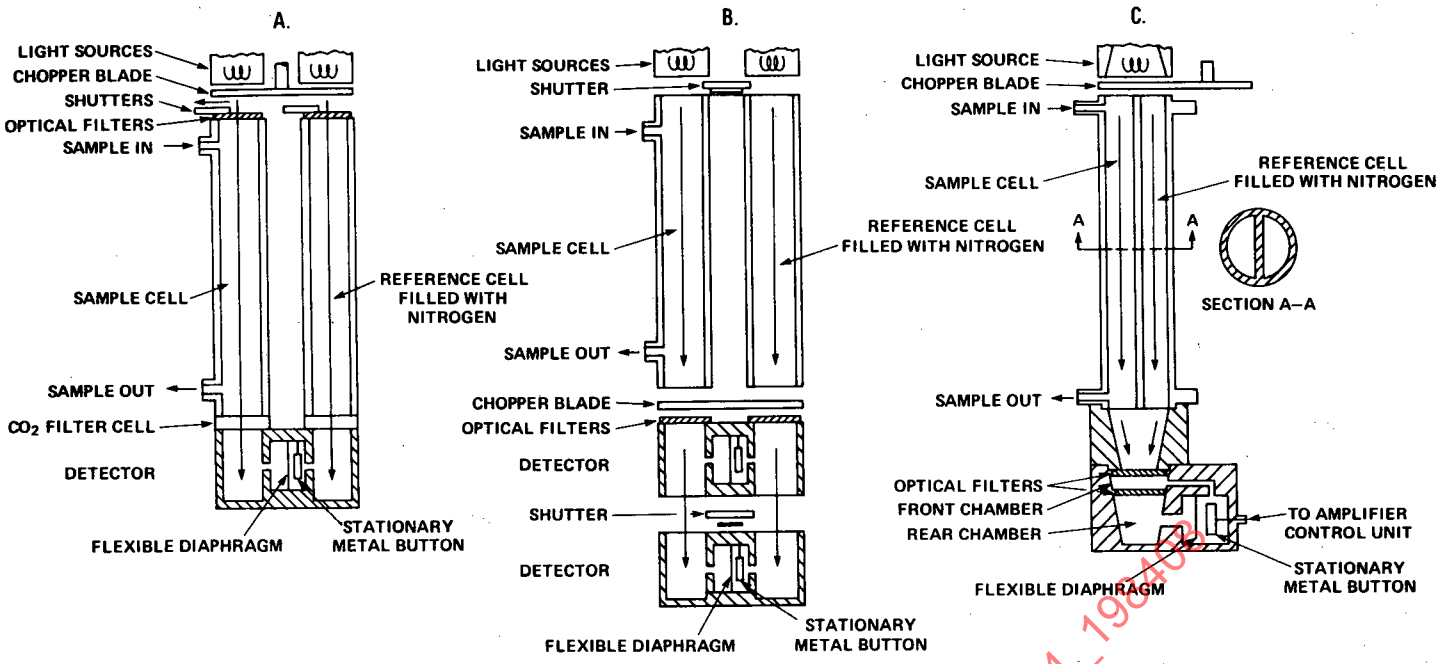


FIG. 4—THREE NONDISPERSIVE INFRARED ANALYZERS SHOWING DIFFERENT DESIGNS USED TO MINIMIZE THE EFFECTS OF INTERFERING GASES

CO bands, it can be nearly eliminated by subtraction of signals from the front and rear chambers.

In any of the above configurations, the oscillating-diaphragm detector could be replaced by a microflow gas sensor.

4.1.4 CALIBRATION—The instrument is calibrated by passing several gases of known concentrations through the analyzer to establish a response curve as shown in Fig. 5. Gases with nominal concentrations of 15, 30, 45, 60, 75, and 90 percent of the maximum level on a given analyzer range should be used. These gases should have values traceable to National Bureau of Standards reference gases. In addition, the response curve must be smoothed to the calibration data points by using a suitable curve fitting technique. If any point does not fall on a smooth curve, it must be considered suspect; that calibration standard gas should not be used until its concentration can be verified. Cylinder contamination, mislabeling, or some other reason may have resulted in an error.

4.1.5 CELL PRESSURE—Since an NDIR analyzer is sensitive to the sample density, the pressure in the sample cell during the measurement of the unknown sample must be the same as that used during the calibration. Maintaining constant flow rates of the sample gases throughout the sample system will generally insure a constant pressure within the sample cell of the analyzer.

The exhaust of the emission analyzer should be plumbed to the laboratory exhaust system and then vented freely into the exhaust system. This plumbing must not put any significant back pressure on the analyzer cell. Care must be taken to avoid conditions at the analyzer sample gas outlet that could create variations in the back pressure to the sample cell. Pressure variation in the sample cell causes a sample-gas density variation which directly affects the analyzer output. If outlet pressure variations exceed 0.2 in H_2O, a back pressure regulator may be required.

4.1.6 SPEED OF RESPONSE—The speed of response of NDIR instruments is usually limited by flow rate, the sample-cell volume, and the time constant of the electronics. The electronic amplification supplied in modern instruments is generally adequate. However, the speed of response is related to the instrument sensitivity. In order to be able to detect low concentrations, path length, and therefore cell volume, is increased to permit more of the energy to be absorbed in the sample. This means that as the cell volume is increased, the flow must be increased to maintain the same response speed.

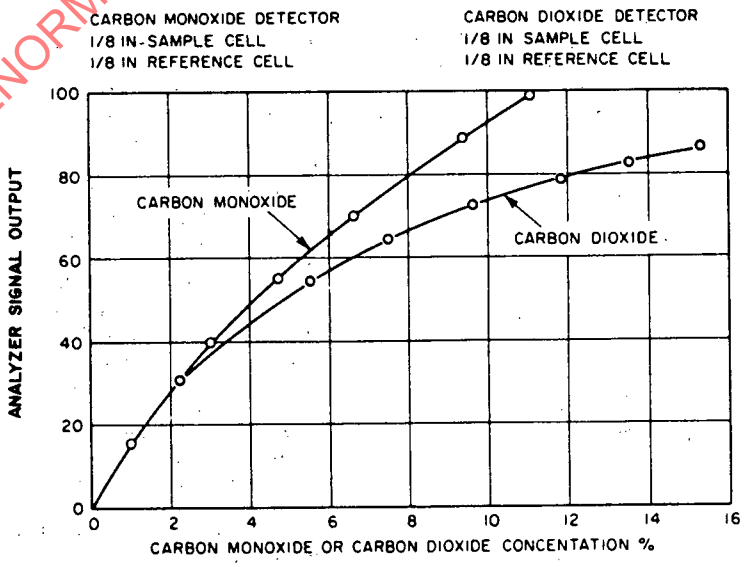


FIG. 5—TYPICAL NDIR ANALYZER RESPONSE CURVES TO CARBON MONOXIDE AND CARBON DIOXIDE

4.1.7 RESPONSE—The response of NDIR CO and CO_2 instruments is nonlinear due to energy absorption characteristics as approximately described by Beer's law (See Fig. 5). The output of the instrument can be made linear using appropriate linearizing circuits. Beer's law states that the exponential output signal, E, is related to the sample gas concentration, c, by the expression:

$$E = A\,(1 - e^{-kcx}),$$

where A is the amplification factor, k is the gas absorption factor for a particular gas, and x is the length of the sample cell. This expression is useful in qualifying an instrument, but because of detector characteristics and characteristics of the signal conditioning by the electronics, it should not be used in place of a multi-point calibration. Even with linear instruments, at least 6 calibration gases spread evenly over each range of the instrument must be used to verify the linearity of the instrument.

4.1.8 SIGNAL NOISE—Noise is the unwanted part of the signal that degrades instrument accuracy. Noise can be caused by many things, but the most common are:

Cell misalignment,
Low detector signal output,
Dirty cells,
Poor electrical connections,
Improper chopper blade alignment and synchronization, and
Pressure fluctuations from changes in flowrate.

Connecting an active filter between the first stage of signal amplification and the phase inverting network of the analyzer signal conditioner reduces the noise level considerably, with little effect on response time. Care should be taken when making this type of modification.

4.2 Flame Ionization Detector—Hydrocarbons—The flame ionization detector (FID) is used to measure the total hydrocarbon content of complex-hydrocarbon mixtures on a carbon mass basis. This measurement can be converted to a hydrocarbon-mass basis by assumption of a specific carbon to hydrogen ratio.

4.2.1 DESCRIPTION—The burner of a typical FID is similar to that shown in Fig. 6. A small stream of fuel, hydrogen diluted with an inert gas, is premixed with the sample gas and burned at the outlet of the jet in a diffusion flame with air.

The FID operates on the principle that the introduction of a gas sample containing hydrocarbon into a hydrogen diffusion flame will increase the concentration of ions within the flame. This increase in ionization is almost directly proportional to the mass flow rate of carbon atoms into the flame. A DC voltage between the burner top and a collector electrode, which surrounds the flame, collects the ions within the flame, causing current to flow through the associated electronic measuring circuits.

4.2.2 INTERFERENCES—Under normal operating conditions, an FID has no significant response to any non-hydrocarbon constituent found in exhaust gas. The presence of O_2 in the sample, though, can interfere with the accuracy of the hydrocarbon measurement.

4.2.3 RELATIVE RESPONSE—To obtain accurate analysis of complex hydrocarbon mixtures, it is necessary that the FID response to each carbon atom in the sample be the same as the single hydrocarbon calibration gas, i.e., uniform relative response. The presence of O_2 in the sample can cause the relative responses of the various sample gas hydrocarbon constituents to differ substantially from that of the calibration gas. It has been suggested that this is due to preflame oxidation of the hydrocarbons at the core of the flame which prevents later ionization. Since the ease of oxidation of a hydrocarbon is different for each species, preferential oxidation takes place, which results in differing sensitivities for each hydrocarbon, i.e., nonuniform relative response. Several investigators have shown that more uniform relative response can be obtained by the following steps:

(1) Maintain sample flow rate to the FID burner at a minimum to reduce the O_2 concentration within the core of the flame available for preflame oxidation.

(2) Use high fuel flow rate to the FID burner to dilute any O_2 entering with the sample, again reducing the O_2 concentration.

(3) Use H_2-He mixed fuel instead of H_2-N_2 fuel. Since the fuel type changes the response to various hydrocarbons, it is important to use the specified fuel in complying with governmental standards.

(4) Select a calibration and zero gas with an oxygen content approximating that of the sample to be analyzed, as this will tend to normalize the relative response between sample and span gas.

Because sample, fuel, and air-flow rates affect the uniformity of relative response of an FID to the various exhaust hydrocarbons, good correlation between FID's of the same model will occur only when their flow rates are the same. To establish correlation between dissimilar FID's, it may be necessary to actually determine their relative response to several major hydrocarbon species and normalize them by adjustment of sample, fuel, and air flow rate for equal relative response. As an initial guide in setting flow rates, the following is recommended:

Sample Flow	3 to 5 cm^3/min
Fuel Flow	Adjusted for maximum response
Air Flow	3-1/2 to 4 times the fuel flow rate

4.2.4 VISCOSITY—The response of an FID is directly proportional to the volumetric sample flow to the FID burner. Therefore, a stringent control of sample flow rate is mandatory. Because most FID's use a pressure-regulated capillary flow control system, the sample flow to the burner is dependent on both sample pressure and viscosity. Any change in sample viscosity will, therefore, result in an inversely-proportional change in apparent reading, though pressure has remained constant. It is, therefore, necessary to use a calibration gas whose viscosity approximates that of the sample being measured. In actual practice, this is usually neglected because the error is small.

4.2.5 OPERATION—The typical FID, with proper use, is capable of accurate measurement of hydrocarbon concentrations over a very wide dynamic range—commonly several orders of magnitude. To best optimize the accuracy of measurements, especially when using FID ranges of 300 ppmC (C = carbon atoms) or less, the following guidelines are recommended.

4.2.5.1 *Fuel and Air*—Many problems are caused by impurities in the gases and/or lack of cleanliness of regulator and external connecting tubing. The utmost care should be exercised to insure that tubing, fittings, and regulators are not only clean upon installation, but that they remain clean during use. Contaminated burner air is a common cause of high background noise level. Consequently, the use of pure air of less than 3 ppm hydrocarbon impurity is recommended for low level hydrocarbon measurements. As elastomer diaphragm regulator may be used for the burner air, but should be LOX-service cleaned. The hydrogen fuel gas must be essentially hydrocarbon-free, i.e., less than 1 ppmC. A metal diaphragm LOX-service cleaned fuel regulator is required. It is also important that supply gases and lines be maintained at a relatively constant temperature as temperature fluctuation will result in absorption-desorption of hydrocarbons which will appear as analyzer drift.

4.2.5.2 *Calibration Gases*—As with the fuel and air, care should be exercised to insure that all lines, fittings, and regulators used with the calibration gases are contamination-free. LOX-service cleaned, metal diaphragm regulators are especially recommended for low concentration (less than 300 ppmC) calibration gases and the zero gas.

As discussed previously, it is important that the calibration and zero gases have approximately the same oxygen content and viscosity as the sample gas.

4.2.5.3 *Sample Lines*—The sampling system should be kept short with minimum volume to minimize sample transit time. Sample lines, fittings, filters, and pumps should be constructed of stainless steel or Teflon. Sample system cleanliness is extremely important. Contamination, such as scale, grease, or fingerprints, will not only contribute to high sample backgrounds, but absorption of sample hydrocarbons by the contamination will retard the sample and increase response time. A particulate filter should be used to prevent blockage of the fine capillary used to control sample flow. Samples with a dew point above room temperature, such as tail-pipe exhaust, must be dried to prevent condensation of water within the system. The use of a heated FID, which allows heating of both internal and external sample lines, eliminates the necessity for water removal.

4.2.5.4 *Response Curve*—Typically, an FID requires calibration with a zero gas and with only one other, one-component, calibration gas at

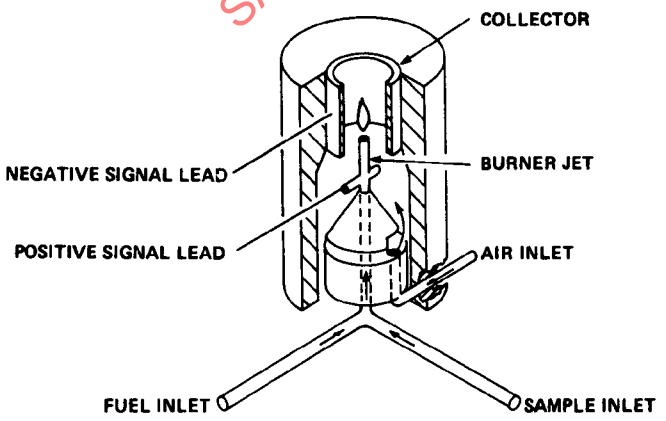


FIG. 6—TYPICAL BURNER OF FLAME IONIZATION DETECTOR

full scale, since response is generally linear with carbon content of the sample. However, this should be verified for each FID because some instruments at certain conditions are nonlinear and require a response curve.

4.3 Chemiluminescent Gas Analyzer—The chemiluminescent (CL) analyzer (see Fig. 7) can be used for the direct measurement of oxides of nitrogen (NO_x) concentrations in continuous or bag samples. The CL analyzer measures only the concentrations of nitric oxide (NO) in a gaseous sample. By the use of a high-efficiency converter that changes any nitrogen dioxide (NO_2) present into NO, the total concentration of NO_x ($NO + NO_2$) present can also be determined.

4.3.1 THEORY—The analyzer measures the light from the chemiluminescent reaction of NO and O_3. When a gaseous sample to be measured is blended with dilute O_3 in a reaction chamber, some of the NO_2 produced exists in an excited state (NO_2^*). The excited NO_2^* can return to its ground energy state by emitting a photon according to the following equations:

$$NO + O_3 \longrightarrow NO_2^* + O_2$$
$$NO_2^* \longrightarrow NO_2 + hV.$$

In the presence of an excess of O_3, the light emitted by this specific reaction is proportional to the concentration of NO. This light can be detected by an optical filter-photomultiplier combination to produce an output which is essentially linear with respect to the NO concentration of the sample. To measure the concentration of NO_x in a sample, a converter which converts NO_2 into NO at high efficiency is inserted into the input sample flow stream.

4.3.2 CALIBRATION—Since the CL analyzer produces an essentially linear response with respect to NO concentration of the sample, a two-point calibration (at zero and full scale) is required. However, linearity should be verified periodically. Some CL instruments may be non-linear, and may require a response curve with known gases having nominal concentrations equal to 0.15, 30, 45, 60, 75, and 90 percent of full-scale concentrations. Calibration gases should consist of a known mixture of NO with nitrogen as the balance gas. The actual concentration should be known to within ± 1% of the true values. Zero-grade nitrogen or zero-grade air shall be used to obtain zero response of the CL analyzer.

4.3.3 NO_x CONVERTER EFFICIENCY DETERMINATION—Periodically, the efficiency of the NO_x converter should be measured using the apparatus illustrated in Fig. 8 to determine the NO_2 to NO conversion efficiency. Efficiency checks should be made using an NO span gas concentration appropriate to the instrument range to be used. Appropriate adjustments to the converter temperature should be made to obtain converter efficiency between 97 and 100%. The following procedure is to be used for determining the values for the equation in Step (7) below.

(1) Attach the NO/N_2 supply at C2, the O_2 supply at C1 and the analyzer inlet connection to the efficiency detector at C3 as shown in Fig. 8. At low concentrations of NO, air may be used in place of O_2 to facilitate control of the NO_2 generated during step 4 and to minimize the fire hazard.

(2) With the variable transformer off, place the NO_2 converter in the bypass mode and close valve V3. Open Valve V2 until sufficient flow and stable readings are obtained at the analyzer. Zero and span the analyzer output to indicate the value of the NO concentration being used. Record this concentration.

(3) Open Valve V3 (on/off flow control solenoid valve for O_2) and adjust valve V1 (O_2 supply metering valve) to blend enough O_2 to lower the NO concentration (2) about 10%. Record this concentration.

(4) Turn on the ozonator and increase its supply voltage until the NO concentration of (3) is reduced to about 20% of (2). NO_2 is now being formed from the $NO + O_2$ reaction. There must always be at least 10% unreacted NO at this point. Record this concentration.

(5) When a stable reading has been obtained from (4), place the NO_x converter in the converter mode. The analyzer now indicates the total NO_x concentration. Record this concentration.

(6) Turn off the ozonator and allow the analyzer reading to stabilize. The mixture $NO + O_2$ is still passing through the converter. This reading is the total NO_x concentration of the dilute NO span gas used at step (3). Record this concentration.

(7) Close valve V3. The NO concentration should be equal to or greater than the reading of (2). Calculate the efficiency of the NO_x converter by substituting the concentrations obtained during the test into the equation:

$$\% \text{ Efficiency} = \frac{[(3) - (4)] - [(6) - (5)]}{[(3) - (4)]} \times 100\%$$

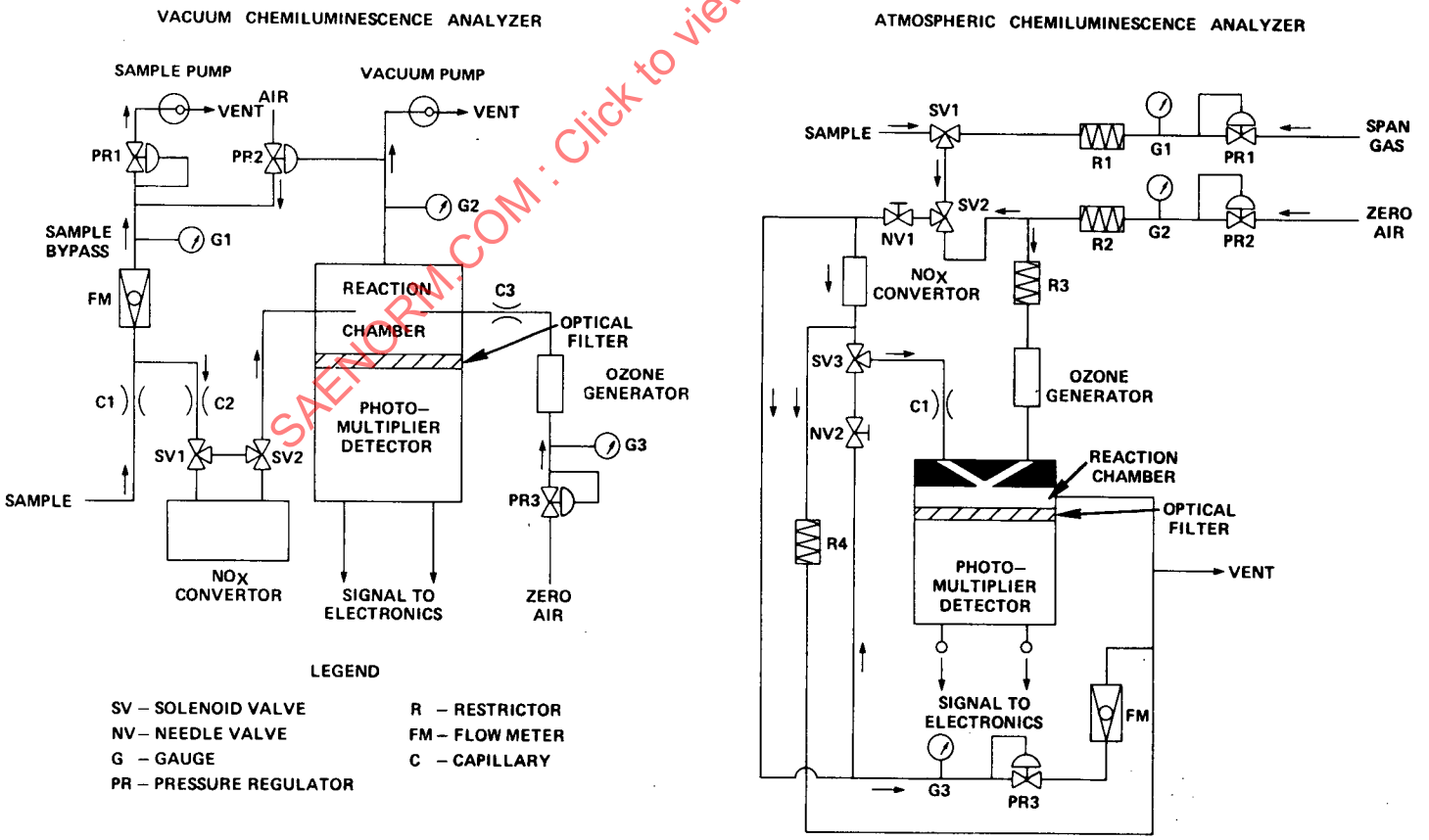


FIG. 7—SCHEMATICS OF TWO CHEMILUMINESCENT ANALYZERS SHOWING A LOW PRESSURE TYPE (LEFT ABOVE) AND AN ATMOSPHERIC PRESSURE TYPE (RIGHT ABOVE)

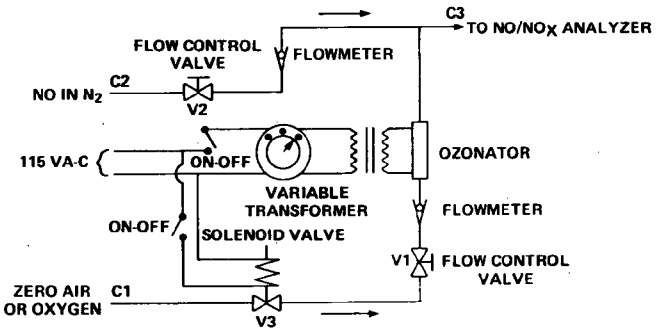


FIG. 8—NO_x GENERATOR FOR CONVERTER EFFICIENCY DETERMINATION

4.3.4 Viscosity—The response of a CL analyzer is directly proportional to the volumetric sample flow to the CL analyzer reaction chamber, making stringent control of sample flow rate mandatory. Because most CL analyzers use a pressure-regulated capillary flow control system, the sample flow to the reaction chamber is dependent on both sample pressure and viscosity. Any change in sample viscosity will result in an inversely proportional change in apparent reading, though pressure has remained constant. It is necessary to use a calibration gas whose viscosity approximates that of the sample being measured.

4.3.5 Operation—Prior to use, the CL analyzer should be calibrated with gases of known concentration. Pass zero gas through the analyzer and adjust the dark current suppression or amplifier zero control for zero instrument response. A known concentration NO span gas is then applied and the photomultiplier high voltage supply or the amplifier gain is adjusted for the proper corresponding instrument response.

4.3.6 Analyzer Performance Improvement—Output signal drift is often encountered in analyzers using photomultiplier tubes (PMT). This drift is characteristic of the PMT referred to as fatigue. Fatigue can be reduced in certain analyzers by providing illumination to the PMT during prolonged periods when there is no chemiluminescent reaction. A light emitting diode may be inserted into the reaction chamber to illuminate the PMT while the analyzer isn't being used for testing. Use of light during analyzer idle periods has been shown to reduce warmup drift and increase analyzer-to-analyzer correlation in certain instances.

Interference from H_2O and CO_2 quenching in atmospheric pressure CL analyzers can be reduced by moving the sample capillary further upstream from the reaction chamber, reducing sample flow rate, and increasing the ozone flow rate.

4.4 Oxygen Analyzers

4.4.1 Polarographic Analyzers

4.4.1.1 *Theory*—Polarographic oxygen analyzers operate on the principle that different gases are reduced at different applied voltage potentials. Of the gases normally found in exhaust gas, oxygen is reduced at the lowest potential and can, therefore, be readily measured. The instrument actually measures the partial pressure of oxygen in the sample, but for fixed operating conditions, it can be calibrated in other units such as percent oxygen by volume.

The analyzer consists of two basic units, a sensor and an amplifier. The sensor (Fig. 9) which detects oxygen content, normally consists of a gold cathode insulated from a silver anode between which a potential of approximately 0.8 V is applied. The anode is electrically connected to the cathode by a potassium chloride gel. The entire anode-cathode assembly is separated from the sample by a Teflon gas-permeable membrane.

4.4.1.2 *Interferences*—There are other gases, such as SO_2, Cl_2, Br_2, I_2, and NO which will reduce at 0.8 V. Fortunately, none of these gases are found in exhaust gas in sufficient concentrations to give a significant interference

4.4.1.3 *Continuous Operation*—In operation, the sensor is placed in the sample stream and oxygen diffuses through the Teflon membrane and is reduced, by the 0.8 V potential, at the cathode. This reduction causes a current flow which is proportional to the partial pressure of oxygen in the sample.

An example of a sensor installed in a gas stream is shown in Fig. 10. The housing for the sensor was designed for low dead volume to reduce response time for the instrument. The sensor can be incorporated into the sampling system of other exhaust analysis instruments as shown in Fig. 10, provided close control of the system pressure is maintained. Since the instrument measures only the partial pressure of oxygen, it is sensitive to changes in the total pressure of the sample.

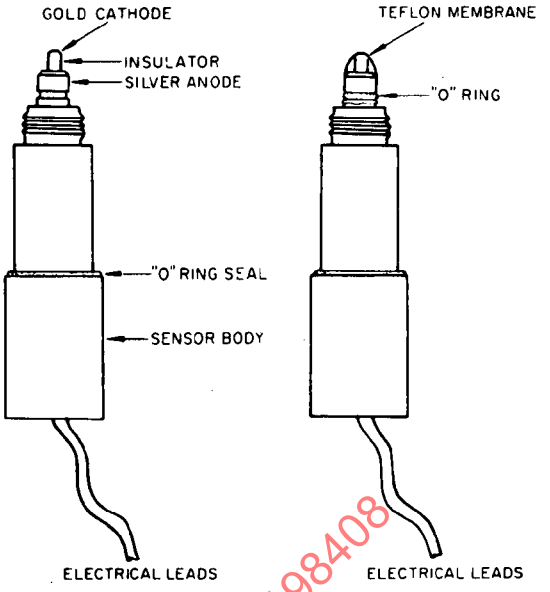


FIG. 9—POLAROGRAPHIC OXYGEN ANALYZER SENSOR

For example, if the total pressure of the sample is doubled, the partial pressure of the oxygen will double, and, as a result, the output of the sensor will double while the actual percent oxygen in the sample will remain the same. Because of this characteristic, direct readings in percent oxygen are valid only if the gas mixture is analyzed under the same total pressure as when calibrated.

4.4.1.4 *Calibration Considerations*—Since sensor response is linear with oxygen partial pressure in the sample, a simple two-point calibration, at zero and full scale, is required. Span settings can normally be made using room air. However, if the room air is not relatively clean, blends of oxygen in N_2 should be used. The instrument is zeroed using nitrogen.

4.4.2 Paramagnetic Analyzers

4.4.2.1 *Theory*—Paramagnetic oxygen analyzers measure the oxygen partial pressure of a gas sample by measuring its magnetic susceptibility. This property of the sample is largely due to the oxygen in it. This type of measurement is possible because oxygen is strongly paramagnetic, while other common gases with the exception of NO and NO_2 are weakly diamagnetic. The magnetic susceptibility of oxygen can be thought of as a measure of the ability of an oxygen molecule to become a temporary magnet when placed in a magnetic field.

The susceptibility measurement is made in the analysis cell where a dumbbell-shaped test body mounted on a quartz fiber is suspended in a nonuniform magnetic field (Fig. 11). As the partial pressure of oxygen in the gas sample surrounding the test body changes, the body will rotate. An optical system which senses this rotation causes a voltage to be applied to the test body to maintain it in a null position. This voltage is the output voltage of the amplifier circuit, and is the voltage required to

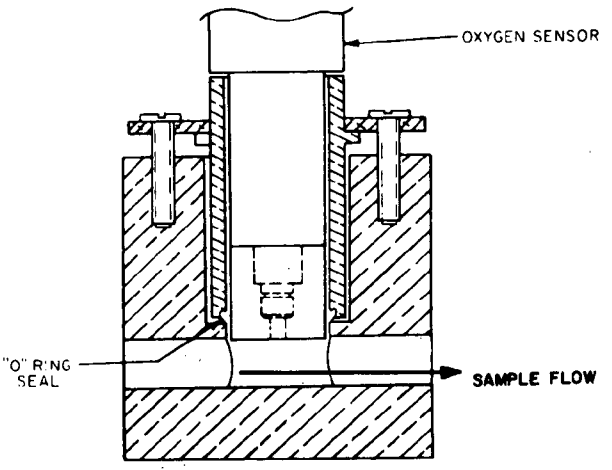


FIG. 10—POLAROGRAPHIC OXYGEN ANALYZER INSTALLATION

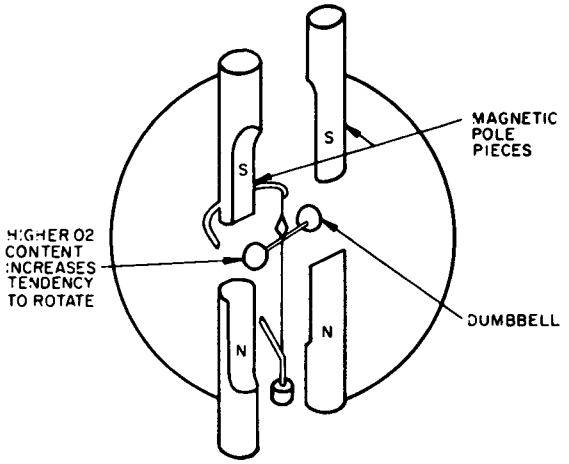


FIG. 11—PARAMAGNETIC ANALYZER TEST BODY

hold the test body stationary against the forces exerted by the magnetic field.

4.4.2.2 *Interferences*—Although the instrument response caused by most gases other than oxygen is comparatively slight, it is not in all cases negligible, as can be seen in Table 1. Therefore, in making oxygen measurements in exhaust gas, correction should be made for the interfering compounds such as CO_2, CO, and NO.

4.4.2.3 *Operation*—This instrument, because it depends on the physical movement of a relatively large mass, does not have the speed of response necessary to measure dynamic changes in oxygen content, such as may occur when analyzing exhaust gas. Therefore, it is not recommended for use during cyclic operation. However, it can be used to measure oxygen either at steady-state conditions or in collected samples of exhaust gas. Since the analyzer measures the partial pressure of oxygen, an instrument calibrated in percent oxygen must be operated at the same system pressure at which it is calibrated to obtain reliable analytical results.

4.4.2.4 *Calibration Consideration*—Instrument response is linear with oxygen partial pressure in the sample; therefore, only a one-point calibration is required. Span settings can normally be made on room air. However, if the room air is not relatively clean, blends of oxygen in N_2 should be used. The instrument is normally zeroed on nitrogen.

5. Data Analysis and Reduction

5.1 Automatic Processing

5.1.1 INTEGRATION TECHNIQUES—Average concentrations may be desired for the individual modes of the test cycle. When mode concentrations are determined manually, the average height of the curve on the analyzer strip chart is considered proportional to the average concentration; that is, the analyzer calibration curve is assumed to be linear. The average chart height may be determined electronically by integrating the area under the curve and dividing the area by the integration time. One technique for doing this is shown in Fig. 12. The analyzer output is converted to a frequency which is proportional to the analyzer output. By counting the frequency pulses, integration of the area under the curve is performed. If the number of counts is divided by the integration time period, the average frequency is obtained. From the average frequency, the average voltage or chart height is obtained.

Another method of obtaining the average concentration is to apply the analyzer output voltage to a digitial computer, and to program the computer to sample the analyzer output at specified intervals, for example, at 0.3 s intervals. Once the computer has acquired the analyzer output voltages, a data reduction program can be written to calculate the average modal concentrations. This method permits analyzer output voltage to be converted to concentration for each data point taken. Therefore, the computer can time-average the concentrations rather than the analyzer signals. If the analyzer calibration curve is not linear, the time average of the analyzer signals, when converted to a concentration, will not give the same result as time-averaging the concentration, which is the correct value. Therefore, this integration technique is adaptable to use with analyzers having nonlinear calibration curves.

A third method of obtaining average model concentration is to connect the output voltage of the analyzers to an analog computer (modified to linearize calibration of the input signal) and perform integration of the concentrations and division by the mode length in the analog computer. The recorder response when measuring exhaust gas concentrations will lag the driver's event signal because of driver response time, a variable exhaust system delay, and fixed sample system delay. Therefore, the concentrations for each mode will not be located on the charts at a point corresponding to the event signal time of the mode. Where automatic data processing by means of a computer is used, compensation for time delay and nonlinearity of analyzer response will be incorporated in the integrating program.

Whenever water is removed from a gas stream with a cold trap, all concentrations must be corrected for the water removed if concentrations of the original wet stream are desired.

5.1.2 EVENT MARKING METHODS—As mentioned in the previous paragraph, recorder response will lag the driver's event signal by a variable amount. When automatic data acquisition is used, some method must be provided for triggering integration of the analyzer outputs for each mode of the driving cycle.

Triggering may be accomplished by means of a two-channel tape deck, one channel being used for driver audio commands, the other channel for integrator triggering. In this case, the time lag between the driver's command signal and the recorder response can be experimentally determined, and the integrator triggering channel delayed by that amount relative to the driver command tape channel. In this case, it is desirable to match the time lags for the various analyzers as closely as possible by varying sample flow rates through the individual analyzers, or by removing excess sample tubing.

If integration is accomplished in a computer, the computer can be programmed for separate time lags for each analyzer. Another method of triggering integrations is to sense abrupt changes in the recorder response, since an abrupt concentration change usually accompanies a change from one driving mode to another. The integrator or computer can sense rate of change of the analyzer output, and begin integration when an abrupt change is detected.

5.2 Manual Processing

5.2.1 INTEGRATION TECHNIQUES—The recorder response for measuring exhaust gas concentrations will always lag the engine's operation because of a variable exhaust system delay and a fixed sample system delay. Therefore, the concentrations for each mode will not be located on the charts at a point corresponding to the exact time of the mode. For each cycle to be evaluated, proceed as indicated by paragraphs 5.2.1 (a)—(c).

(a) Determine whether the cycle was driven in accordance with the specified cycle timing by observing either event marks, speed trace, manifold vacuum trace, or concentration traces. Deviation by more than 2 s from the specified time for each mode will invalidate the data.

(b) Time correlate the hydrocarbon, carbon monoxide, carbon dioxide, and NO_2 charts, if used. Use all clues available to determine the location on the chart of concentrations corresponding to each mode. Use judgment in recognizing and compensating for trace abnormalities.

(c) Integrate the concentrations for each mode, and record data for each cycle of the test.

6. Associated Test Equipment

6.1 Chassis Dynamometers—Chassis dynamometers should be of the power absorption type with variable inertia load capabilities. Installation of the dynamometer should be such that the vehicle is level.

6.1.1 VEHICLE SPEED—The dynamometer apparatus should include a

TABLE 1—OXYGEN EQUIVALENTS OF COMMON GASES

Gas 100% Concentration	Equivalent Percent of Oxygen	Gas 100% Concentration	Equivalent Percent of Oxygen
Acetylene, C_2H_2	−0.612	Hydrogen bromide, HBr	−0.968
Allene, C_3H_4	−0.744	Hydrogen chloride, HCl	−0.650
Ammonia, NH_3	−0.479	Hydrogen fluoride, HF	−0.253
Argon, A	−0.569	Hydrogen iodide, HI	−1.403
Bromine, Br_2	−1.83	Hydrogen sulfide, H_2S	−0.751
1, 2-butadiene, C_4H_6	−1.047	Krypton, Kr	−0.853
1, 3-butadiene, C_4H_6	−0.944	Methane, CH_4	−0.512
n-butane, C_4H_{10}	−1.481	Neon, Ne	−0.205
iso-butane, C_4H_{10}	−1.485	Nitric oxide, NO	+44.2
1-butene, C_4H_8	−1.205	Nitrogen, N_2	−0.358
cis-2-butene, C_4H_8	−1.252	Nitrogen dioxide, NO_2	+28.7
iso-butene, C_4H_8	−1.201	Nitrous oxide, N_2O	−0.56
trans-2-butene, C_4H_8	−1.274	n-octane, C_8H_{18}	−2.84
Carbon dioxide, CO_2	−0.623	Oxygen, O_2	+100
Carbon monoxide, CO	−0.354	n-pentane, C_5H_{12}	−1.81
Ethane, C_2H_6	−0.789	iso-pentane, C_5H_{12}	−1.853
Ethylene, C_2H_4	−0.553	neo-pentane, C_5H_{12}	−1.853
Helium, He	−0.059	Propane, C_3H_8	−1.135
n-heptane, C_7H_{16}	−2.508	Propylene, C_3H_6	−0.903
n-hexane, C_6H_{14}	−2.173	Water, H_2O	−0.381
cyclo-hexane, C_6H_{12}	−1.915	Xenon, Xe	−1.34
Hydrogen, H_2	−0.117		

$$\text{Interference} = \frac{\text{Equivalent \% } O_2 \times \text{Observed concentration}}{100}$$

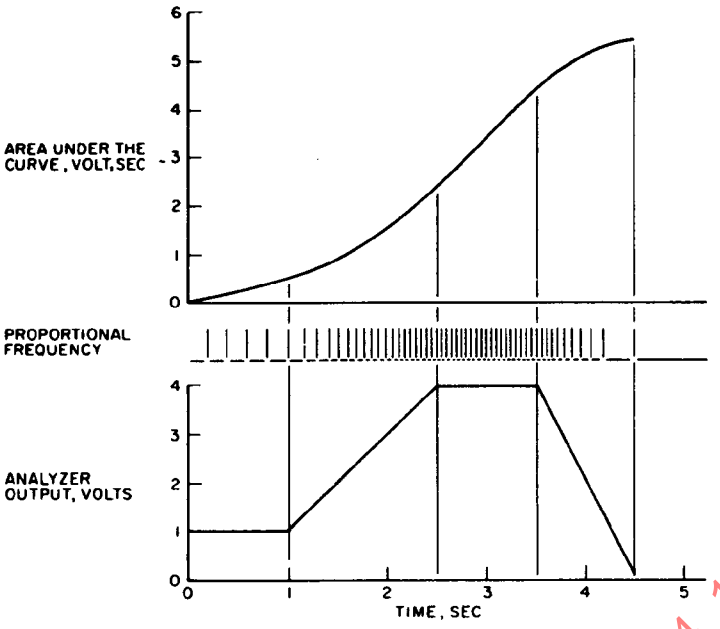


FIG. 12—INTEGRATION USING VOLTAGE-TO-FREQUENCY CONVERSION

means to read and/or record (on a strip chart recorder) vehicle speed (mph).

6.1.2 Power Absorption Unit—The power absorption unit must be adjustable for road-load conditions. For good repeatability, the dynamometer absorption unit should be warmed up by running for several minutes before horsepower settings are made. Refer to SAE J1263 "Road Load Measurement and Dynamometer Simulation Using Coastdown Techniques" for an indication of acceptable repeatability.

6.1.3 Vehicle Inertia—Under transient conditions, vehicle inertia must be reproducible on the vehicle test dynamometer. This is commonly accomplished through the use of flywheels, with the appropriate inertia loading, 57 kg (125 lb) increment, for the weight of the vehicle. Electrical simulation of inertia weight may also be used.

6.2 Engine Dynamometers—Engine dynamometers can be used, but the exhaust emission results will not necessarily correlate with those from chassis dynamometer tests. Carburetor air inlet temperature or engine soak temperatures during engine dynamometer tests must approximate those obtained with a chassis dynamometer.

6.3 Air Flow Measuring Systems—Air flow measurements are often requested to complement exhaust emission measurements.

6.3.1 Intake Air

6.3.1.1 *Orifice Plate Meter*—The orifice plate has been successfully used for many years to measure the carburetor airflow of laboratory engines, both single and multicylinder. When used correctly, the orifice plate air meter provides a reliable, accurate method for measuring carburetor airflow. For good results, the orifice meter must be designed for proper inlet and outlet conditions. In addition, it must be recognized that serious errors in flow measurements can be caused by engine pulsations, either in the form of pressure waves traveling through the air with the speed of sound, or by pulsations in the flow of air itself. These errors are introduced because the differential manometer, or other recording device positioned across the orifice, indicates approximately the arithmetic mean differential pressure, while the airflow varies with the mean square root of the differential pressure.

Errors due to pressure variations may be reduced by insuring that the pressure lines leading to the meter have equal coefficients of discharge for inflow and outflow, and the capacity in the lines and meter on each side of the mercury or water column are equal. Errors due to velocity variations change with many factors, and the variations should be minimized since there is no satisfactory manner for making proper corrections. These velocity pulsations can be reduced by increasing the capacity of the line between the engine and meter and by increasing the pressure drop between the engine and the atmospheric side of the orifice meter. Most orifice meters used with laboratory engines are combined with large surge chambers to reduce the effect of velocity pulsations so that correct airflow measurements can be made. The orifice plate airflow meter is, therefore, used primarily for steady-state airflow measurements.

6.3.1.2 *Laminar Flow Meter*—During recent years, laminar flow meters have been developed for measurement of carburetor airflow of automobiles during all normal operating modes. In order to minimize the possibility of disturbing normal air-fuel mixture distribution, the laminar flow element can be adapted to fit most carburetor air cleaner housings. The flow element is usually constructed with hundreds of small triangular openings, which are formed by winding a crimped, stainless-steel sheet sandwiched between two flat sections. A matrix element is formed in which all of the passages have the same triangular geometry. These elements form a bundle of capillary columns having sufficient length-to-diameter ratio to assure laminar flow throughout the engine operating regime. With proper design and construction, Reynolds numbers can be kept low and the pressure drop across the laminar flow meter can approximate that of the standard air cleaner. A major advantage of the laminar element airflow meter is compactness. Since no surge tank is needed, the units can be used for road tests as well as laboratory measurements. Even with engine pulsations, the flow rate indicated by the laminar element is correct. When used in conjunction with electronic transducers and electronic integrators, the laminar element flow meter can be used to record airflow during transient flow conditions. Precautions should be taken to make sure that all sources of air inducted into the engine are measured.

6.3.1.3 *Smooth Approach Orifice*—The SAO, like the laminar flow element (LFE) is a "differential pressure" meter. As the flow is drawn through the SAO, a differential pressure is produced, which is caused by the energy losses encountered in accelerating the fluid into the SAO and discharging the fluid into the plenum. The SAO's flow pressure relationship is not linear like an LFE. The SAO follows approximately a square root function: $Q = k\sqrt{P}$. The SAO is much less sensitive to viscosity changes than an LFE but is sensitive to the fluid density. The main advantage of an SAO is that it is much less susceptible than the laminar flow element to physical damage and contamination. The SAO can be visually inspected without disassembly, while an LFE must be completely disassembled. Further, the LFE must be recalibrated after each assembly.

6.4 Cooling System

6.4.1 Chassis Dynamometer—For a vehicle undergoing exhaust emissions testing on a chassis dynamometer, engine cooling is maintained by utilizing the vehicle's normal water-cooling system and a fixed-speed cooling fan. The cooling fan should have a capacity of 150 ± 8 m³/min (5300 ± 300 cfm).

The cooling fan should be located immediately in front of the vehicle's normal cooling air inlet with the hood or engine compartment lid open. Additional cooling to maintain the equivalent of road temperatures may be used.

6.4.2 Engine Dynamometer—The engine cooling system on the engine dynamometer test stand can resemble, as nearly as possible, the system intended for the vehicle application with additional airflow being provided

TABLE 2—TEST FUEL SPECIFICATIONS

Item	ASTM	Leaded	Unleaded
Octane, research, min	D2699	98	93
Sensitivity, min		7.5	7.5
Lead (organic), grams/U.S. gallon		1.4[a]	0.00—0.05
Distillation Range:			
IBP[b], °F	D86	75–95	75–95
10 pct point, °F	D86	120–135	120–135
50 pct point, °F	D86	200–230	200–230
90 pct point, °F	D86	300–325	300–325
EP, °F (max)	D86	415	415
Sulfur, weight percent, max	D1266	0.10	0.10
Phosphorus, grams/U.S. gallon, max		0.01	0.005
RVP[c,d] pounds per square inch	D323	8.7–9.2	8.7–9.2
Hydrocarbon composition:			
Olefins, percent, max	D1319	10	10
Aromatics, percent max	D1319	35	35
Saturates	D1319	[e]	[e]

[a] Minimum.
[b] For testing at altitudes above 1219 m (4000 ft) the specified range is 75—105.
[c] For testing which is unrelated to evaporative emission control, the specified range is 8.0—9.2.
[d] For testing at altitudes above 1219 m (4000 ft) the specified range is 7.9—9.2.
[e] Remainder.

by the cooling fan described in paragraph 6.4.1. If this system is not convenient, an external source for cooling water can be used; however, if good correlation between engine and chassis dynamometer tests is desired, care should be taken to reproduce, as nearly as possible, the cooling water temperature as compared with the chassis dynamometer test.

7. *Test Procedures*

7.1 Vehicle (Engine) Preparation—Preparation and preconditioning operations must be performed on all test vehicles prior to any exhaust emission testing in order to insure the acquisition of reliable and valid emission measurements. These operations are necessary to help minimize the introduction of scatter in the data due to variations in engine operation, ambient temperature conditions, and changing the crankcase oil.

7.1.1 Ambient Temperature—Temperatures during the soaking prior to cold-start emission tests shall be maintained between 20 and 30°C (68 and 86°F). During actual testing, the ambient temperatures should be held between 20 and 30°C (68 and 86°F). For best repeatability, the temperatures should be maintained even more closely at 24 ± 1°C (75 ± 2°F).

7.1.2 Preliminary Operation—The vehicle should then be checked and set, if necessary, to the manufacturer's tune-up specifications. The following list of precautionary checks could serve to insure that the vehicle's engine is in proper operating condition:

(a) Cylinder compression,
(b) Choke calibration and idle settings,
(c) Ignition system operation,
(d) Exhaust heat valve operation, and
(e) Ignition timing operation.

7.1.3 Test Fuel—The fuel recommended for testing purposes should conform to the specifications shown in Table 2. The purpose of using this particular fuel is to allow correlations to be established with laboratories that are geographically separated. If a different fuel is used, its characteristics should be recorded with the test data.

The test fuel may be stored in the test vehicle fuel tank, or in a safety-approved auxiliary vessel which can be connected to the vehicle fuel system. If the test fuel is to be stored in the vehicle fuel tank, the fuel system should be purged and kept free of pump-grade fuel. When fuel evaporative emissions are to be measured, the fuel and fueling requirements specified in the SAE procedure for evaporative emissions should be followed.

APPENDIX A—HISTORICAL MEASUREMENT TECHNOLOGY

A1. Variable Rate Proportional Sampler—In order to measure the emissions from moving vehicles, a portable sampling system has been developed that collects a fixed fraction of the total exhaust discharged from a vehicle. This device, the Variable Rate Proportional Sampler, is an electromechanical, servomechanism designed to collect an exhaust sample at a rate that is proportional to engine airflow. The sampler system (Fig. A-1) consists of five functional units: inlet air measuring system, sample collection and transfer module, control module, ice bath condenser, and electrical supply.

The inlet-air measuring system consists of a laminar flow metering element and housing in conjunction with the stock carburetor air cleaner for the test vehicle. The flow element matrix is described in paragraph

FIG. A-1—PROPORTIONAL SAMPLER

6.3. The matrix is mounted in a housing attached to the air cleaner to provide airflow through the snorkel opening and minimize effects on cylinder-to-cylinder distribution. The flow element is sized to provide a pressure drop of the order of 2.5 cm (1 in) of water at a flow of 8 m³/min (150 cfm) to prevent carburetor enrichment due to a choking effect. The laminar element housing is designed with a flow straightener at the air inlet, with pressure taps across the laminar element for a pressure transducer, and with a carburetor-temperature sensor to provide a signal for flow correction.

The sample collection and transfer module contains the sample handling equipment consisting of a laminar sample flow element and transducer, a servo-operated flow control valve, a sample-temperature transducer, a vacuum pump, and a plastic sample bag. The sample bag is contained in a sealed housing which is pressurized or evacuated to permit moving the sample in or out of the bag without passing it through a pump.

The control module contains a pair of carrier-demodulators for the carburetor and sample flow transducers, integrators to total carburetor and sample flow, a recorder for carburetor air and exhaust sample temperature, and a servo amplifier which operates the sample flow control valve to hold proportionality between sample and carburetor airflow.

An ice-bath condenser is used to remove moisture from the exhaust gas sample before the gas reaches the sample flow element. This is to prevent errors introduced by moisture condensing in the capillary passage of the laminar element.

Electrical power is provided by an inverter, with good voltage regulation capability and with a capacity of approximately 250 W of 120 V, 60 Hz, from the 12 V system of the test vehicle. During calibration and laboratory operation, the sampler can be operated from line voltage.

The sampler is installed in the car with the control module on the front seat accessible to the driver. The other components are usually placed in the rear passenger compartment.

Prior to collecting an exhaust sample, the sample bag is partially filled with nitrogen from a portable cylinder. The purpose of the nitrogen dilution is to reduce reactions within the exhaust sample during the collection and storage period before an analysis is made. Sufficient nitrogen should be introduced to provide a final dilution of nitrogen to exhaust of at least three to one.

Before sample collection is initiated, sampler controls are adjusted with the sampler in a bypass configuration, so the operator can determine if the sampler is operating properly. At the starting point of the test route,