

CONTINUOUS HYDROCARBON ANALYSIS OF DIESEL EMISSIONS—SAE J215

Report of Automotive Emissions and Air Pollution Committee approved November 1970.

Purpose—This SAE Recommended Practice provides for the continuous measurement of the hydrocarbon concentration in diesel exhaust.

Scope—The method presented is the current recommendation for the use of flame ionization detectors to determine the hydrocarbon content of diesel engine exhaust, or exhaust of vehicles using diesel engines, when operating at steady-state. The requirements of the associated sampling system and a general procedure for a continuous measuring method are presented.

Sections—This report is divided into the following sections:

1. Definition of Terms and Abbreviations
2. Equipment
3. Instrument Operating Procedures
4. Engine Test Procedure
5. Data to be Recorded
6. Data Analysis and Report
7. Supplementary Discussion

1. Definitions of Terms and Abbreviations

1.1 Terms Used

1.1.1 EXHAUST EMISSION—Any substance emitted into the atmosphere from any opening downstream from the exhaust port of the combustion chamber.

1.1.2 DIESEL ENGINE—Any compression ignition internal combustion engine.

1.1.3 STEADY-STATE CONDITION—An engine operating at a constant speed and load and at stabilized temperatures and pressures.

1.1.4 RATED SPEED—The speed at which rated horsepower is obtained.

1.1.5 **RATED HORSEPOWER**—The maximum brake horsepower output of an engine as stated in the sales and service literature or as certified by the manufacturer.

1.1.6 HORSEPOWER—The observed brake horsepower unless otherwise indicated.

1.1.7 FLAME IONIZATION DETECTOR—A hydrogen-air diffusion flame detector that produces a signal proportional to the mass flow rate of hydrocarbons entering the flame per unit time.

1.1.8 HYDROCARBONS—All organic materials including unburned fuel and combustion byproducts present in the exhaust which are detected by the flame ionization detector.

1.1.9 PARTS PER MILLION CARBON—The mole fraction of hydrocarbon measured on a methane equivalence basis.

1.1.10 CALIBRATING GAS—Gas of known concentration used to establish instrument hydrocarbon response.

1.1.11. SPAN GAS—A calibrating gas used routinely to check instrument hydrocarbon response.

1.1.12 AIR ZERO GAS—Air containing less than 2 ppm hydrocarbon on a methane equivalence basis.

1.2 Abbreviations Used

A/F—Air/fuel ratio
atm—Atmosphere, atmospheric
bhp—Brake horsepower
C—Degrees Centigrade
cfh—Cubic feet per hour
cfm—Cubic feet per minute
CHA—Continuous hydrocarbon analyzer
conc.—Concentration
cm—Centimeters
DI—Direct injection
diam—Diameter
exh—Exhaust
F—Degrees Fahrenheit
F/A—Fuel/air ratio
FID—Flame ionization detector
gm—Gram(s)
H₂—Hydrogen
HC—Hydrocarbon

He—Helium
Hg—Mercury
ID—Internal diameter
kg—Kilogram
l—Liter(s)
lb—Pound(s)
m—Meter(s)
max—Maximum
min—Minimum, minute(s)
mI—Milliliter(s)
N₂—Nitrogen
NA—Naturally aspirated
O₂—Oxygen
OD—Outside diameter
PC—Precombustion chamber engine
ppm—Parts per million
ppmc—Parts per million carbon
rpm—Revolutions per minute
s—Second(s)
SS—Stainless steel
TC—Turbocharged
wt—Weight
%—Percent

2. Equipment

2.1 Instruments—The Continuous Hydrocarbon Analyzers (CHA) recommended for measuring unburned hydrocarbons in diesel exhaust can be of a positive pressure burner type (Fig. 1) or a reduced pressure burner type (Fig. 2). In both systems a fraction of the engine exhaust stream flows through a heated sampling line and filters to the sample pump inlet. The sample stream is split with a fraction of the exhaust stream sample diverted to the burner. The sample split is made upstream of the pump inlet in the reduced pressure system and downstream of the pump outlet in the positive pressure system. The burner in both systems (Figs. 1 and 2) is a flame ionization detector; the system components are described in paragraph 2.2. The system

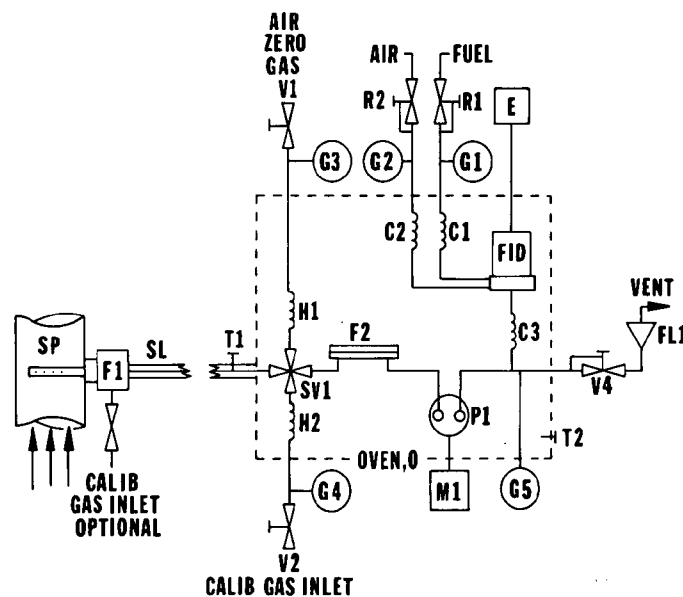


FIG. 1—CHA POSITIVE PRESSURE BURNER

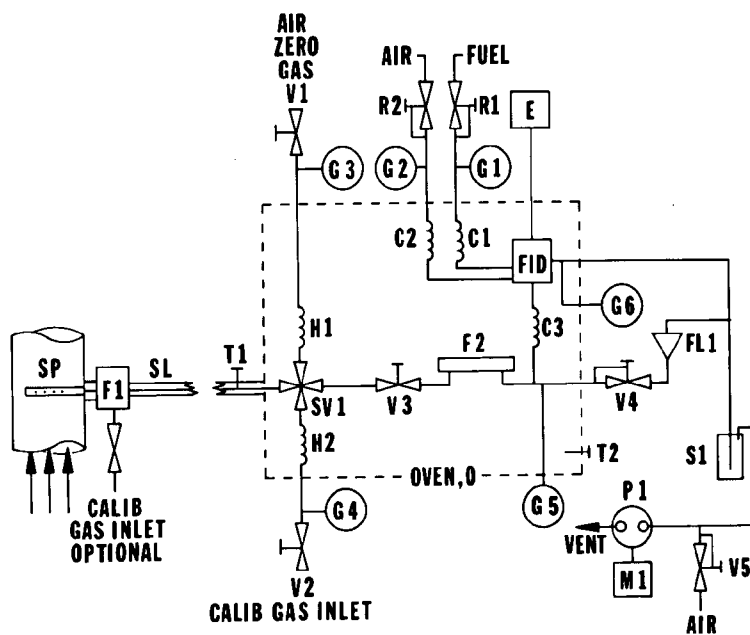


FIG. 2-CHA REDUCED PRESSURE BURNER

employed should be capable of measuring hydrocarbons over a range of 10-6000 ppmc and have the ability to follow rapid changes in hydrocarbon concentration. Response with diesel exhaust should be at least 90% of maximum in 30 s.

2.2 Component Description—The following components are utilized in the CHA of Figs. 1 and 2. All parts are common to both systems unless otherwise stated.

2.2.1 Pressure regulators, R1 and R2, pressure gages, G1 and G2, and capillary tubes or restrictors, C1 and C2, to control air and fuel flows to CHA detector burner. C1 and C2 should be maintained at constant temperature ± 2 C (± 3.6 F). Optional—Flow controllers and flowmeters may be used in place of R1, R2, G1, and G2.

2.2.2 Flame ionization detector, FID, capable of operating in the range of 150-200 C (302-392 F).

2.2.3 Electrometer, E, coupled to a recorder, meter, or other comparable readout device may be used.

2.2.4 Constant temperature oven, O, for detector and sampling system components, capable of operating in the range of 150-200 C (302-392 F) and holding temperature ± 2 C (± 3.6 F).

2.2.5 Stainless steel sample probe, SP, to obtain sample from the exhaust system. A closed end, multihole static probe extending at least 80% across the exhaust pipe is recommended. The probe location should be governed by the purpose of the test. For routine emission measurements, the probe should be located in the exhaust line at a distance of 1-3 m from the exhaust manifold outlet flange or the outlet of the turbocharger.

2.2.6 Heated prefilter, F1, spun Pyrex glass in line to remove soot and reduce acoustic effects in sample flow (optional).

2.2.7 Sampling line, SL, must be heated as required to maintain a sample temperature equal to that of the oven compartment. Construction of line should be of stainless steel or stainless steel and Teflon.¹ A 0.635 cm OD or 0.9525 cm OD line is recommended. The line should be kept short, preferably less than 3 m in length.

2.2.8 Temperature readout, T1, of sample stream entering oven compartment.

2.2.9 Suitable valving, SV1, for selecting sample, span gas or air zero gas flow to the system. The valve(s) should be in the oven compartment or heated. Optional—Use external pump to supply sufficient heated clean air to flush the entire system when not calibrating or sampling.

2.2.10 Valves, V1 and V2, and gages, G3 and G4, to regulate calibration gas and air zero gas.

2.2.11 Coils, H1 and H2, to preheat calibration gas and air zero gas.
Optional—Introduce gases into sampling line near probe inlet.

2.2.12 Filter, F2, to remove particulates. A 7 cm dia glass fiber type filter disc is suitable. Filter should be readily accessible and changed daily or more frequently as needed.

2.2.13 Regulating valve, V3, (reduced pressure system only) to control pressure in sample line.

2.2.14 Sample pump, P1, and motor, M1. In the positive pressure system, the pump is mounted inside the oven and the motor is mounted outside. In the reduced pressure system, both are outside the oven. The pump used in the positive pressure system should not affect the emission concentration or composition.

2.2.15 Capillary tubing or restrictor, C3, to control sample flow to the detector.

2.2.16 Pressure gage, G5, to measure pressure in sample line. Pressure tap should be located near the capillary line (C3) takeoff and designed to minimize velocity effects.

2.2.17 Pressure regulator valve, V4, to control pressure in sample line and flow to detector. This valve could be connected across the detector in the vacuum system. The valve should be maintained at a temperature above the dew point. Optional—Use a fixed restrictor and vary the pump speed to control the pressure.

2.2.18 Vacuum gage, G6, (reduced pressure system only) to measure pressure in detector or cannister. Optional—Combine with G5 and use one gage to measure pressure drop across detector.

2.2.19 Surge tank, S1, (reduced pressure system only) to stabilize flow. Tank, if required, should be sized for system. A 1-2 l tank is suggested for 2 l/min sample flow.

2.2.20 Flowmeter, FL1, (reduced pressure system) to measure sample bypass flow. Maintain above dew point. Flowmeter is optional on positive pressure system.

2.2.21 Vacuum regulator, V5, (reduced pressure system only) to control vacuum in detector.

2.2.22 Oven temperature readout, T2, thermocouple or equivalent.

3. Instrument Operating Procedures—Follow the instrument manufacturer's startup and operating procedure for the particular type CHA. In addition, the following minimum calibration and instrument checks should be included.

3.1 Calibration and Instrument Checks

3.1.1 INITIAL—The following instrument checks may have been determined by the manufacturer. If not, they should be evaluated prior to instrument use.

3.1.1.1 Optimize Detector Response

(a) Set burner fuel and air settings as prescribed by the manufacturer. Ignite the burner. Set sample flows recommended by the manufacturer.

(b) Set the oven temperature at 160 ± 10 C (320 ± 18 F). Allow at least $1\frac{1}{2}$ hr after heatup for system to reach equilibrium.

(c) Determine optimum burner fuel flow for maximum response. Introduce a constant continuous concentration of propane in N_2 . Use about 500 ppmc hydrocarbon concentration. Vary burner fuel flow and determine peak response. Select an operating flow that gives maximum response and the least variation in response with minor flow variations. Normally, there is a plateau in the region of peak response.

¹Registered trademark.

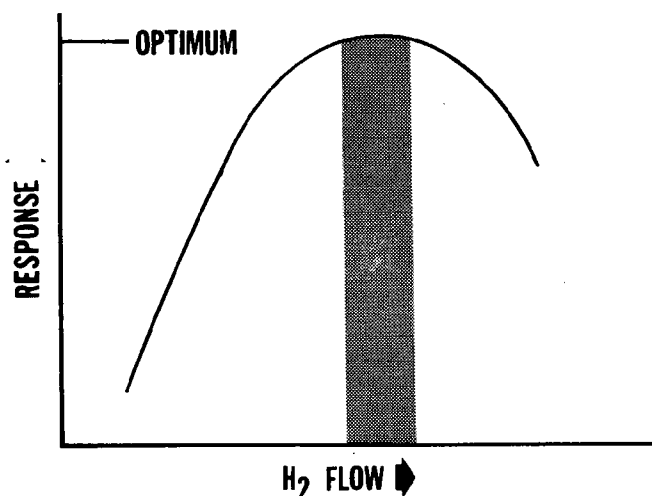


FIG. 3—EFFECT OF HYDROGEN FLOW

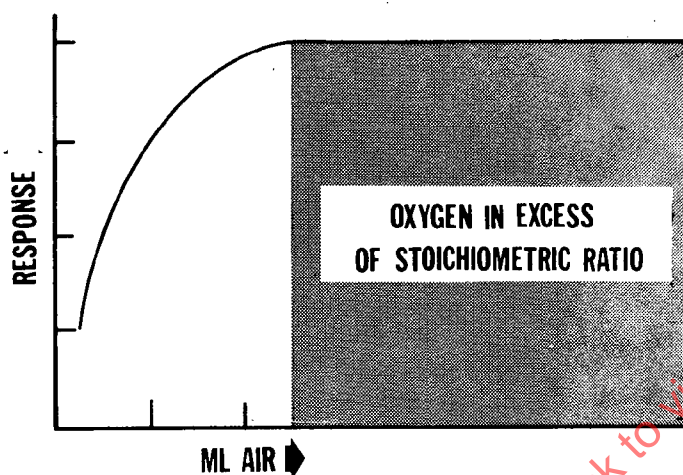


FIG. 4—EFFECT OF AIR FLOW

(see Fig. 3). Use best judgment in selecting optimum fuel flow.

(d) Determine optimum air flow. Set burner fuel flow as determined in paragraph 3.1.1.1(c) and vary air flow. Although less critical than burner fuel flow, nonoptimized conditions may reduce quantitative accuracy. If air flow is too low, response is low. High air flow may result in increased noise. A typical curve is shown on Fig. 4. Select desired air flow and, if it is significantly different than that used in paragraph 3.1.1.1(c), repeat step (c).

(e) Measure optimum flows accurately and record.

3.1.1.2 *Determine Oxygen Response Curve of CHA*—Excess air in diesel exhaust can cause variations in detector response. This effect is due to the oxygen concentration in the sample and its magnitude must be determined and minimized.

(a) Ignite burner and set flows as determined in paragraph 3.1.1.1. Set oven temperature as in paragraph 3.1.1.1 and allow at least ½ hr after heat up for system to reach equilibrium.

(b) Introduce air zero gas and zero the analyzer.

(c) Determine oxygen response by introducing propane calibration gases in the following carrier gases: 100% N₂, 90% N₂/10% O₂, 85% N₂/15% O₂, 100% air.

The concentration level of the propane should equal the expected upper HC level, or about 1000 ppmc. The HC concentration and O₂ concentration should be known within ±2% of true value (see paragraph 7.1).

Recheck zero after each calibration gas is used. If zero has changed by more than 2% of the measure response value, rezero and repeat the test.

(d) Using propane in air as the baseline for no O₂ correction, plot a curve of oxygen correction versus the percent of oxygen in the sample (see Fig. 5). If the O₂ correction is less than ±2% at the oxygen levels present in the exhaust sample, no O₂ correction need be applied to the observed HC concentrations. If the correction is greater than ±2%,

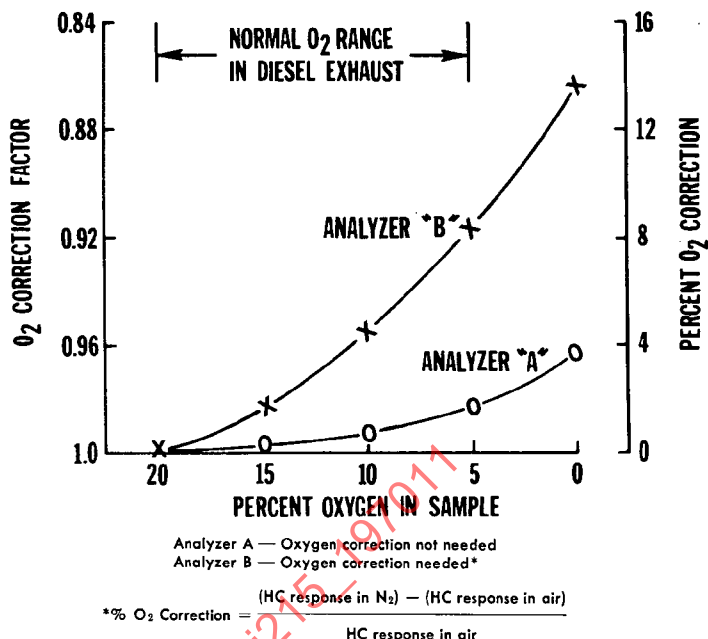


FIG. 5—FID OXYGEN INTERFERENCE

apply an O₂ correction to all measured values as follows:

Corrected ppmc = (observed ppmc) × (O₂ correction)

(e) Check effect of O₂ using a propane concentration typical of the expected lower HC level that will be encountered engine tests, or about 100 ppmc. If significantly different from the 1000 ppmc data in paragraph 3.1.1.2(d), establish curve and apply the O₂ correction on a prorated basis as a function of the measured concentration.

(f) If the oxygen response correction in paragraphs 3.1.1.2(d) and (e) is greater than 4% over the normal O₂ range encountered in diesel exhaust (Fig. 5), see paragraph 7.2.

3.1.1.3 *Determine Linearity of CHA*

(a) Ignite burner. Set flows as determined in paragraphs 3.1.1.1 and 3.1.1.2.

(b) Set temperatures as in paragraph 3.1.1.1 and allow at least ½ hr after heatup for system to reach equilibrium.

(c) Using propane in air, vary the concentration of HC. If response is linear, record response per ppmc. If the response is not linear over the expected operating range, prepare a calibration curve.

3.1.1.4 *System Operating Temperature*

(a) The initial operating temperature recommended is 160 ± 10 C (320 ± 18 F).

(b) The optimum system operating temperature should be checked as discussed in paragraph 7.3.

3.1.2 **MONTHLY**—These checks are to be made monthly or more frequently if there is any doubt regarding accuracy of HC values.

3.1.2.1 Ignite burner. Set air, fuel, and sample rates as determined in paragraphs 3.1.1.1 and 3.1.1.2.

3.1.2.2 Set system temperatures as determined in paragraph 3.1.1.4. Allow at least ½ hr after heatup for the system to come to equilibrium.

3.1.2.3 Introduce air zero gas and zero the analyzer.

3.1.2.4 Check oxygen effect on response by introducing calibration gases of propane in air, propane in nitrogen, and propane in 90% N₂, 10% O₂. The hydrocarbon and O₂ concentrations should be known within ±2% accuracy.

3.1.2.5 Recheck zero after measuring each span gas. If zero varies by more than 2% of the measured response, rezero and repeat step 3.1.2.4.

3.1.2.6 Compare oxygen response values with previous curves. Any significant (±10%) change in response reflects a change in the burner operating characteristics; that is, air, fuel, or sample flow rates. Check for leaks or plugged capillaries and remeasure flows. If change in response cannot be resolved, establish a new oxygen response curve as per paragraph 3.1.1.2.

3.1.2.7 Check calibration curve or response data as per paragraph 3.1.1.3(c).

3.1.3 **DAILY**—Prior to daily testing, carry out the following:

3.1.3.1 Ignite burner. Set air, fuel, and sample rates as determined

in paragraphs 3.1.1.1 and 3.1.1.2.

3.1.3.2 Insert clean filters.

3.1.3.3 Set system temperatures as determined in paragraph 3.1.1.4. Allow at least ½ hr after heatup for the system to come to equilibrium.

3.1.3.4 Introduce air zero gas and zero the analyzer.

3.1.3.5 Introduce HC span gas (propane in air) appropriate to anticipated operating range. (See paragraph 7.4.) Check agreement with calibration curve. (NOTE: Sample flow for air zero gas and calibration gas should be the same as exhaust sample flow.) If calibration curve and value differ by more than $\pm 2\%$, check and adjust flows as necessary. Recheck zero and span gas response. If there is still more than $\pm 2\%$ difference, repeat paragraph 3.1.1.3(c).

3.1.3.6 Conduct analyses. Recheck zero after each analysis. If zero changes by more than 2% or more of measured value, rezero and repeat test. Caution: Do not mistake HC hangup for zero change.

3.1.3.7 At the conclusion of the test, flush the system and clean out the sampling line.

4. Engine Test Procedure—The following test procedure is recommended for emission measurements at steady-state operating conditions. The engine operating cycle is not dictated by this procedure and the engine break-in, pretest conditioning, and measurement procedure may be modified depending on the purpose of the test; that is, emission certification or routine laboratory development test.

4.1 Engine Break-In Procedure—The engine shall be run-in according to the manufacturer's recommendation.

4.2 Emission Measurement Procedure

4.2.1 Install probe and connect CHA to exhaust system.

4.2.2 Start the engine and warm it up. Complete warmup at rated speed and full load for 10 min or until all temperatures and pressures have reached equilibrium.

4.2.3 Operate for at least 20 min in each mode for emission stabilization, allowing last 5 min for emission measurement.

4.2.4 Measure hydrocarbon emissions as follows:

4.2.4.1 Follow daily instrument procedure (paragraph 3.1.3).

4.2.4.2 Analyze exhaust for at least 5 min during each mode.

4.2.4.3 Check and reset zero and span after each mode; if either changed more than 2% of measured response, repeat the mode.

4.2.5 Chart reading—HC determination as follows:

4.2.5.1 Locate last 3 min of each test and average the chart reading over this 3 min period.

4.2.5.2 Determine the concentration of hydrocarbons as ppmc at each point by the following equation or the calibration curve from paragraph 3.1.1.1(c).

$$\text{HC conc.} = \frac{\text{Measured response}}{\text{Span gas response/ppmc in span gas}}$$

4.2.5.3 Correct concentration obtained in paragraph 4.2.5.2 for oxygen effect as determined in paragraph 3.1.1.2.

4.2.5.4 Additional mass calculations may be required, depending on the purpose of the test.

5. Information to be Recorded—The following information should be included as part of the recorded data for each test performed. A typical data sheet is shown in Fig. 6.

5.1 Test number.

5.2 Engine or vehicle tested:

(a) Identification number.

(b) Brief description including type precombustion or direct injection (PC or DI), naturally aspirated or turbocharged (NA or TC), 2- or 4-cycle, bore and stroke.

5.3 Date.

5.4 Instrument operator and test engineer or vehicle operator.

5.5 Starting and finishing time.

5.6 Analyzer identification.

5.7 Ambient temperature, start and finish of testing.

5.8 Number of engine conditions tested.

5.9 Atmospheric pressure, start and finish of testing.

5.10 Relative humidity, start and finish of testing.

5.11 Fuel used, identification number, and type (No. 1 or No. 2 diesel, etc.).

5.12 Lube oil used, identification number and type.

5.13 Oven temperature.

5.14 Sample line temperature.

5.15 Burner fuel and flow rate and/or pressure.

5.16 Air flow rate and/or pressure.

5.17 Sample flow rate, pressure and/or pressure drop in capillary.

5.18 Engine data at test point.

5.19 Analysis data at each test point.

5.20 Recorder chart notations:

(a) Items 5.1, 5.2, 5.3, and 5.4.

(b) Identify zero traces, calibration or span traces, steady state test point identification, start and finish of each condition.

(c) Instrument range used at each test point.

(d) Time of analysis.

(e) Remarks.

6. Calculations, Data Analysis and Report—Data from paragraph 5 should be checked for any obvious errors. The exhaust gas concentration of hydrocarbons as measured in this procedure are determined by the following equation:

$$\text{HC conc., ppmc} = \left(\frac{\text{Measured diesel response}}{\text{Span gas response/ppmc in the span gas}} \right) (\text{O}_2 \text{ corr})$$

where: ($\text{O}_2 \text{ corr}$) = oxygen correction determined in paragraph 3.1.1.2.

Mass calculations can be made using the ppmc and the calculated or measured engine exhaust flow rate. A typical emission report sheet is shown on Fig. 7.

7. Supplementary Discussion

7.1 Calibration Gases—There are several suppliers of the calibration gases used in this procedure. The gases can be obtained with an analysis by the supplier indicating an accuracy of $\pm 2\%$ or better. However, it is recommended that internal cross checks be made on all incoming standards. If a difference greater than $\pm 2\%$ is indicated, comparison with a reference standard is advised.

7.2 Reducing the Oxygen Effect on Response—The oxygen correction should be reduced to attain the limits described in paragraph 3.1.1.2. The oxygen effect on response for a particular FID burner design may depend on (1) the type of burner fuel used, for example, H_2 , 40% H_2 /60% N_2 , or 40% H_2 /60% He ; (2) on the sample flow rate into the burner; and (3) the air and fuel rate to the burner. The oxygen effect may be reduced by changing one or more of the above variables. The effect of these variables should be investigated in the order shown above using the procedures described in paragraphs 3.1.1.1 and 3.1.1.2. It is recommended that a different detector be obtained if the oxygen correction factor over the normal oxygen range found in diesel exhaust exceeds 10%.

EMISSION DATA WORK SHEET									
TEST NO. _____	DATE _____	ENGINE NO. _____							
ENGINE DESCRIPTION _____									
DATE OF MANUFACTURE _____		ENGINE HOURS _____							
FUEL USED _____		OIL USED _____							
TIME STARTED _____		TIME FINISHED _____		NO. OF TEST POINTS _____					
ENGINE OPERATOR _____		INSTRUMENT OPERATOR _____							
ANALYSIS DATA									
ANALYZER NO. (S) _____									
		START		FINISH					
AMBIENT TEMPERATURE, C (F) _____		_____		_____					
ATM. PRESSURE IN. HG _____		_____		_____					
OVEN TEMPERATURE, C (F) _____		_____		_____					
EXHAUST SAMPLE FLOW, L/MIN _____		_____		_____					
BURNER FLOW OR PRESSURE _____		_____		_____					
POINT NO.									
ENGINE:									
RPM									
BHP									
BMFP									
FUEL RATE, LB/MIN									
AIR, LB/MIN									
SMOKE (OPTIONAL)									
INLET AIR TEMPERATURE, C (F)									
EXHAUST TEMPERATURE, C (F)									
EXHAUST SYSTEM BACK PRESSURE, IN. H_2O									
AIR/FUEL RATIO									
O_2 IN EXHAUST, %									
HYDROCARBONS:									
SAMPLE LINE TEMPERATURE, C (F)									
CHART READING									
PPMC*									
GM/HR									
REMARKS: _____									

*CORRECTED FOR FID O_2 EFFECT.									

FIG. 6—EMISSION DATA WORK SHEET