

produce accurate results, exact conformance with the drawing is not required. Additional components such as instruments, valves, solenoids, pumps and switches may be used to provide additional information and coordinate the functions of the component systems. Other components such as snubbers, which are not needed to maintain accuracy in some systems, may be excluded if their exclusion is based on good engineering judgement.

(b) *Major component description.* The analytical system, Figure 4 in Appendix B of this subpart, consists of a flame ionization detector (FID) or a heated flame ionization detector (HFID) for the measurement of hydrocarbons, nondispersive infrared analyzers (NDIR) for the measurement of carbon monoxide and carbon dioxide, and a chemiluminescence detector (CLD) (or heated CLD (HCLD)) for the measurement of oxides of nitrogen. The exhaust gas analytical system shall conform to the following requirements:

(1) The CLD (or HCLD) requires that the nitrogen dioxide present in the sample be converted to nitric oxide before analysis. Other types of analyzers may be used if shown to yield equivalent results and if approved in advance by the Administrator.

(2) If CO instruments are used which are essentially free of CO₂ and water vapor interference, the use of the conditioning column may be deleted. (See §§ 91.317 and 91.320.)

(3) A CO instrument will be considered to be essentially free of CO₂ and water vapor interference if its response to a mixture of three percent CO₂ in N₂, which has been bubbled through water at room temperature, produces an equivalent CO response, as measured on the most sensitive CO range, which is less than one percent of full scale CO concentration on ranges above 300 ppm full scale or less than 3 ppm on ranges below 300 ppm full scale. (See § 91.317.)

(c) *Alternate analytical systems.* Analysis systems meeting the specifications and requirements of this subpart for dilute sampling may be used upon approval of the Administrator.

(d) *Other analyzers and equipment.* Other types of analyzers and equipment may be used if shown to yield

equivalent results and if approved in advance by the Administrator.

§ 91.424 Dilute sampling procedure—CVS calibration.

(a) The CVS is calibrated using an accurate flowmeter and restrictor valve. (1) The flowmeter calibration shall be traceable to the National Institute for Standards and Testing (NIST), and will serve as the reference value (NIST “true” value) for the CVS calibration.)

NOTE: In no case should an upstream screen or other restriction which can affect the flow be used ahead of the flowmeter unless calibrated throughout the flow range with such a device.)

(2) The CVS calibration procedures are designed for use of a “metering venturi” type flowmeter. Large radius or American Society of Mechanical Engineers (ASME) flow nozzles are considered equivalent if traceable to NIST measurements. Other measurement systems may be used if shown to be equivalent under the test conditions in this section and traceable to NIST measurements.

(3) Measurements of the various flowmeter parameters are recorded and related to flow through the CVS.

(4) Procedures used by EPA for both PDP-CVS and CFV-CVS are outlined below. Other procedures yielding equivalent results may be used if approved in advance by the Administrator.

(b) After the calibration curve has been obtained, verification of the entire system may be performed by injecting a known mass of gas into the system and comparing the mass indicated by the system to the true mass injected. An indicated error does not necessarily mean that the calibration is wrong, since other factors can influence the accuracy of the system (e.g., analyzer calibration, leaks, or HC hangup). A verification procedure is found in paragraph (e) of this section.

(c) *PDP-CVS calibration.* (1) The following calibration procedure outlines the equipment, the test configuration, and the various parameters which must be measured to establish the flow rate of the CVS pump.

(i) All the parameters related to the pump are simultaneously measured with the parameters related to a flowmeter which is connected in series with the pump.

(ii) The calculated flow rate, in cm³/s, (at pump inlet absolute pressure and temperature) can then be plotted versus a correlation function which is the value of a specific combination of pump parameters.

(iii) The linear equation which relates the pump flow and the correlation function is then determined.

(iv) In the event that a CVS has a multiple speed drive, a calibration for each range used must be performed.

(2) This calibration procedure is based on the measurement of the absolute values of the pump and flowmeter parameters that relate the flow rate at each point. Two conditions must be maintained to assure the accuracy and integrity of the calibration curve:

(i) The temperature stability must be maintained during calibration. (Flowmeters are sensitive to inlet temperature oscillations; this can cause the

data points to be scattered. Gradual changes in temperature are acceptable as long as they occur over a period of several minutes.)

(ii) All connections and ducting between the flowmeter and the CVS pump must be absolutely void of leakage.

(3) During an exhaust emission test the measurement of these same pump parameters enables the user to calculate the flow rate from the calibration equation.

(4) Connect a system as shown in Figure 5 in appendix B of this subpart. Although particular types of equipment are shown, other configurations that yield equivalent results may be used if approved in advance by the Administrator. For the system indicated, the following measurements and accuracies are required:

CALIBRATION DATA MEASUREMENTS

Parameter	Symbol	Units	Sensor-readout tolerances
Barometric pressure (corrected)	P _B	kPa	±0.34 kPa
Ambient temperature	T _{EH}	°C	±0.28 °C
Air temperature into metering venturi ...	T _{EH}	°C	±1.11 °C
Pressure drop between the inlet and throat of metering venturi.	P _{ED}	kPa	±0.012 kPa
Air flow	Q _s	m ³ /min.	±0.5 percent of NIST value
Air temperature at CVS pump inlet	P _{TI}	°C	±1.11 °C
Pressure depression at CVS pump inlet.	P _{PI}	kPa	±0.055 kPa
Pressure head at CVS pump outlet	P _{PO}	kPa	±0.055 kPa
Air temperature at CVS pump outlet (optional).	P _{TO}	°C	1.11 °C
Pump revolutions during test period	N	Revs	±1 Rev.
Elapsed time for test period	t	s	±0.5 s.

(5) After the system has been connected as shown in Figure 5 of appendix B of this subpart, set the variable restrictor in the wide open position and run the CVS pump for 20 minutes. Record the calibration data.

(6) Reset the restrictor valve to a more restricted condition in an increment of pump inlet depression that will yield a minimum of six data points for the total calibration. Allow the system to stabilize for 3 minutes and repeat the data acquisition.

(7) Data analysis:

(i) The air flow rate, Q_s, at each test point is calculated in standard cubic feet per minute 20 °C, 101.3 kPa from the flowmeter data using the manufacturer's prescribed method.

(ii) The air flow rate is then converted to pump flow, V_o, in cubic meter per revolution at absolute pump inlet temperature and pressure:

$$V_o = \frac{Q_s}{n} \times \frac{T_p}{293} \times \frac{101.3\text{kPa}}{P_p}$$

Where:

- V_o=Pump flow, m³/rev at T_p, P_p.
- Q_s=Meter air flow rate in standard cubic meters per minute, standard conditions are 20 °C, 101.3 kPa.
- n=Pump speed in revolutions per minute.
- T_p=Pump inlet temperature in Kelvin, =P_{TI}+273 [°K].
- P_p=Absolute pump inlet pressure, kPa. =P_p - P_{PI}
- Where:
- P_p=barometric pressure, kPa.

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P_{PI} =Pump inlet depression, kPa.

(iii) The correlation function at each test point is then calculated from the calibration data:

$$X_o = \frac{1}{n} \sqrt{\left(\frac{\Delta p}{P_e}\right)}$$

Where:

X_o =correlation function.
 ΔP = The pressure differential from pump inlet to pump outlet, kPa.

= $P_E - P_P$.
 P_E =Absolute pump outlet pressure, [kPa]
 = $P_B + P_{PO}$

Where:
 P_{PO} =Pressure head at pump outlet, kPa (inches fluid).

(iv) A linear least squares fit is performed to generate the calibration equation which has the form:

$$V_o = D_o - M(X_o)$$

D_o and M are the intercept and slope constants, respectively, describing the regression line.

(8) A CVS system that has multiple speeds should be calibrated on each speed used. The calibration curves generated for the ranges will be approximately parallel and the intercept values, D_o , will increase as the pump flow range decreases.

(9) If the calibration has been performed carefully, the calculated values

from the equation will be within ± 0.50 percent of the measured value of V_o . Values of M will vary from one pump to another, but values of D_o for pumps of the same make, model and range should agree within \pm three percent of each other. Calibrations should be performed at pump start-up and after major maintenance to assure the stability of the pump slip rate. Analysis of mass injection data will also reflect pump slip stability.

(d) CFV-CVS calibration. (1) Calibration of the CFV is based upon the flow equation for a critical venturi.

(i) Gas flow is a function of inlet pressure and temperature:

$$Q_s = \frac{K_v P}{\sqrt{T_K}}$$

Q_s =flow rate [$m^3/min.$].
 K_v =calibration coefficient.
 P =absolute pressure [kPa].
 T_K =absolute temperature [$^{\circ}K$].

(ii) The calibration procedure described in paragraph (d)(3) of this section establishes the value of the calibration coefficient at measured values of pressure, temperature and air flow.

(2) The manufacturer's recommended procedure shall be followed for calibrating electronic portions of the CFV.

(3) Measurements necessary for flow calibration are as follows:

CALIBRATION DATA MEASUREMENTS

Parameter	Symbol	Units	Tolerances
Barometric Pressure (corrected)	P_B	kPa	± 0.34 kPa
Air Temperature into flow meter	T_{EI}	$^{\circ}C$	± 0.28 $^{\circ}C$
Pressure drop between the inlet and throat of metering venturi.	P_{ED}	kPa	± 0.012 kPa
Air flow	Q_s	$m^3/min.$	± 0.5 percent of NIST value
CVS inlet depression	P_{PI}	kPa	± 0.055 kPa
Pressure head at CVS pump outlet	P_{PO}	kPa	± 0.055 kPa
Temperature at venturi inlet	T_V	$^{\circ}C$	± 2.22 $^{\circ}C$

(4) Set up equipment as shown in Figure 6 in appendix B of this subpart and eliminate leaks. (Leaks between the flow measuring devices and the critical flow venturi will seriously affect the accuracy of the calibration.)

(5) Set the variable flow restrictor to the open position, start the blower, and allow the system to stabilize. Record data from all instruments.

(6) Vary the flow restrictor and make at least eight readings across the critical flow range of the venturi.

(7) Data analysis. The data recorded during the calibration are to be used in the following calculations:

(i) The air flow rate (designated as Q_s) at each test point is calculated in standard cubic feet per minute from

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the flow meter data using the manufacturer's prescribed method.

(ii) Calculate values of the calibration coefficient for each test point:

$$K_v = \frac{Q_s \sqrt{T_v}}{P_v}$$

Q_s=Flow rate in standard cubic meter per minute, at the standard conditions of 20 °C, 101.3 kPa.

T_v=Temperature at venturi inlet, °K.

P_v=Pressure at venturi inlet, kPa

=P_B - P_{Pi}

Where:

P_{Pi} = Venturi inlet pressure depression, kPa.

(iii) Plot K_v as a function of venturi inlet pressure. For choked flow, K_v will have a relatively constant value. As pressure decreases (vacuum increases), the venturi becomes unchoked and K_v decreases. (See Figure 7 in appendix B of this subpart)

(iv) For a minimum of eight points in the critical region calculate an average K_v and the standard deviation.

(v) If the standard deviation exceeds 0.3 percent of the average K_v, take corrective action.

(e) CVS system verification. The following "gravimetric" technique can be used to verify that the CVS and analytical instruments can accurately measure a mass of gas that has been injected into the system. (Verification can also be accomplished by constant flow metering using critical flow orifice devices.)

(1) Obtain a small cylinder that has been charged with 99.5 percent or greater propane or carbon monoxide gas (CAUTION—carbon monoxide is poisonous).

(2) Determine a reference cylinder weight to the nearest 0.01 grams.

(3) Operate the CVS in the normal manner and release a quantity of pure propane into the system during the sampling period (approximately five minutes).

(4) The calculations are performed in the normal way except in the case of propane. The density of propane (0.6109 kg/m³carbon atom is used in place of the density of exhaust hydrocarbons.

(5) The gravimetric mass is subtracted from the CVS measured mass and then divided by the gravimetric

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mass to determine the percent accuracy of the system.

(6) Good engineering practice requires that the cause for any discrepancy greater than ±2 percent must be found and corrected.

§91.425 CVS calibration frequency.

Calibrate the CVS positive displacement pump or critical flow venturi following initial installation, major maintenance or as necessary when indicated by the CVS system verification (described in §91.424(e)).

§91.426 Dilute emission sampling calculations.

(a) The final reported emission test results must be computed by use of the following formula:

$$A_{wm} = \frac{\sum(W_i \times f_i)}{\sum(P_i \times f_i)} \times K_{Hi}$$

Where:

A_{wm}=Weighted mass emission level (HC, CO, CO₂, or NO_x) for a test [g/kW-hr].

W_i=Average mass flow rate of an emission from a test engine during mode i [g/hr].

WF_i = Weighting factor for each mode i as defined in §91.410(a).

P_i = Gross average power generated during mode i [kW] calculated from the following equation (power for the idle mode shall always be zero for this calculation):

$$P_i = \frac{2 \Pi}{60,000} \times \text{speed} \times \text{torque}$$

speed = average engine speed measured during mode i [rev./minute]

torque = average engine torque measured during mode i [N-m]

K_{Hi} = Humidity correction factor for mode i.

This correction factor only affects calculations for NO_x and is equal to one for all other emissions. K_{Hi} is also equal to one for all two-stroke engines.

(b) The mass flow rate (W_i) of an emission for mode i is determined from the following equation:

$$W_i = Q_i \times D \times \left(C_{Di} - C_{Bi} \times \left(1 - \frac{1}{DF_i} \right) \right)$$

Where:

Q_i = Volumetric flow rate of the dilute exhaust through the CVS at standard conditions [m³/hr at STP].