

RECOMMENDED HEAVY DUTY DIESEL  
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. Instrumentation

### A. Schematic Drawing.

- (1) Figure IA-1 is a schematic drawing of the exhaust gas sampling and analytical system. 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 non-reactive diaphragms is recommended.

### B. System Components.

The following is a list of components shown in Fig. IA-1 by numeric identifier. Pressure ranges and accuracies when given are suggested values. Any component indicated as being heated means maintaining that component at 190°C; +10°C, -5°C (375°F; +18°F, -9°F).

#### (1) Filters.

- (a) F1 - Particulate filter.
- (b) F2 - Particulate filter.
- (c) F3 - Heated particulate filter.

#### (2) Flowmeters FL1 and FL2 to indicate sample flow rates through the CO and CO<sub>2</sub> analyzers.

#### (3) Gauges (0-15" H<sub>2</sub>O) G1 and G2 to measure input pressure to CO and CO<sub>2</sub> 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).

#### (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" H<sub>2</sub>O).

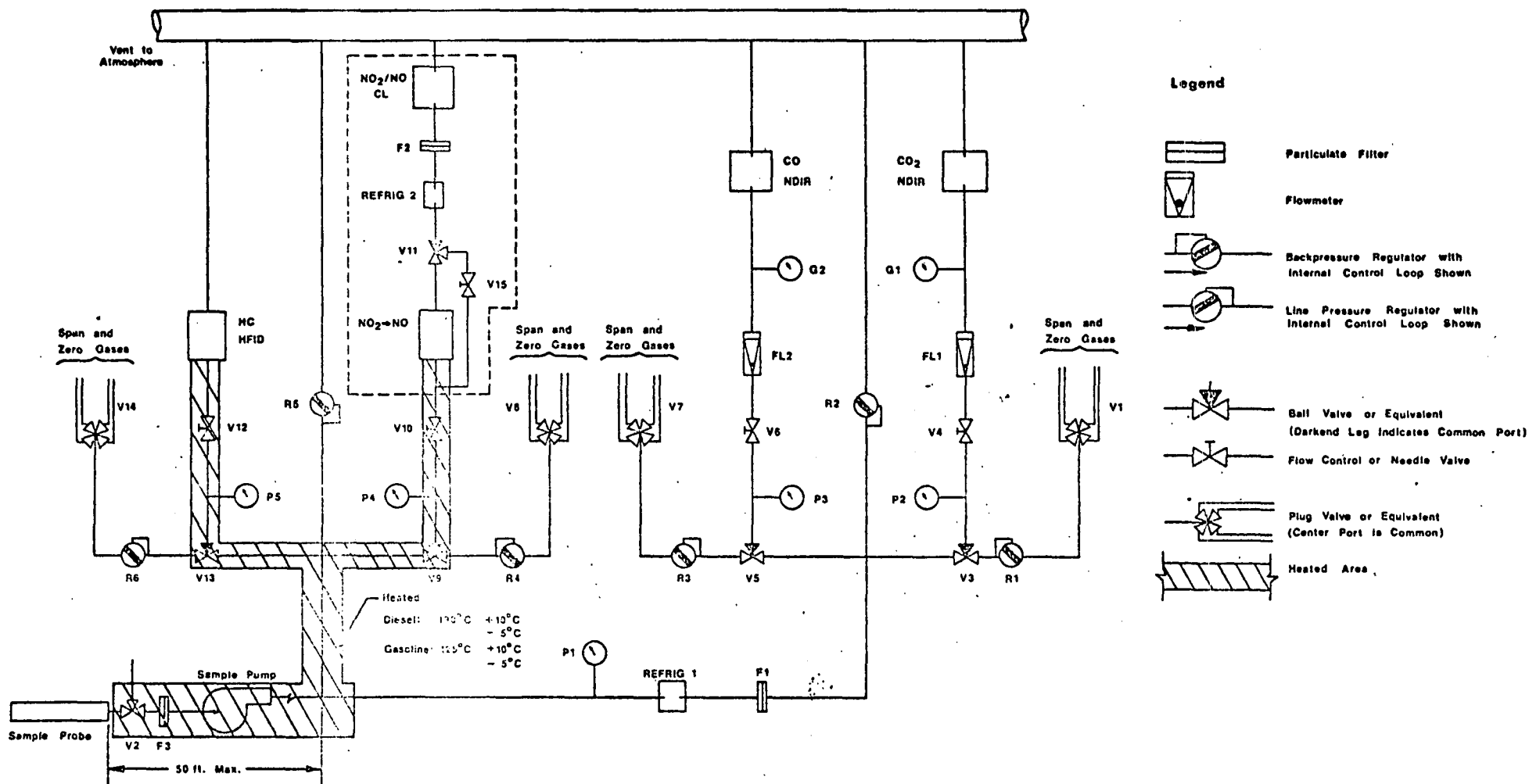


Fig. I A-1

Heavy Duty Exhaust Gas  
Sampling and Analytical Train

(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 V13 - 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<sub>x</sub> 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 a 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 orifice 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 190°C; +10°C, -5°C (375°F; +18°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<sub>x</sub>). 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<sub>x</sub>) mode. This requires the (NO<sub>2</sub>) 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. IA-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. IA-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<sub>2</sub>) 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 (CO<sub>2</sub>). 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.

## II. 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) Exhaust pipe diameters.
- (6) Fuel injector type.
- (7) Low idle rpm.
- (8) Governed speed.
- (9) Maximum power and torque speeds.
- (10) Maximum horsepower and torque.
- (11) Fuel consumption at maximum power and torque.
- (12) Air aspiration system.
- (13) Exhaust system back pressure.
- (14) Air inlet restriction.

### 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 measurements 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 to 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 IV).
- (14) Date of most recent analytical assembly calibration.

- (15) All pertinent instrument information such as tuning-gain-serial numbers-detector numbers-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 .5 inches per minute.
- (18) Record engine torque and engine r.p.m. continuously on the same chart.

### III. 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 IV A.
  - (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 CO<sub>2</sub> 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 CO<sub>2</sub> 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. Verifications and instrument checks should be performed in accordance with Section IV on in-use system.
  - 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.

#### IV. Sampling procedures.

- A. HC, CO, CO<sub>2</sub> and NOx measurements. Allow a minimum of 2 hours warmup for the CO, CO<sub>2</sub>, 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, CO<sub>2</sub>, and NOx 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 (± 5°C, 9°F).
  - (d) Pressure gauges P1, P2, P3, P4, and P5 read the same pressure (± 15% of original value).
- (8) Check instrument flow rates and pressures.
- (9) Operate the engine in accordance with Section V. Measure HC, CO, CO<sub>2</sub>, and NOx volume concentration in the exhaust sample. Record data specified in Section II. 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) would not apply when the full-scale value is 120 ppm (or ppmC) 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 particular mode must have the zero response and span response recorded prior to the emission measurement at least once every 30 minutes. Only the range(s) used to measure emissions need be checked. At the completion of the test the zero response and span response for each range that was used during test should be recorded. If the difference between the span-gas response and the zero-gas response has changed more than ± 2.0 percent of full scale based on the 30 minute check, 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. 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.

V. Test run.

- A. The temperature of the air supplied to the engine shall be between 68°F and 86°F. The fuel temperature at the pump inlet shall be 100°F,  $\pm 10^\circ\text{F}$ . The observed barometric pressure shall be between 28.5 inches and 31 inches Hg. Higher air temperature or lower barometric pressure may be used, if desired, but no allowance shall be made for increased emissions because of such conditions.
- B. The governor and fuel system shall have been adjusted to provide engine performance at the levels specified by the engine manufacturer for maximum rated horsepower and maximum rated torque.
- C. The following steps shall be taken for each test:
  - (1) Install instrumentation and sample probes as required.
  - (2) Observe sampling procedure in Section IV.

- (3) Start cooling system.
- (4) Start the engine, warm it up and precondition it by running it at rated speed and maximum horsepower for 10 minutes or until all temperature and pressures have reached equilibrium.
- (5) Determine by experimentation the maximum torque at rated speed and intermediate speed to calculate the torque values for specified test modes.
- (6) Start the test sequence. Operate the engine for 10 minutes in each mode, completing engine speed and load changes in the first minute. If a delay of more than 10 minutes occurs between the end of one mode and the start of the next mode, discontinue the sequence and repeat the test from Mode No. 1. Record the response of the analyzers on a strip chart recorder for the full 10 minutes with exhaust gas flowing through the analyzers at least during the last 5 minutes. Record the engine speed and load, intake air temperature and restriction, exhaust back pressure, fuel flow and air or exhaust flow during the last 5 minutes of each mode, making certain that the speed and load requirements are met during the last minute of each mode. Fuel flow during idle or 2 percent load conditions may be determined just prior to or immediately following the dynamometer sequence, if longer times are required for accurate measurements.
- (7) Read and record any additional data as required for Section II.
- (8) Check analyzer zero and spans as required for Section IV.
- (9) Backflush condensate trap and replace filters as required, per Section IV.

VI. Chart reading.

- A. Locate the last 60 seconds of each mode. Integrate the chart reading to determine the percent of full scale deflection of the CO<sub>2</sub>, CO, HC, and NO<sub>x</sub> analyzers during this 60 seconds.
  - (1) If the excursion from a straight line (other than instrument noise) during this 60 seconds is less than 1 percent of full scale, a simple average may be used to determine analyzer deflection.

- B. Determine the concentration of the CO<sub>2</sub>, CO, HC, and NO during the last 60 seconds of each mode from the percent of full scale analyzer deflection, span gas response, range correction factor, linearity curves, and other calibration data.

## VII. Calculations.

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

- A. Determine the exhaust species volume concentration for each mode per Section VI.
- B. Convert the measured hydrocarbon (HC) volume concentrations to dry basis per the following:

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

where:

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

$\alpha$  = atomic hydrogen/carbon ratio

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

DCO<sub>2</sub> = CO<sub>2</sub> volume concentration in exhaust, % (dry)

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

K = Water - gas equilibrium constant = 3.5

Y = H<sub>2</sub>O volume concentration of intake air, % (See the Appendix)

$\phi$  = 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:

$$\frac{1}{1+A (H-75) + B (T-85)}$$

where:

$$A = 0.044 (f/a) - 0.0038$$

$$B = -0.116 (f/a) + 0.0053$$

H = humidity of the inlet air in grains of water per pound of dry air.

T = Temperature of inlet air °F.

- 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

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

$\alpha$  = 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<sub>2</sub> = Dry volume concentration of CO<sub>2</sub> 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 2% modes 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:

$\alpha$  = atomic hydrogen/carbon ratio

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

DCO<sub>2</sub> = CO<sub>2</sub> 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)

HC = Molecular weight of the carbon

(M<sub>C</sub> +  $\alpha$  M<sub>H</sub>) = mean molecular weight of the fuel/carbon atom

MCO = Molecular weight of CO

M<sub>H</sub> = Molecular weight of hydrogen

$M_{NO_2}$  = Molecular weight of nitrogen dioxide ( $NO_2$ )

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

$W_f$  = Mass flow rate of fuel used in the engine, grams/hr.  
 =  $(453.59) \times (W_f \text{ lbs/hr.})$

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

$W_{NOx}$  = Mass rate of NOx in exhaust, grams/hr.

F. Weight the values of BHP,  $W_{HC}$ ,  $W_{CO}$ ,  $W_{NOx}$ , and  $W_f$

(1) Average the values obtained from the three idle modes and multiply this value by  $(.02 \div 3)$ . Substitute this value for each of the three idle modes.

(2) Weight the remaining modes by multiplying the values by 0.08.

G. Calculate the brake specific emission for each test by summing the weighted values ( $BHP$ ,  $W_{HC}$ ,  $W_{CO}$ , and  $W_{NOx}$ ) from each mode as follows:

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

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

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

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

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

$$(1) \text{ Corrected BHP} = BHP \left( \frac{29.38}{\text{BARO}} \right) \left( \frac{T + 459.69}{85 + 459.69} \right)^{.7}$$



where:

BARO = Barometric pressure (in Hg A)

$W_f$  = Fuel flow (lb/hr)

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:

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

$W_f$  = Fuel flow in lb/hr

## Appendix

General Design Specifications for Heavy Duty Vehicle Analytical Instruments.

I. Measurement accuracy:

A. All emission analyzers: Listed are suggested ranges for all emission analyzers. Select the appropriate ranges and number of ranges for each analyzer. The analyzers must operate between 20 percent and 95 percent of full-scale value for non-linear instruments (20 to 100 percent for linear analyzers) during the measurement of the emissions for each mode. The exceptions to the lower limit of this operating rule are:

- (1) The analyzer response may be less than 20 percent of full-scale if the full-scale value is 120 ppm (or ppm C) or less.
- (2) The analyzers response may be less than 20 percent of full-scale if the emissions from the engine are irratic and the integrated chart-deflection value is greater than 20 percent of full-scale.
- (3) The analyzer response may be less than 20 percent of full-scale during the initial part of the CT mode provided that the integrated chart-deflection value is greater than 20 percent of full-scale.

The magnitude of full-scale value of the suggested ranges may vary somewhat to suit instrument characteristics or to facilitate data collection.

| <u>Suggested Ranges</u> | <u>Instrument Accuracy</u> |
|-------------------------|----------------------------|
| 0-10. ppm or ppm C      | 5 percent of full-scale    |
| 0-40. ppm or ppm C      | 2 percent of full-scale    |
| 0-100. ppm or ppm C     | 1 percent of full-scale    |
| 0-400. ppm or ppm C     | 1 percent of full-scale    |
| 0-1000. ppm or ppm C    | 1 percent of full-scale    |
| 0-4000. ppm or ppm C    | 1 percent of full-scale    |
| 0-10000. ppm or ppm C   | 1 percent of full-scale    |
| 0-40000. ppm or ppm C   | 1 percent of full-scale    |
| 0-10.00 percent         | 1 percent of full-scale    |
| 0-15.00 percent         | 1 percent of full-scale    |
| 0-20.00 percent         | 1 percent of full-scale    |

B. The dynamometer test stand and other instruments for measurement of power output shall be accurate to within  $\pm 2$  percent of full-scale at all power settings.

C. The fuel flow measurement instrumentation shall have a minimum accuracy of 1 percent of full-scale for each range used. Fuel flow measurements may not be used as official values if the readings are below 20 percent of full scale value unless the point accuracy has an error of less than 5 percent.

II. NDIR instruments: Nondispersive infrared (NDIR) analyzers shall be used for the continuous monitoring of carbon monoxide and carbon dioxide.

A. Analyzer description: The NDIR instruments operate on the principle of differential energy absorption from parallel beams of infrared energy. The energy is transmitted to a differential detector through parallel cells, one containing a reference gas, and the other, sample gas. The detector, charged with the component to be measured, transduces the optical signal to an electrical signal. The electrical signal thus generated is amplified and continuously recorded.

B. Analyzer specification:

Response time (pneumatic)--15 percent of full-scale in 0.5 seconds or less.

Response time (electrical)--95 percent of full-scale in 0.5 seconds or less.

Noise-- $\pm 1$  percent of full scale on most sensitive range.

Repeatability-- $\pm 1$  percent of full scale.

Zero drift--Less than  $\pm 1$  percent of full-scale in 2 hours on all ranges.

Span drift--Less than  $\pm 1$  percent of full-scale in 2 hours on all ranges.

Cell Temperature--Minimum 50°C maintained within  $\pm 2^\circ\text{C}$ .

C. Cell length: All NDIR instruments shall be equipped with cells of sufficient length to accurately measure the exhaust concentrations encountered during the test. (See I A.) Range changes shall be accomplished either by the use of stacked sample cells or changes in the electronic circuitry, or both.

D. Zero suppression: Various techniques of zero suppression may be used to increase readability. Note, that by suppressing the zero response, the

readability of the emission response is increased, but accuracy of this response expressed as a percent of full-scale value does not change.

### III. Total hydrocarbon analyzer:

A. Analyzer description: The measurement of total hydrocarbon is to be made by an analyzer using a flame ionization detector (FID). With this type detector an ionization current proportional to the mass rate of hydrocarbon entering a hydrogen flame is measured by an electrometer amplifier and continuously recorded.

The analyzer shall be fitted with a constant-temperature oven housing the detector and sample-handling components. It shall maintain temperature within  $\pm 2^{\circ}\text{C}$  of the set point.

The detector and sample-handling components shall be suitable for continuous operation at temperatures to  $200^{\circ}\text{C}$ .

#### B. Analyzer specification:

Response time (pneumatic)--15 percent of full-scale in .5 seconds or less.

Response time (electrical)--95 percent of full scale in 0.5 seconds or less.

Noise-- $\pm 1$  percent of full scale on most sensitive range.

Repeatability-- $\pm 1$  percent of full scale.

Zero drift--Less than  $\pm 1$  percent of full scale in 2 hours on all ranges.

Span drift--Less than  $\pm 1$  percent of full scale in 2 hours on all ranges.

Linearity--Response with propane in air shall be linear within  $\pm 2$  percent.

#### C. Detector response optimization:

(1) Follow manufacture's instructions for instrument start-up and basic operating adjustments.

(a) The fuel shall contain  $40 \pm 1\%$  hydrogen. The balance shall be helium. The mixture shall contain less than 2 ppm C hydrocarbon.

(b) The air shall contain  $21 \pm 1\%$  oxygen. Compressed "hydrocarbon-free" grade of atmospheric air meets the oxygen-concentration requirements. The air shall contain less than 2 ppm C hydrocarbon.

(2) Set the oven temperature  $5^{\circ}\text{C}$  hotter than the required sample-line temperature. Allow at least one-half hour after the oven has reached temperature for the system to equilibrate.

(3) Peak the detector: With the fuel and air set at the manufacturer's settings, introduce a mixture of propane in air to the detector. The propane concentration should be approximately  $80 \text{ ppm C} \pm 20 \text{ ppm C}$ . Determine the response at a given fuel flow from the difference between the span-gas response and the zero-gas response. Incrementally adjust the fuel flow above and below the manufacturer's specification. Record the span and zero response at these fuel flows. A plot of the difference between the span and zero response versus fuel flow will be similar to the one shown in Fig III-1. Adjust the fuel flow-rate to the rich side of the curve, as shown. This is an initial flow-rate setting and may not be the final optimized-flow-rate.

(4) Oxygen effect: check the response of the detector with various concentrations of oxygen in the sample. Conduct this test with the oven temperature set as required by step III B (2). The initial fuel flow shall be the same as that determined by step III B (3).

(a) Zero the analyzer with hydrocarbon-free air. Introduce nitrogen ( $\text{N}_2$ ) zero-gas. The response to the nitrogen zero-gas must be less than 0.5 percent of full-scale value of the lowest anticipated range.

(b) The following blends of calibration gases shall be used to determine the effect of oxygen ( $\text{O}_2$ ) in the sample.

| <u>Calibration-Gas</u> | <u><math>\text{O}_2</math> concentration</u> | <u>Balance</u> |
|------------------------|--|----------------|
| Propane                | 21%  | $\text{N}_2$   |
| Propane                | 15%  | $\text{N}_2$   |
| Propane                | 10%  | $\text{N}_2$   |
| Propane                | 5%   | $\text{N}_2$   |
| Propane                | 0%   | $\text{N}_2$   |

The oxygen-concentration blend-tolerance is  $\pm 1\%$  (i.e.  $10 \pm 1\%$  means 9% to 11%). The analysis of the oxygen-concentration must be within  $\pm 1\%$  of the absolute concentration-value. The calibration-gas concentration should be about  $80 \text{ ppm C} \pm 20 \text{ ppm C}$  and must be known within  $\pm 1\%$  of the absolute concentration-value.

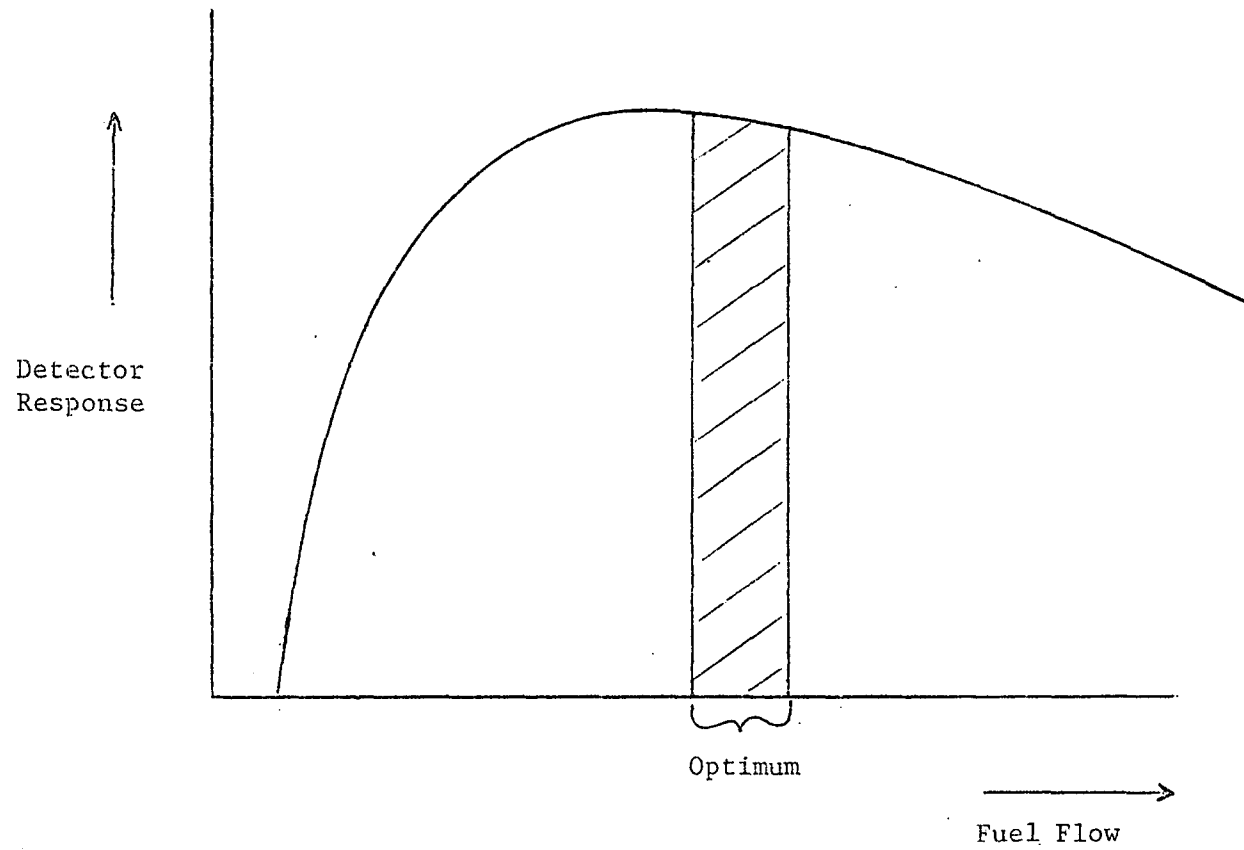


Figure III - I

(c) Calibrate the analyzer with the calibration mixture containing 21% oxygen.

(d) Introduce the calibration mixtures containing the 15, 10, 5 and 0 percent oxygen to the detector in sequence. Record the response to each of the mixtures.

(e) Recheck the zero response. If it has changed, repeat the test.

(f) Calculate the oxygen interference (%  $O_{2I}$ ) for the 15, 10, 5, and 0 percent oxygen-mixtures by equation III-1.

$$(III-1) \% O_{2I} = \frac{Bx - \text{Analyzer Response (ppm C)}}{Bx}$$

where

Bx = hydrocarbon concentration of the oxygen-interference cylinders (15%, 10%, 5% and 0%)

(III-2) Analyzer Response =

$$\frac{[\text{hydrocarbon concentration (ppm C) in the 21\% mixture}]}{\% \text{ of full-scale analyzer response due to 21\% mixture}} (100) (\% \text{ of Full-Scale analyzer response due to Bx})$$

(g) If the oxygen interference for the 15, 10, and 5 percent oxygen mixtures is less than  $\pm 2\%$  and less than  $\pm 2.5\%$  for the zero percent oxygen mixture, then no oxygen-interference correction-factor need be used.

(h) If the oxygen interference is greater than the specifications, incrementally adjust the air flow above and below the manufacturer's specifications, and repeat subparagraphs (c) through (g) of step III C (4).

(j) If the oxygen interference is still greater than the specifications, repair or replace the detector.

(5) Linearity:

(a) With the fuel flow, air flow, and sample flow adjusted to meet the oxygen interference specification, the instrument linearity shall be checked for the ranges covering the range of analysis using propane-in-air with nominal concentrations of 30, 60, and 90 percent of full-scale of each range. The deviation of a best-fit curve from a least-squares best-fit

straight line should not exceed 2 percent of the value at any point. If this specification is met, concentration values may be calculated by use of single calibration factor.

Note, by varying the air, fuel, and sample flow-rates within the boundaries of the oxygen interference specifications, the analyzer may produce a more linear response. If the deviation exceeds 2 percent at any point, concentration values shall be calculated from a calibration curve prepared during this alignment procedure (III C (5)).

(b) With the exception of any possible changes required by subparagraph (6) of III C, the flow-rate, air flow-rate, and sample flow-rate are defined as "optimized" at this point.

(6) Initially, and within every 180 days thereafter, make a comparison of response to the different classes of compounds using (individually) propylene, toluene, n-hexane, and propane, each at 20 to 50 ppm C concentration in air. If the response to propylene, toluene, or n-hexane differs by more than 5 percent from the response to propane, check instrument operating parameters. Reducing sample flow rate generally improves uniformity of response.

#### IV. Oxides of Nitrogen (NOx) Analyzer:

A. Analyzer description: The method of measuring total oxides of nitrogen consists of two distinct operations. First the nitrogen dioxide (NO<sub>2</sub>) in the sample is converted to an equivalent amount of nitric oxide (NO). Next this amount of (NO) is added to the NO that was already in the sample. This total amount of NO is then measured by the chemiluminescence method.

(1) NO<sub>2</sub> → NO Convertor: There are at least two methods of converting NO<sub>2</sub> to NO. The most frequently used methods employ either a thermal-conversion principle or a combination of thermal-conversion and catalytic-conversion. In order to meet the sample response-times required, it is usually necessary to employ a high flow-rate convertor. The governing criterion for the convertor is that it must have a minimum conversion efficiency of 90% when converting NO<sub>2</sub> → NO.

(2) Chemiluminescence Reaction Chamber: The chemiluminescence method utilizes the principle that nitric oxide (NO) reacts with ozone (O<sub>3</sub>) to give nitrogen dioxide (NO<sub>2</sub>) and oxygen (O<sub>2</sub>). Approximately 10 percent of the NO<sub>2</sub> is electronically excited. The transition of excited NO<sub>2</sub> to the ground state yields a light emission (600-2600 nanometer region at low pressures). The detectable



region of this emission depends on the PM-tube/optical filter being used in the detector. The intensity of this emission is proportional to the mass flow rate of NO into the reactor. The light emission can be measured utilizing a photomultiplier tube and associated electronics.

B. Analyzer specifications: Specifications for the oxides of nitrogen analysis system are:

Response time (pneumatic)--15 percent of full-scale in 1.5 seconds or less.

Response time (electrical)--95 percent of full-scale in 0.5 seconds or less.

Noise--Less than 1 percent of full-scale.

Repeatability-- $\pm 1$  percent of full-scale.

Zero drift--Less than  $\pm 1$  percent of full-scale in 2 hours.

Span drift--Less than  $\pm 1$  percent of full-scale in 2 hours.

Linearity--Linear to within  $\pm 2$  percent of full-scale on all ranges.

C. System optimization:

(1) Follow manufacturer's instructions for instrument start-up and basic operating adjustments.

(2) NO<sub>2</sub> → NO Converter Check: The apparatus described and illustrated in Figure IV-1 is to be used to determine the conversion efficiency of devices that convert NO<sub>x</sub> to NO. The following procedure is to be used for determining the values to be used in Equation IV-1.

(a) Attach the NO/N<sub>2</sub> supply (150-250 ppm) at C2, the O<sub>2</sub> supply at C1 and the analyzer inlet connection to the efficiency detector at C3. If lower concentrations of NO are used, air may be used in place of O<sub>2</sub> to facilitate better control of the NO<sub>2</sub> generated during step (d).

(b) With the efficiency detector variac off, place the NO<sub>x</sub> converter in bypass mode and close valve V3. Open valve NV2 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.

(c) Open valve V3 (on/off flow control solenoid valve for  $O_2$ ) and adjust valve MV1 ( $O_2$  supply metering valve) to blend enough  $O_2$  to lower the NO concentration (b) about 10 percent. Record this concentration.

(d) Turn on the ozonator and increase its supply voltage until the NO concentration of (c) is reduced to about 20 percent of (b).  $NO_2$  is now being formed from the NO +  $O_3$  reaction. There must always be at least 10 percent unreacted NO at this point. Record this concentration.

(e) When a stable reading has been obtained from (d), place the NOx converter in the convert mode. The analyzer will now indicate the total NOx concentration. Record this concentration.

(f) 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 NOx concentration of the dilute NO span gas used at step (c). Record this concentration.

(g) Close valve V3. The NO concentration should be equal to or greater than the reading of (b) indicating whether the NO contains any  $NO_2$ . Calculate the efficiency of the NOx converter by substituting the concentrations obtained during the test into Equation (IV-1).

$$(IV-1) \% \text{ Eff.} = \frac{[(e) - (f)]}{1 + [(c) - (d)]} \times 100\%$$

The efficiency of the converter should be greater than 90 percent. Adjusting the converter temperature may be needed to maximize the efficiency. Although steps (b) and (g) are not used in the calculations, their values should be recorded to complete the data set for the test sequence. This procedure does not depend on the amount of  $NO_2$  in the span gas nor the equivalence of flows in the by-pass and converter modes. However, to be consistent with good operating practice, flows should be nominally the same, and the  $NO_2$  concentration should be less than 5% of the NOx span concentration. Efficiency checks shall be made weekly.

(h) If the convertor does not meet the conversion-efficiency specifications, repair or replace the unit.

(3) Carbon Dioxide (CO<sub>2</sub>) and carbon monoxide interference check:

- (a) Calibrate the NO<sub>x</sub> analyzer on the lowest anticipated range that may be used during testing.
- (b) Introduce (separately) blends of CO<sub>2</sub>/NO<sub>x</sub> and CO/NO<sub>x</sub> (diluent N<sub>2</sub>) to the analysis system. The CO<sub>2</sub> and CO concentrations should be approximately equal to the highest concentration that may be measured during testing. The NO<sub>x</sub> concentration should be similar to the concentration used in step a). Record the response.
- (c) Recheck calibration. If it has shifted, recalibrate and rerun the interference test.
- (d) The difference between the NO<sub>x</sub> response with the interference gases and the calculated NO<sub>x</sub> response must not be greater than  $\pm 2$  percent. The calculated response is based on the calibration curve (Step (c)) and the interference-bottle NO<sub>x</sub> concentration.
- (e) The interference from CO<sub>2</sub> and CO in this checking procedure must be less than 2 percent.

(4) Linearity:

- (a) With the operating parameters adjusted to meet the convertor efficiency check and the interference checks, the instrument linearity shall be checked for the ranges of analysis using NO in N<sub>2</sub> at nominal concentrations of 30, 60, and 90 percent of full-scale of each range. The deviation of a best-fit curve from a least-squares best-fit straight line should not exceed 2 percent of the value at any point. If this specification is met, concentration values may be calculated by use of a single calibration factor. If the deviation exceeds 2 percent at any point, concentration values shall be calculated from a calibration curve prepared during this alignment procedure (IV C (4)).
- (b) The operating parameters are defined as "optimized" at this point.

V. Humidity Calculations:

- A. The specific humidity (H) is defined by equation (V-1).

$$(V-1) H = \frac{K P_v}{\text{BARO} - P_v}$$

where

BARO = barometric pressure (Pa)

Pv = partial pressure of water vapor (Pa)

$$K = \frac{\frac{(18.01534 \text{ LB. of H}_2\text{O})}{\text{LB. Mole}}}{\frac{(18.01534 \text{ gm of H}_2\text{O})}{\text{gm Mole}}} = .6219$$

$$\frac{(28.967 \text{ LB. of Dry Air})}{\text{LB. Mole}} \quad \frac{(28.967 \text{ gm of Dry Air})}{\text{gm Mole}}$$

$$\text{units of H} = \frac{\text{LB. of H}_2\text{O}}{\text{LB. of Dry Air}} = \frac{\text{gm of H}_2\text{O}}{\text{gm of Dry Air}}$$

B. The partial pressure of water vapor may be determined in two manners:

(1) A dew point device may be used. In that case:

Pv = P<sub>DP</sub> = saturation vapor pressure of water at the Dew-Point temperature, (Pa)

(2) A wet-bulb, dry-bulb method may be used. In that case "Ferrel's equation" (eq. (V-2)) is used.

$$(V-2) P_v = P_{WB} - (3.67)(10)^{-4} (\text{BARO})(t_{db} - t_{wb}) \frac{[t_{wb} + 1539]}{1571}$$

P<sub>WB</sub> and (BARO) must have the same units

where

$$\begin{aligned} t_{db} &= \text{Dry bulb temperature } (^{\circ}\text{F}) \\ t_{wb} &= \text{Wet bulb temperature } (^{\circ}\text{F}) \end{aligned}$$

C. The saturated vapor pressure of water at the wet-bulb temperature (P<sub>WB</sub>) is defined by equation (V-3) (Ref. Wexler and Greenspan, equation (23), National Bureau of Standards).

$$(V-3) P_{WB} = (e) \left[ B \ln T_{WB} + \sum_{i=0}^9 F_i T_{WB}^{i-2} \right]$$

where

$$\begin{aligned} P_{WB} &= \text{is in Pascals (Pa)} \\ T_{WB} &= \text{Wet-bulb temperature } (^{\circ}\text{K}) \end{aligned}$$

$$\begin{aligned}
 B &= -12.150799 \\
 F_0 &= -8.49922(10)^3 \\
 F_1 &= -7.4231865(10)^3 \\
 F_2 &= 96.1635147 \\
 F_3 &= 2.4917646(10)^{-2} \\
 F_4 &= -1.3160119(10)^{-5} \\
 F_5 &= -1.1460454(10)^{-8} \\
 F_6 &= 2.1701289(10)^{-11} \\
 F_7 &= -3.610258(10)^{-15} \\
 F_8 &= 3.8504519(10)^{-18} \\
 F_9 &= -1.4317(10)^{-21}
 \end{aligned}$$

D. The saturate vapor pressure of water at the dry-bulb temperature ( $P_{DB}$ ) is found (if required) by using dry-bulb absolute-temperature ( $^{\circ}K$ ) in equation (V-3).

E. The percent of relative humidity (RH) (if required) is defined by equation (V-4).

$$(V-4) \text{ RH} = \frac{P_v}{P_{DB}} (100)$$

(6) The water-vapor volume-concentration of the engine intake air (Y) is defined by equation (V-5):

$$(V-5) Y = \frac{(H) (M_{air})}{(M_{H_2O})} = \frac{P_v}{BARO - P_v}$$

where

$$M_{air} = \text{Molecular weight of air} = 28.967$$

$$M_{H_2O} = \text{Molecular weight of water} = 18.01534$$

VI. Airflow Measurement: There are many different methods of measuring airflow to Diesel and gasoline engines. The method used should have a turn-down ratio large enough to accurately measure the airflow over the engine operating range during the test. Preferred measurement techniques include measurement by a laminar flow device or a vortex shedding device. Other techniques may be used; however, the overall measurement accuracy should be +1 percent of full-scale value of the measurement device.

(1) Engine System: When measuring inlet air, various engines systems may have additions or subtractions of small quantities of air downstream of the airflow measuring device. An example of air addition would be an air injection system (i.e. air pump). An example of air subtraction would be compressor bleed-air that

is used to operate an intercooler fan on a turbocharged engine. This bleed-air is normally vented to the atmosphere and does not pass through the engine. In determining the (f/a) ratio for the required calculations, use the following conventions:

- (a) Wet to Dry conversion factor ( $K_w$ ): When calculating the (f/a) ratio to be used in determining  $K_w$ , use only the airflow entering the combustion chamber. This may require subtraction of bleed-air, etc. from the measured airflow.
  - (b) Fuel/Air ratio comparison: When comparing measured (f/a) ratio to an emissions calculated (f/a) ratio the, measured airflow (in terms of mass) is the total mass of air entering the exhaust pipe. This may include additions of air mass to the exhaust pipe by an air injection system.
- (2) Corrections to the measured air mass-flow-rate: When an engine system incorporates devices that add or subtract air mass as determined by VI (1), determine the air mass from these devices by one of the following methods:
- (a) Measure the air mass-flow from the device during each operating mode.
  - (b) Determine that the air mass-flow for each mode from the device is typical for many system applications. Then the device flow-rate for each mode may be generally applied.
  - (c) Under certain circumstances, such as turbomachinery, theoretical calculations that predict the device mass flow-rate during each mode may be used.
- (3) Gasoline fueled engine systems: When measuring air flow-rate of a gasoline engine, special care must be taken in the areas of flow distribution, velocity profiles, and pressure drop to the engine system:
- (a) Flow distribution: The air-cleaner is considered part of the engine system. Flow distribution should be considered as flow distribution to the air cleaner. A plenum chamber of sufficient volume is recommended to insure uniform distribution to the engine.
  - (b) Velocity profile: The velocity profile is considered the velocity profile to the air cleaner. The shape of the plenum chamber and the entrance to the plenum chamber in-

fluence the velocity distribution. The desired condition is a uniform velocity - profile with a velocity between 3.3 to 13.2 metres per second (10 to 40 feet per second delivering air to the air cleaner.

(c) Pressure drop: During the measurement process of air flow, the velocity at the point of measurement is usually quite high, i.e. as high as 61 metres/sec (200 ft/sec). In order to slow this velocity down to the desired velocity range in the plenum chamber without incurring additional pressure-losses, it is recommended that a diffuser be used between the air-flow measurement device and the plenum chamber. In any case, the pressure drop (from atmospheric pressure) at the inlet to the air cleaner should not be more than 1.74 kPa (7.0 in H<sub>2</sub>O).

(d) Vents: Devices like PCV valves that vent to the air cleaner, should continue to be vented to the air cleaner. Devices that vent to the atmosphere as some carburetor float vents, governors, etc. should vent to the plenum chamber.

(e) Hot air: Engine inlet air temperature: Due to the preconditioning schedule, ambient soak, and subsequent warm-up idle, the first test-sequence should not be considered a cold test-sequence. Therefore, considering current under-hood-temperatures on a 20°C (68°F) to 30°C (86°F) day, devices that provide hot air to the carburetor are defined as non-functional during the test sequence. Use the following convention in determining the inlet air temperature to the engine:

(A) Ducted Ambient-Air: On engines that use ducted ambient-air to the carburetor, the hot-air device should be non-functional during the test sequence. The engine should induct ambient air at 20°C (68°F) to 30°C (86°F).

(B) Under-Hood Air: On engines that induct air under the hood, the hot air device (if used) will be non-functional during the test sequence. The engine should induct air at a typical under hood temperature that would occur on a 20°C (68°F) to 30°C (86°F) day. The manufacturer should specify and substantiate the under hood intake air temperature.