

RECOMMENDED HEAVY DUTY GASOLINE
INSTRUMENTATION AND TEST PROCEDURES

To the User: This recommended practice reflects the experience of industry and government to date. This practice is subject to change as new data are gathered and experience is obtained.

Environmental Protection Agency
Office of Air and Waste Management
Office of Mobile Source Air Pollution Control
Emission Control Technology Division
Standards Development and Support Branch

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I. Test sequence and dynamometer equipment.

- A. (1) The following nine-mode cycle shall be followed in dynamometer operation tests of gasoline-fueled heavy duty engines.

Sequence No.	Mode	Observed Torque (% of max. observed)	Time in Mode-secs.	Cumulative Time-secs.	Weighting Factors
1	Idle	Idle	60	60	0.232
2	Cruise	25	60	120	.077
3	PTA	55	60	180	.147
4	Cruise	25	60	240	.077
5	PTD	10	60	300	.057
6	Cruise	25	60	360	.077
7	FL	90	60	420	.113
8	Cruise	25	60	480	.077
9	CT	CT	60	540	.143

- (2) The engine dynamometer should be operated at a constant speed of 2,000 r.p.m. \pm 100 r.p.m. (Speed deviations, should not exceed 200 r.p.m. during the first four seconds of each mode.)

- (3) The idle operating mode shall be carried out at the manufacturers recommended engine speed. Arrive at the last idle mode by closing the throttle and unloading the dynamometer or by actuating a clutch mechanism. The CT operating mode should be carried out at the same engine speed as in paragraph A. (2) of this section.

B. The following equipment should be used for dynamometer tests.

- (1) An engine dynamometer capable of maintaining constant speed \pm 100 r.p.m. from full throttle to closed throttle motoring.
- (2) A chassis-type single pipe exhaust system shall be used. Standard or specially fabricated "Y" pipes may be used for "V" type engines, however the probe location shall conform to III-C-1 and this location is to be at least three feet downstream of the "Y" intersection.
- (3) A radiator typical of that used with the engine in a vehicle, or other means of engine cooling which will maintain the engine operating temperatures at approximately the same temperature as would the radiator, shall be used to maintain engine cooling during sustained operation on the dynamometer.

II. Dynamometer procedures.

An initial 5-minute idle, one warmup cycle, and one hot cycle constitute a complete dynamometer run. Idle modes may be run at the beginning and end of each test, thus eliminating the need to change speed between cycles.

III. Instrumentation

A. Schematic Drawing.

- (1) Fig. IIIA-1 is a schematic drawing of the exhaust gas sampling and analytical system which shall be used for testing under the regulations in the subpart. All components or parts of components that are wetted by the sample or corrosive calibration gases should be either chemically clean stainless steel or teflon. Use of hydrocarbon derivatives such as Buna-N for packings, seals, diaphragms or any other device that may come in contact with the sample or span gas is not recommended. The use of "gauge savers or protectors" with nonreactive diaphragms is permissible and recommended.

B. System Components.

The following is a list of components shown in Fig. IIIA-1 by numeric identifier. Pressure ranges and accuracies when given are suggested values. Any component indicated as being heated means maintaining that component at 125°C; +10°C, -5°C (257°F; +18°F, -9°F).

- (1) Filters.
 - (a) F1 - Particulate filter.
 - (b) F2 - Particulate filter.
 - (c) F3 - Heated particulate filter.
- (2) Flowmeters FL 1 and FL 2 to indicate sample flow rates through the CO and CO₂ analyzers.
- (3) Gauges (0-15" H₂O) G1 and G2 to measure input pressure to CO and CO₂ analyzers and any unwanted changes in downstream restrictions.
- (4) Pressure gauges.
 - (a) P1 - bypass pressure (0-20 psig).
 - (b) P2, P3, P4, and P5 - sample or span pressure at inlet to flow control valves (0-10 psig).

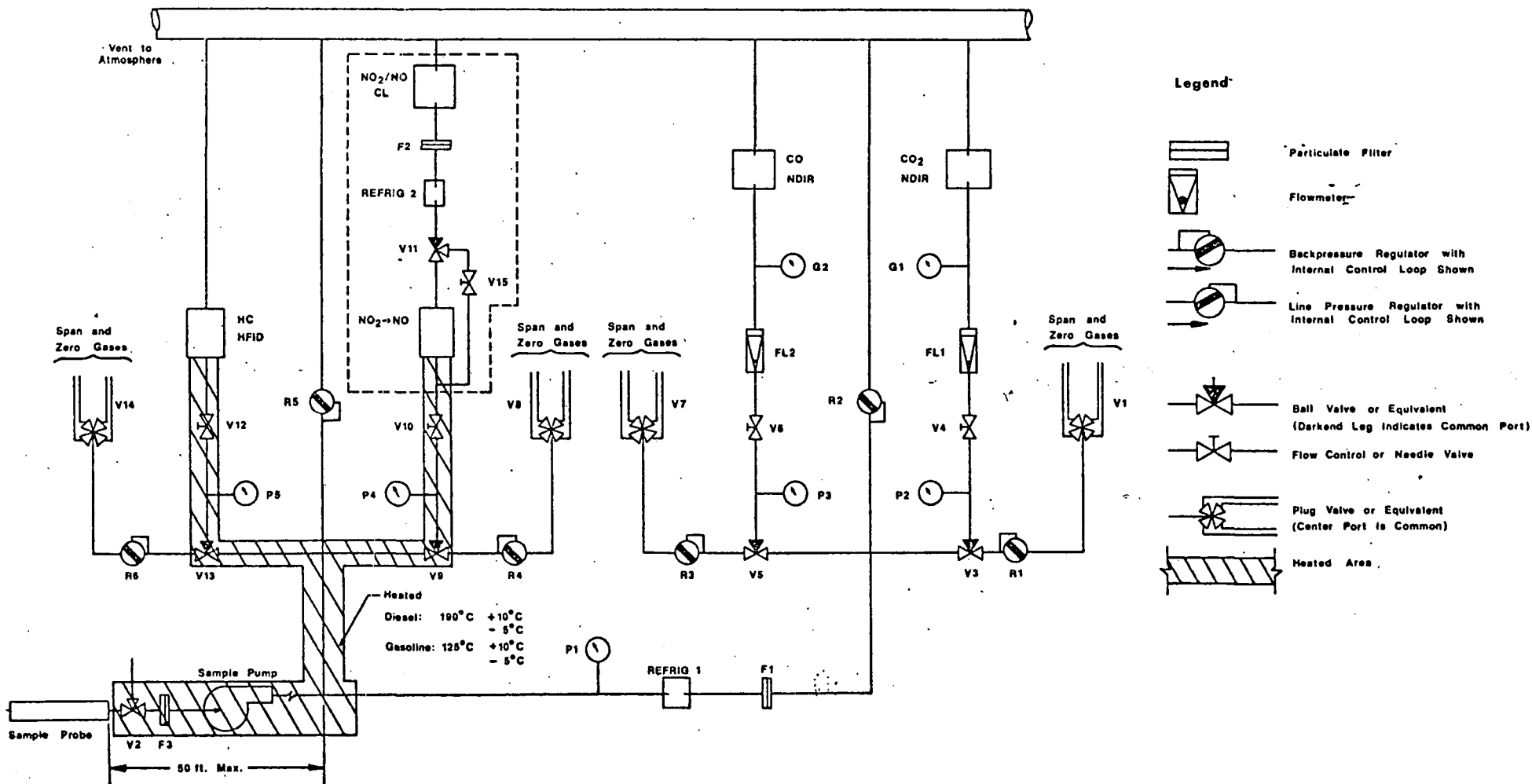


Fig. III A-1
Heavy Duty Exhaust Gas
Sampling and Analytical Train

- (5) Refrigerator or ice bath water traps (Temperature: 0-3 °C, 32-37°F) REF1 and REF2 to remove water vapor from the sample. May include suitable method for draining trap.
- (6) Regulators.
 - (a) R1, R3, R4, and R6 - line pressure regulators to control span pressure at inlet to flow control valves (0-10 psig \pm 2" H₂O).
 - (b) R2 and R5 - back pressure regulators to control sample pressure at inlet to flow control valves (0-10 psig \pm 2" H₂O).
- (7) Valves.
 - (a) V1, V7, V8, and V14 - selector valves to select zero or calibration gases.
 - (b) V2 - Optional heated selector valve to purge sample probe.
 - (c) V3 and V5 - Selector valves to select sample or span gases.
 - (d) V4, V6, and V15 - flow control valves.
 - (e) V9 and V13 - heated selector valve to select sample or span gases.
 - (f) V10 and V12 - heated flow control valves.
 - (g) V11 - Selector valve to select NO_x or bypass mode in the chemiluminescence analyzer.
- (8) Pump - sample transfer pump to transport sample to analyzers (1.5 CFM at free flow).

C. Component Description (exhaust gas sampling).

The following components are recommended for the exhaust gas sampling system.

- (1) Sampling probe. The sample probe shall be closed end, stainless steel, multi-hole probe 1/4 inch outside diameter extending at least 80% across the exhaust pipe. There shall be a minimum of 3 ports in probe covering approximately equal areas of the duct and oriented such that they face into the exhaust stream. The orifices should be sized such that each port has approximately the same flow. The probe shall be located approximately three to nine feet downstream from the exhaust manifold outlet

flange or turbocharger exit flange and this position must be downstream of any exhaust emission control device(s) (catalyst, etc.).

- (2) Sample transfer. The exhaust gas sample shall be transferred to the analytical instruments through a heated filter and heated line by a hot pump. The heated line shall be of stainless steel or teflon construction and have an I.D. between .18 and .32 inches. The sample line wall temperature must be maintained at $125^{\circ} + 10^{\circ}\text{C}$, -5°C (257°F , $+18^{\circ}\text{F}$, -9°F) with a maximum line length of 50 ft. The sample pump shall be located as close as practical to the sample probe and the wetted surfaces of the pump must be heated. The pump must be capable of transporting the sample from the probe to the analyzers in 5 seconds or less. The filter must also be heated.

D. Component Description (exhaust gas analysis system).

- (1) Total hydrocarbon measurement (HC). The determination of hydrocarbon concentrations is to be ascertained by a heated flame ionization detector (FID). See the Appendix for general design specifications.
- (2) Oxides of Nitrogen Measurement (NO_x). The concentration of Oxides of Nitrogen ($\text{NO} + \text{NO}_2 = \text{NO}_x$) is to be determined by a chemiluminescence analyzer in the (NO_x) mode. This requires the (NO_2) in the sample to be converted to (NO) by the converter before analyzing the sample in the reaction chamber. See the Appendix for general design specifications.
- (3) Carbon Monoxide Measurement (CO). The carbon monoxide concentration is to be determined by an NDIR analyzer. See the Appendix for general design specifications. If the turn down ratio of the analyzer is not great enough for the desired application, a combination of two or more separate instruments, two or more separate cells with one amplifier, or a multi-cell analyzer may be used. Accomplish this by adding a selector valve between flowmeter FL2 and gauge G2 (see Fig. IIIA-1). All cell flow paths must be parallel and must have a gauge G2 immediately upstream of all detector cells. Vent all detector cells to atmospheric pressure as shown in Fig. IIIA-1. If the cells are in series optically as in some dual cell arrangements, the cell not in use must be continuously purged with nitrogen (N_2) when analyzing a sample. Furthermore the purge pressure at G2 should be approximately the same as the sample pressure at G2 although the flow rate may be somewhat lower.

- (4) Carbon Dioxide Measurement (CO₂). The carbon dioxide concentration is to be determined by an NDIR analyzer. See the Appendix for general design specifications.

E. Venting. The method of disposing of the sample is not specified. However, caution must be used in routing of the vent lines:

- (1) Venting of the instruments, especially the NDIR analyzers, must be such that the analyzer vent does not see a back pressure caused by the proximity of other vents.
- (2) Pressure relief vents provided by some manufacturers of regulators and located in the bonnet of the regulator should be vented to the atmosphere.

IV. Information.

The following information, as applicable, should be recorded for each test.

A. Engine Description.

- (1) Engine identification numbers.
- (2) Date of manufacture.
- (3) Number of hours of operation accumulated on engine.
- (4) Engine family.
- (5) Engine displacement.
- (6) Curb idle r.p.m.
- (7) Warm-up fast idle r.p.m.
- (8) Governed speed.
- (9) Maximum horsepower and torque.
- (10) Maximum horsepower and torque speeds.
- (11) Fuel consumption at maximum power and torque.
- (12) Number of carburetors.
- (13) Number of carburetor venturies.
- (14) Maximum torque at 2000 r.p.m.
- (15) Fuel consumption at maximum torque at 2000 r.p.m.
- (16) Maximum air flow at 2000 r.p.m.

B. Test data.

- (1) Test number.
- (2) Instrument operator.
- (3) Engine operator.
- (4) Date and time of day.
- (5) Fuel identification, including H/C ratio.
- (6) Ambient temperature in dynamometer testing room.

- (7) Engine intake air temperature and humidity for each mode. Air temperature and humidity measurement should be made within 18 inches of the inlet for engine intake air. Temperature and humidity measurement devices must respond to 90% of a step change between 30 and 120 seconds.
- (8) Barometric pressure.
- (9) Observed engine torque for each mode.
- (10) Intake air flow for each mode.
- (11) Fuel flow and temperature for each mode.
- (12) Sample line temperature. Line temperature shall be taken at a minimum of three locations, two of which should be the sample probe outlet and instrumentation inlet.
- (13) Sample line residence time (Refer to section VI).
- (14) Date of most recent analytical assembly calibration.
- (15) All pertinent instrument information such as tuning-gain-serial numbers-detector number-range.
- (16) Recorder chart. Identify for each test mode: zero traces for each range used-calibration or span traces for each range used - emission concentration traces and associated analyzer range(s) - start and finish of each test.
- (17) Record chart speed of recorder and date of last speed calibration. The minimum chart speed allowed is 3 inches per minute.
- (18) Record engine torque and engine r.p.m. continuously on the same chart.
- (19) All chart recorders (analyzers, torque, r.p.m., etc.) should be provided with automatic markers which indicate one second intervals. Preprinted chart paper (one second intervals) may be used in lieu of the automatic markers provided the correct chart speed is used.

V. Calibration and instrument checks.

- A. Calibrate the analytical assembly including recorder chart speeds at least once every 30 days. Use the same flow rate and chart speed as when analyzing samples.
 - (1) Perform a pressure leak check per section VI.
 - (2) Adjust analyzers to optimize performance. See the Appendix.

- (3) Zero the hydrocarbon analyzer with zero grade air and the carbon monoxide, carbon dioxide, and oxides of nitrogen analyzers with zero grade nitrogen. The allowable zero gas impurity concentrations should not exceed 0.1 p.p.m. equivalent carbon response, 1 p.p.m. carbon monoxide, 400 p.p.m. carbon dioxide, and 0.1 p.p.m. nitric oxide.
 - (4) Calibration gas concentrations shall be determined within $\pm 1.0\%$ of the absolute value.
 - (5) Set the CO and CO₂ analyzer gains to give the desired range. Select desired attenuation scale of the HC analyzer and adjust the electronic gain control to give the desired full scale range. Select the desired scale of the NOx analyzer and adjust the phototube high voltage supply or amplifier gain to give the desired range. Normally, zero and gain adjustment should be performed on the lowest anticipated range.
 - (6) Calibrate the HC analyzer per the Appendix.
 - (7) Calibrate the CO analyzer with carbon monoxide (nitrogen diluent) gases and the CO₂ analyzer with carbon dioxide (nitrogen diluent) gases having nominal concentrations of 20, 30, 40, 50, 60, 70, 80, and 90 percent of full scale of each range used.
 - (8) Calibrate the NOx analyzer per the Appendix.
 - (9) Check NOx converter efficiency per the Appendix.
 - (10) Compare values obtained on all analyzers with previous calibration curves. Any significant change reflects some problem in the system.
- B. Verification and instrument checks should be performed in accordance with section VI on in-use systems.
- C. For the purposes of this section, the term "zero grade air" includes artificial "air" consisting of a blend of nitrogen and oxygen with oxygen concentrations between 20.0- and 22.0-mole percent.
- D. Calibrate the dynamometer test stand and other instruments for measurement of power output and the fuel flow measurement instrumentation at least once every 180 days.

VI. Sampling procedures.

A. HC, CO, CO₂ and NOx measurements. Allow a minimum of 2 hours warmup for the CO, CO₂, HC, and NOx analyzers. (Power is normally left on for the infrared, chemiluminescence, and FID analyzers; but when not in use, the chopper motors of the infrared analyzers are turned off and the phototube high voltage supply of the chemiluminescence analyzer is placed in the standby position. Also, leaving the flame and the oven "on" in the FID leads to a more stable response.) The following sequence of operations should be performed in conjunction with each series of measurements:

(1) Replace or clean filters.

(2) After the filter(s) have been replaced or cleaned, check the sampling system for any leaks that could dilute the exhaust gas. If during the test, the filters are replaced or cleaned, a leak check must be performed after the test is completed. This post test leak check must be performed after hangup checks are made. The pressure side leak check may be borrowed from the 30 day check of the system. Check sample system leakage in the following manner:

(a) Vacuum Side

(A) Cap the probe or sample line at the probe fitting.

(B) Measure the flow at the discharge of the pump.

(C) If the measured flow exceeds 2.0 cc/min, effect repairs to the system.

(b) Pressure Side

(A) Vent the inlet of the pump to the atmosphere.

(B) Cap the sample line at the point the line connects to the analysis train.

(C) Measure the flow at the inlet to the pump.

(D) If the measured flow exceeds 10.0 cc/min, effect repairs to the system.

(E) All other pressure fittings may be checked by using the bubble-check method. Various commercial preparations are available for this purpose. Fitting leakage should be corrected.

- (3) Introduce the zero grade gases at the same flow rates used to analyze the test samples and zero the analyzers on the lowest anticipated range that may be used during the test. Record a stable zero for each anticipated range that may be used during the test prior to the test. Record these zero values for each analyzer.
- (4) Introduce span gases to the instruments under the same flow conditions as were used for the zero gases. Adjust the instrument gains on the lowest range to be used to give the desired value. Span-gases should have a concentration greater than 65% of full-scale for each range used. A significant shift in gain setting indicates an instrument or system problem. If necessary, recheck calibration and span-gas concentration-label. Record the response to the span-gas and the span-gas concentration for each anticipated range that may be used during the test prior to the test. Record these values for each analyzer.
- (5) Recheck zeros; repeat the procedure in subparagraphs (3) and (4) of this paragraph, if required.
- (6) Check sample line temperature and sample residence time. To check sample residence time:
 - (a) Introduce HC span gas into sampling system at sample inlet and simultaneously start timer.
 - (b) When HC instrument indication is 15 percent of full-scale, stop timer.
 - (c) If elapsed time is more than 5.0 seconds, make necessary adjustments.
 - (d) Repeat (a) through (c) with CO, CO₂, and NO_x instruments and span gases.
- (7) Sample residence-time may be used from previous tests if all of the following conditions are met:
 - (a) The same size and type of pump is used.
 - (b) The sample line I.D. is the same and the length is equal to or shorter than the tested line.
 - (c) The sample line temperature is the same ($\pm 5^{\circ}\text{C}$, 9°F).
 - (d) Pressure gauges P1, P2, P3, P4, and P5 read the same pressure ($\pm 15\%$ of original value).

- (8) Check instrument flow rates and pressures.
- (9) Operate the engine in accordance with section VII. Measure HC, CO, CO₂, and NOx volume concentration in the exhaust sample. Record data specified in section IV. Should the emission volume concentration exceed 95% of full-scale value for non linear instruments (100% of full-scale value for linear instruments) or respond less than 20% of full-scale value, (for all instruments) the next higher or lower analyzer range should be used per the Appendix. Note: the lower limit (20% of full-scale) does not apply when the full-scale value is 120 ppm (or ppm C) or less. Should the fuel flow instrument read below 20% of full-scale value, a smaller flow measurement unit must be used unless the option in the Appendix is desired.
- (10) Each range that may be used during a test must have the zero and span responses recorded prior to the execution of that test. Only the range(s) used to measure the emissions during a test are required to have their zero and span recorded after the completion of the test. If the difference between the span-gas response and the zero-gas response has changed more than ± 2.0 percent, the test should be rerun after instrument maintenance. In addition the test should be rerun if the zero response changes more than ± 6.0 percent of full scale. If the zero response has changed less than ± 2.0 percent, the pre-test zero response is to be used. However if the response change is between ± 2.0 and ± 6.0 percent of full scale, a zero response correction based on an interpolation which is linear with time is acceptable.

B. Sample system contamination.

- (1) Care shall be taken to avoid loading of the sampling system with raw fuel discharged during engine starting.
- (2) When the sample probe is in the exhaust stream and sampling is not in process, a back purge with air or an inert gas may be necessary to protect the probe and sample line from particulate buildup which could affect hydrocarbon readings. Check sample line for contamination before and after each test. Use the following procedure to check the sample line:

- (a) With the HC analyzer calibrated on the lowest range to be used for the test, and the sample line at the required temperature, check the sample-line hangup at least 45 minutes prior to the start of the test sequences. Introduce an HC zero-gas into the sample probe. If the instrument reading increases from the calibrated-zero reading by more than 5.0 percent of full-scale, the sample-line shall be purged or cleaned as required to bring the instrument reading within limits.
- (b) Within 10 minutes after the completion of the post-test zero and span check of the analyzers, check the sample-line hangup. Remove the probe from exhaust pipe. Turn the engine off. Introduce an HC zero-gas into the sample probe. If the instrument reading increases from the calibrated-zero reading by more than 5.0 percent of full scale, rerun the test.

VII. Dynamometer test run.

- A.
 - (1) Mount test engine on the engine dynamometer.
 - (2) Install instrumentation and sample probe as required.
- B. Precondition the engine by the following steps.
 - (1) The engine should be turned off and allowed to stand for a minimum of 5 hours.

NOTE: The engine is not required to be installed in a test cell to meet this requirement. The engine may be in transit to another laboratory.
 - (2) The engine should be started and operated at:
 - (a) Zero load at the manufacturer's warm-up fast idle speed for 1 minute.
 - (b) A torque load equivalent to 10 ± 3 percent of the most recent determination of maximum torque for 4 minutes.
 - (c) A torque load equivalent to 55 ± 5 percent of the most recent determination of maximum torque for 35 minutes.
 - (3) Check the manufacturer's specifications as required. This check should be performed within 10 minutes.
 - (4) Determine the maximum torque of the engine at the speed specified in section I.

- (a) After the engine has reached the speed specified in section I, run the engine at wide open throttle. Record the high and low torque reading during the second minute of operation at wide open throttle. Do not operate the engine at wide open throttle for more than 3 minutes. The average of the recorded high and low torque readings is the maximum torque value for the test.
 - (b) Calculate the torque corresponding to 10, 25, 55, and 90 percent of the maximum torque value determined.
- (5) Determine the analyzer ranges required for each mode to meet the range specifications of section VI. The engine must not be operated for more than 5 minutes.
 - (6) The engine shall be turned off and allowed to stand for at least 1 hour, but not more than 2 hours, at an ambient temperature of $25^{\circ}\text{C} \pm 5^{\circ}\text{C}$ ($77^{\circ}\text{F} \pm 9^{\circ}\text{F}$).
 - (7) Should it be determined that the test must be rerun, and if the time requirements of section VII.B(6) have not been exceeded, then only the preconditioning specified in that section need be performed prior to continuing with the test.
- C. The following steps should be taken for each test:
- (1) Maintain dynamometer test cell temperature ambient temperature at $25^{\circ}\text{C} \pm 5^{\circ}\text{C}$ ($77^{\circ}\text{F} \pm 9^{\circ}\text{F}$).
 - (2) Observe sampling procedures in section VI. Zero and span emission analyzers.
 - (3) Start cooling system.
 - (4) Start engine and idle at manufacturer's warm-up fast idle specification for 5 minutes.
 - (5) Release the choke-idle-stop (if necessary) and return the engine throttle control to the curb idle position, start sample flow and recorders, and begin test sequence of section I.
 - (6) Check analyzer and spans as required for section VI.
 - (7) The calculated-torque values from section VII are used as the control parameters for the test sequence of section I. During the test the observed torque value for each mode should not deviate more than ± 2.0 percent of maximum torque from the calculated-torque value.

- (8) Perform test sequence of section I. Repeat this sequence until a total of two consecutive test sequences have been completed.

VIII. Chart reading.

The exhaust gas analyzer recorder response always lags the engine's operation because of a variable exhaust system delay and a fixed sample system delay. Therefore, the analyzer responses for each mode may not be located on the charts at a point corresponding to the exact time of the mode. A computer or any other automatic data processing device may be used as long as the system meets the requirements under this subpart. For each warmup or hot cycle to be evaluated, proceed as follows:

- A. Determine whether the cycle was run in accordance with the procedure specified in section I by observing either chart pipe, speed trace, torque trace, or concentration traces. The test should be invalidated if there is a deviation by more than: (1) two seconds from the specified time for the CT mode, or (2) ± 2 percent of maximum torque during each mode excluding the first 10 seconds of each mode, or (3) 200 r.p.m. during the first 4 seconds of each mode, or 100 r.p.m. during the remainder of each mode.
- B. Time correlate the hydrocarbon, carbon monoxide, carbon dioxide, and nitric oxide charts. Determine the location on the chart of analyzer response corresponding to each mode. Determine and compensate for trace abnormalities.
- C. Determine concentrations.
 - (1) For all modes except the CT mode, locate the last 10 seconds for each of these modes. Integrate the chart reading to determine the percent of full-scale deflection of the CO₂, CO, HC, and NO_x analyzers during this 10 seconds.
 - (2) For all CT modes, locate the last 50 seconds for each of these modes. Integrate the chart reading to determine the percent of full-scale deflection of the CO₂, CO, HC, and NO_x analyzers during this 50 seconds.
 - (3) If the excursion from a straight line (other than instrument noise) during these specified time intervals is less than 1 percent of full scale, a simple average may be used to determine analyzer deflection.

- (4) For each mode, determine the concentration of the CO₂, CO, HC, and NOx during the time interval specified from the percent of full scale analyzer deflection, span gas response, range correction factor, linearity curves, and other calibration data.

IX. Calculations

The final reported test results should be derived through the following steps.

- A. Determine the exhaust species volume concentration for each mode of each test sequence as described in section I as required by specific instructions in section VIII.
- B. Convert the measured hydrocarbon (HC) volume concentration to dry basis per the following:

$$\text{wet-concentrations} = K_W \times \text{dry-concentrations}$$

where:

$$K_W = \frac{1}{1 + \left[\alpha \left(\frac{\text{DCO}_2}{10^2} + \frac{\text{DCO}}{10^6} \right) + \frac{2Y}{\phi} \left(\frac{\text{DCO}_2}{10^2} + \frac{\text{DCO}}{10^6} + \frac{\text{WHC}}{10^6} \right) \left(1 + \frac{\alpha}{4} \right) - 2 \left(1 + \frac{\frac{\text{DCO}}{10^6}}{\left(\frac{\text{DCO}_2}{10^2} \right) K} \right) \right]}$$

α = atomic hydrogen/carbon ratio

DCO = CO volume concentration in exhaust, ppm (dry)

DCO₂ = CO₂ volume concentration in exhaust, % (dry)

WHC = HC volume concentration in exhaust, ppm C (wet)

K = Water - gas equilibrium constant = 3.5

Y = H₂O volume concentration of intake air, % (See the Appendix)

ϕ = fuel-air ratio (actual)/fuel-air ratio (stoichiometric)
(See the Appendix)

- C. Multiply the dry nitric oxide volume concentrations by the following humidity correction factor:

$$K_{(\text{NO})_x} = 0.6272 + 0.00629H - 0.0000176H^2$$

H = humidity of the inlet air in grains of water per pound of dry air (See the Appendix).

- D. Compute the dry (f/a) as follows:

$$(f/a) = \frac{4.77 \left(1 + \frac{\alpha}{4}\right) (f/a)_{\text{stoich}}}{\frac{1}{\bar{X}} - \left(\frac{\text{DCO}}{2\bar{X} (10)^6}\right) - \left(\frac{\text{DHC}}{\bar{X} 10^6}\right) + \frac{\alpha}{4} \left(1 - \frac{\text{DHC}}{\bar{X} (10)^6}\right) - \frac{.75 \alpha}{\left(\frac{K}{\bar{X} (10)^6}\right) + \left(\frac{(1-K)}{1 - \frac{\text{DHC}}{\bar{X} (10)^6}}\right)}}$$

where the stoichiometric (f/a) is

$$(f/a)_{\text{stoich}} = \frac{M_C + \alpha M_H}{138.18 \left(1 + \frac{\alpha}{4}\right)}$$

α = atomic hydrogen/carbon ratio

M_C = Molecular weight of carbon

M_H = Molecular weight of hydrogen

DCO = Dry volume concentration of CO in exhaust, ppm (dry)

DCO_2 = Dry volume concentration of CO_2 in exhaust, % (dry)

DHC = Dry volume concentration of HC in exhaust computed from the wet volume concentration in ppm C by:

$$\text{dry concentration} = \text{wet concentration} / K_W$$

K = water-gas equilibrium constant = 3.5

$$\bar{X} = \text{DCO}_2 / 10^2 + \text{DCO} / 10^6 + \text{DHC} / 10^6$$

Compare the calculated dry (f/a) to the measured fuel and air flow. For a valid test the emission calculated (f/a) must agree within 10% of the measured (f/a) for each mode (idle and CT mode excepted).

E. Calculate the mass emissions of each species in grams per hour for each mode as follows:

$$1) \text{ HC grams/hr} = W_{\text{HC}} = \frac{\frac{\text{DHC}}{10^4} W_f}{\frac{\text{DCO}}{10^4} + \text{DCO}_2 + \frac{\text{DHC}}{10^4}}$$

$$2) \text{ CO grams/hr} = W_{\text{CO}} = \frac{M_{\text{CO}} \frac{\text{DCO}}{10^4} W_f}{(M_{\text{C}} + \alpha M_{\text{H}}) \left(\frac{\text{DCO}}{10^4} + \text{DCO}_2 + \frac{\text{DHC}}{10^4} \right)}$$

$$3) \text{ NOx grams/hr} = W_{\text{NOx}} = \frac{M_{\text{NO}_2} \frac{\text{DKNO}}{10^4} W_f}{(M_{\text{C}} + \alpha M_{\text{H}}) \left(\frac{\text{DCO}}{10^4} + \text{DCO}_2 + \frac{\text{DHC}}{10^4} \right)}$$

where

α = atomic hydrogen/carbon ratio

DCO = CO volume concentration in exhaust, ppm (dry)

DCO₂ = CO₂ volume concentration in exhaust, % (dry)

DHC = HC volume carbon concentration in exhaust, ppm C (dry)

DKNO = NO volume concentration in exhaust, in ppm (dry and humidity corrected)

M_C = Molecular weight of the carbon

(M_C + α M_H) = mean molecular weight of the fuel/carbon atom

M_{CO} = Molecular weight of CO

M_H = Molecular weight of hydrogen

M_{NO₂} = Molecular weight of nitrogen dioxide (NO₂)

W_{CO} = Mass rate of CO in exhaust, grams/hr,

W_f = Mass flow rate of fuel used in the engine, grams/hr
 = (453.59) x (W_f lbs/hr)

W_{HC} = Mass rate of HC in exhaust, grams/hr

W_{NOx} = Mass rate of NO in exhaust, grams/hr

- F. Weight the mass values of BHP, W_{HC} , W_{CO} , W_f , and W_{NOx} for each mode by multiplying the modal mass values by the appropriate modal weighting factor prescribed by section I.
- G. Calculate the brake specific emission for each test sequence by summing the weighted values (BHP , W_{HC} , W_{CO} , and W_{NOx}) from each mode as follows:

$$BSHC(i) = \frac{\sum \text{weighted } W_{HC}}{\sum \text{weighted BHP}}$$

$$BSCO(i) = \frac{\sum \text{weighted } W_{CO}}{\sum \text{weighted BHP}}$$

$$BSNOx(i) = \frac{\sum \text{weighted } W_{NOx}}{\sum \text{weighted BHP}}$$

(i) = Test sequence number (i = 1, 2)

- H. Calculate the brake specific fuel consumption (BSFC) from the non-weighted BHP and W_f values for each mode (except the idle and CT modes) as follows:

$$BSFC = \frac{W_f}{\text{Corrected BHP}}$$

W_f = Fuel flow in lb/hr

$$(1) \text{ Corrected BHP} = BHP \left(\frac{29.38}{BARO} \right) \left(\frac{T + 459.69}{85 + 459.69} \right)^{.5}$$

where:

BARO = Barometric pressure (in Hg A)

T = Temperature of inlet air, °F

- I. Calculate the weighted brake specific fuel consumption (WBSFC) for each test sequence by summing the weighted values (W_f and corrected BHP) from each mode as follows:

$$WBSFC(i) = \frac{\sum \text{weighted } W_f}{\sum \text{weighted corrected BHP}}$$

W_f = Fuel flow in lb/hr

(i) = Test sequence number (i = 1, 2)

- J. Calculate the brake specific emissions and fuel consumption for the complete test as follows:

$$BSHC(T) = 0.35 \text{ BSHC}(1) + 0.65 \text{ BSHC}(2)$$

$$BSCO(T) = 0.35 \text{ BSCO}(1) + 0.65 \text{ BSCO}(2)$$

$$BSNOx(T) = 0.35 \text{ BSNOx}(1) + 0.65 \text{ BSNOx}(2)$$

$$WBSFC(T) = 0.35 \text{ WBSFC}(1) + 0.65 \text{ WBSFC}(2)$$