(f) For diesel fuel testing only. The carbon monoxide analyzer shall be calibrated at least every two months or after any maintenance which could alter calibration.

[59 FR 48530, Sept. 21, 1994, as amended at 60 FR 34371, June 30, 1995; 62 FR 47126, Sept. 5, 1997]

§ 86.1318–84 Engine dynamometer system calibrations.

(a) The engine flywheel torque and engine speed measurement transducers shall be calibrated at least once each month with the calibration equipment described in § 86.1308–84.

(b) The engine flywheel torque feedback signals to the cycle verification equipment shall be electronically checked before each test, and adjusted as necessary.

(c) Other engine dynamometer system calibrations shall be performed as dictated by good engineering practice.

(d) When calibrating the engine flywheel torque transducer, any lever arm used to convert a weight or a force through a distance into a torque shall be used in a horizontal position (±5 degrees).

(e) Calibrated resistors may not be used for engine flywheel torque transducer calibration, but may be used to span the transducer prior to engine testing.

§ 86.1319–90 CVS calibration.

(a) The CVS is calibrated using an accurate flowmeter and restrictor valve. The flowmeter calibration shall be traceable to the NBS, and will serve as the reference value (NBS ''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.) The CVS calibration procedures are designed for use of a ''metering venturi'' type flowmeter. Large radius or ASME flow nozzles are considered equivalent if traceable to NBS measurements. Other measurement systems may be used if shown to be equivalent under the test conditions in this section and traceable to NBS measurements. Measurements of the various flowmeter parameters are recorded and related to flow through the CVS. 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 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, ft^3/min, (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 N84–6. 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	in. Hg (kPa)	±0.10 in. Hg (±0.340 kPa).
Ambient temperature	T_A	°F (°C)	±0.5 °F (±0.28 °C).
Air temperature into metering venturi	ETI	°F (°C)	±2.0 °F (±1.1 °C).
Pressure drop between the inlet and throat of metering venturi	EDP	in. H_20 (kPa)	±0.05 in H_2O (±0.012 kPa).
Air flow	Q_S	ft^3/min (m^3/min)	±0.5% of NBS "true" value.
Air temperature at CVS pump inlet	PTI	°F (°C)	±2.0 °F (±1.1 °C).
Pressure depression at CVS pump inlet	PPI	in. Fluid (kPa)	±0.13 in. Fluid (±0.055 kPa).
Specific gravity of manometer fluid (1.75 oil)	Sp.Gr.		.
Pressure head at CVS pump outlet	PPO	in. Fluid (kPa)	±0.13 in. Fluid (±0.055 kPa).
Air temperature at CVS pump outlet (optional)	PTO	°F (°C)	±2.0 °F (±1.1 °C).
Pump revolutions during test period	N	Revs	±1 Rev.
Elapsed time for test period	t	sec.	±0.5 sec.

(5) After the system has been connected as shown in Figure N84–6, 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 (68°, 29.92 in. Hg.) 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 feet per revolution at absolute pump inlet temperature and pressure:

$$V_o = (Q_{s/n}) \times (T_p/528) \times (29.92/P_p)$$

Where:

(A) V_o = Pump flow, ft^3/rev (m^3/rev) at T_p, P_p.

(B) Q_s = Meter air flow rate in standard cubic feet per minute, standard conditions are 68 °F, 29.92 in. Hg (20 °C, 101.3 kPa).

(C) n = Pump speed in revolutions per minute.

(D) T_p = Pump inlet temperature °R(°K) = PTI + 460 (°R), or = PTI + 273 (°K).

(E) P_p = Absolute pump inlet pressure, in. Hg. (kPa)

$= P_B - PPI(Sp.Gr./13.5955)$ and

$= PB - PPI$ for SI units.

Where:

(F) P_B = barometric pressure, in. Hg. (kPa).

(G) PPI = Pump inlet depression, in. fluid (kPa).

(H) Sp.Gr. = Specific gravity of manometer fluid.

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

$$X_o = \frac{1}{n}\sqrt{\frac{\Delta P}{P_e}}$$

Where:

(A) X_o = correlation function.

(B) D_p = The pressure differential from pump inlet to pump outlet, in. Hg. (kPa).

= P_{e-Pp}.

(C) P_e = Absolute pump outlet pressure, in. Hg. (kPa)

= P_B + PPO (Sp.Gr./13.5955) and

= P_B + PPO *for SI units.*

Where:

(D) PPO = Pressure head at pump outlet, in. fluid (kPa).

(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 ±3 percent of each other. Particulate influx over time will cause the pump slip to decrease, as reflected by lower values for M. 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 calibration.* (1) Calibration of the CFV is based upon the flow equation for a critical venturi. Gas flow is a function of inlet pressure and temperature:

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

Where:

(i) Q_s = flow.

(ii) K_v = calibration coefficient.

(iii) P = absolute pressure.

(iv) T = absolute temperature.

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	Sensor-readout tolerances
Barometric pressure (corrected)	P_b	in Hg (kPa)	±.01 in Hg (±.034 kPa).
Air temperature, into flowmeter	ETI	°F (°C)	±0.5 °F (±.28 °C).
Pressure drop between the inlet and throat of metering venturi.	EDP	Inches H_2O (kPa)	±0.05 in H_2O (±.012 kPa).
Air flow	Q_s	Ft^3/min. (m^3/min)	±.5 % of NBS "true" value.
CFV inlet depression	PPI	Inches fluid (kPa)	±.13 in fluid (±.055 kPa).
CFV outlet pressure	PPO	Inches Hg (kPa)	±.05 in Hg (±.17 kPa) [1].
Temperature at venturi inlet	T_v	°F (°C)	±4.0 °F (±2.22 °C).
Specific gravity of manometer fluid (1.75 oil)	Sp. Gr		

[1] Requirement begins August 20, 2001.

(4) Set up equipment as shown in Figure N84–7 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, Q_s, at each test point is calculated in standard cubic feet per minute from the flow meter data using the manufacturer's prescribed method.

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

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

Where:

(A) Q_s = Flow rate in standard cubic feet per minute, at the standard conditions of 68 °F, 29.92 in Hg (20 °C, 101.3 kPa).

(B) T_v = Temperature at venturi inlet, °R(°K).

(C) P_v = Pressure at venturi inlet, in. Hg. (kPA)

= P_B − PPI (Sp.GR./13.5955), and

= P_B − PPI *for SI units.*

Where:

(D) PPI = Venturi inlet pressure depression, in. fluid (kPa).

(E) Sp.Gr. = Specific gravity of manometer fluid.

(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 N84–8.)

(iv) For a minimum of 8 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.

(8) Calculation of a parameter for monitoring sonic flow in the CFV during exhaust emissions tests:

(i) *Option 1.* (A) CFV pressure ratio. Based upon the calibration data selected to meet the criteria for paragraphs (d)(7)(iv) and (v) of this section, in which K_v is constant, select the data values associated with the calibration point with the lowest absolute venturi inlet pressure. With this set of calibration data, calculated the following CFV pressure ratio limit, $Pr_{ratio\text{-}lim}$:

$$Pr_{ratio\text{-}lim} = \frac{P_{out\text{-}cal}}{P_{in\text{-}cal}}$$

Where:

$P_{in\text{-}cal}$ = Venturi inlet pressure (PPI in absolute pressure units), and

$P_{out\text{-}cal}$ = Venturi outlet pressure (PPO in absolute pressure units), measured at the exit of the venturi diffuser outlet.

(B) The venturi pressure ratio ($Pr_{ratio\text{-}i}$) during all emissions tests must be less than, or equal to, the calibration pressure ratio limit ($Pr_{ratio\text{-}lim}$) derived from the CFV calibration data, such that:

$$\frac{P_{out\text{-}i}}{P_{in\text{-}i}} = Pr_{ratio\text{-}i} \le Pr_{ratio\text{-}lim}$$

Where:

$P_{in\text{-}i}$ and $P_{out\text{-}i}$ are the venturi inlet and outlet pressures, in absolute pressure units, at each i-th interval during the emissions test.

(ii) *Option 2.* Other methods: With prior Administrator approval, any other method may be used that assure that the venturi operates at sonic conditions during emissions tests, provided the method is based upon sound engineering principles.

(e) *SSV calibration.* (1) The calibration of the SSV located in the tunnel shall be conducted in a similar manner as the CFV or PDP calibration. Gas flow within the SSV is a function of inlet pressure, P_1, the inlet temperature, T_1, and the pressure drop between the throat and the inlet, DP. Note that the following procedure is consistent with SAE J244. The calibration procedure described in paragraph (e)(3) of this section establishes the values of the coefficients at measured values of pressure, temperature and airflow.

(i) The flow rate for a subsonic venturi is calculated as a volumetric flow rate (Q_s) or a mass flow rate (Q_m) as follows: or

$$Q_s = \frac{Q_m}{\rho_s} = \frac{K_q}{\rho_s}\left(\frac{C_d * Y * d^2}{\sqrt{1-\beta^4}}\right)\sqrt{\rho_i * \Delta P}$$

$$Q_m = K_q * C_d * Y * d^2 \left(\frac{\rho_i * \Delta P}{1-\beta^4}\right)^{1/2}$$

Where:

K_q = 0.0021074 (SI units).
Q_s = Air Volume Flow, SCFM (m^3/min).
Q_m = Air Mass Flow, lbm/min (kg/min).
ρ_s = Density at Standard Conditions, lbm/ft^3 (kg/m^3) as specified in paragraph (e)(1)(v) of this section.
ρ_s = Density at inlet conditions, lbm/ft^3 (kg/m^3), as specified in paragraph (e)(1)(iii) of this section.
C_d = Coefficient of Discharge = Actual Air Flow/Theoretical Air Flow.
Y = Expansion factor, as specified in paragraph (e)(1)(ii) of this section.
d = Throat diameter, inch (mm).
β = Ratio of venturi throat diameter to approach pipe diameter.
ΔP = Pressure drop between inlet and throat, in. H_2O (kPa).

(ii) The expansion factor (Y) is calculated as follows:

$$Y = \left[r^{\frac{2}{k}} \left(\frac{k}{k-1} \right) \left(\frac{1 - r^{\left(\frac{k-1}{k}\right)}}{1-r} \right) \left(\frac{1-\beta^4}{1-\beta^4 * r^{\frac{2}{k}}} \right) \right]^{\frac{1}{2}}$$

Where:

$$r = 1 - \frac{\Delta P}{P_{abs}}$$

$$\beta = \frac{d}{D}$$

$$d = \text{Throat diam., in (mm)}$$

$$D = \text{Inlet Pipe diam., in (mm)}$$

$$k = \text{Ratio of Specific Heat (1.40 for Air)}$$

(iii) The inlet density (ρ1) is calculated as follows:

$$\rho_1 = \frac{P_{abs}}{R_{mix} * T_{abs}}$$

Where:
$P_{abs} = P_1 + P_B$
$T_{abs} = T_1 + 2731$
$R_{mix} = R_u$/|MW_{mix}
R_u = 8.3144 kJ/kg-mole-K
MW_{mix} = the molecular weight of the mix, as calculated in paragraph (e)(1)(iv) of this section.

(iv) The molecular weight of the mix, is calculated as follows:

$$MW_{mix} = \frac{MW_{AIR} * \left(P_{abs} - P_V\right) + MW_{H_2O} * P_v}{P_{abs}}$$

Where:

P_V = Vapor pressure, in Hg (kPa)
MW_{AIR} = 28.964 kg/kg-mole
MW_{H_2O} = 18.015 kg/kg-mole

(v) The density at standard conditions of 101.33 kPa and 20 °C is calculated as follows:

$$\rho_s = \frac{101.33}{\frac{8.3144}{28.964} * 293.15} = 1.2041 \text{ kg/m}^3$$

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

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

CALIBRATION DATA MEASUREMENT

Parameter	Sym	Units	Tolerance
(i) Barometric pressure (corrected to 32 °F)	P_B	in. Hg (kPa)	±.01in. Hg (±.034kPa)
(ii) Air temperature, into calibration venturi	ETI	°F (°C)	±.5 °F (.28 °C)
(iii) Pressure drop between the inlet and throat of calibration venturi (corrected to 68 °F)..	EDP	in. H_2O (kPA)	±.05 in. H_2O (±.012kPa)
(iv) Air Flow	Q_S	Std ft³/min (m³/min).	±5% of NIST "true" value
(v) SSV inlet depression	P_I	in. H_2O (kPa)	±.23 in. H_2O (±.057kPa)
(vi) Pressure drop between the inlet and throat of SSV	DP	in. H_2O (kPa)	±.05 in. H_2O (±.012kPa)
(vii) Water vapor pressure of inlet air	P_V	in. Hg (kPa)	±.10 in. Hg (±.34kPa)
(vii) Temperature at SSV inlet	T_I	°F (°C)	±4.0 °F (2.2 °C)

(4) Set up equipment similar to CFV or PDP calibration except the variable flow restrictor valve can be deleted or set in the open position, and the pressure drop reading device must be added. The calibration test must be conducted with the test subsonic venturi in place in its permanent position. Any subsequent changes in upstream or downstream configuration could cause a shift in calibration. Leaks between the calibration metering device and the SSV must be eliminated.

(5) Adjust the variable flow blower or restrictor valve to its maximum in-use flow rate. Allow the system to stabilize and record data from all instruments. Be sure to avoid choke condition.

(6) Vary the flow through a minimum of eight steps covering the intended in-use operating range of the SSV.

(7) Data analyses. If the calibration venturi is used at the tunnel inlet (free standing), then assume a value of β=0. If the SSV installed in the CVS tunnel, use the actual inside tunnel diameter and the throat diameter to compute β.

(i) Assume an initial value for Cd = 0.98 to calculate Q_m for the calculation of Reynolds number, Re,:

$$\mathrm{Re} = \frac{6.667\mathrm{E}4 * Q_m}{\pi * d * \mu}$$

Where: μ = viscosity of air, centipoise

$$\mu = K_\mu * \frac{T_k^{1.5}}{(T_K + 110.4)}$$

$K\mu$=1.458E–3

T_K=(T_I °C+273.16)

(ii) From the initial calibration of the venturi, establish an equation of Cd as a function of Re. The following functional forms should be reviewed, but a power series, least-squares fit polynomial equation may result in the best fit. Many factors involved in the installation of SSV and the operating range of the Reynolds number can affect the functional relationship of the Cd with Re. Calculate Cd based on this initial equation of Re. Compute a final Q_m based on this calculated Cd for both the calibration nozzle and the inline SSV.

(8)(i) Compute the percent difference in air flow between the calibration venturi and the inline SSV. If the difference in percent of point is greater than 1%, compute a new Cd and Re for the in-tunnel venturi as follows:

Cd_{new}=Actual Air Flow/Theoretical Air Flow=Qm_{act} /Qm_{theo}

$$\mathrm{Re}_{new} = \frac{0.8 Qm_{cal}}{\pi * d * \mu}$$

(ii) Qm_{act} is flow measured by the calibration venturi and Qm_{theo} is the theoretical calculated flow based on the in-tunnel SSV conditions with Cd set equal to 1. Re_{new} is based on the calibrated venturi flow, but the in-tunnel SSV properties. Recalculate a new curve fit of Cd_{new} for the inline venturi as a function of Re_{new} following the guidelines in paragraph (e)(7) of this section. Agreement of the fit should be within 1.0% of point. Install the new Cd curve fit in the test cell flow computing device and conduct the propane injection, flow verification test.

(f) *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 pure 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 5 minutes).

(4) Following completion of step (3) above (if methanol injection is required), continue to operate the CVS in the normal manner and release a known quantity of pure methanol (in gaseous form) into the system during the sampling period (approximately five minutes). This step does not need to be performed with each verification, provided that it is performed at least twice annually.

(5) The calculations of § 86.1342 are performed in the normal way except in the case of propane. The density of propane (17.30 g/ft^3/carbon atom (0.6109 kg/m^3/carbon atom)) is used in place of the density of exhaust hydrocarbons. In the case of methanol, the density of 37.71 g/ft^3 (1.332 kg/m^3) is used.

(6) The gravimetric mass is subtracted from the CVS measured mass and then divided by the gravimetric mass to determine the percent accuracy of the system.

(7) The cause for any discrepancy greater than ±2 percent must be found and corrected. (For 1991–1995 calendar years, discrepancies greater than ±2 percent are allowed for the methanol test, provided that they do not exceed ±6 percent.)

(8) The Administrator, upon request, may waive the requirement to comply with ±2 percent methanol recovery tolerance, and instead require compliance with a higher tolerance (not to exceed ±6 percent), provided that:

(i) The Administrator determines that compliance with these specified tolerances is not practically feasible; and

(ii) The manufacturer makes information available to the Administrator which indicates that the calibration tests and their results are consistent with good laboratory practice, and that the results are consistent with the results of calibration testing conducted by the Administrator.

[54 FR 14591, Apr. 11, 1989, as amended at 60 FR 34371, June 30, 1995; 63 FR 24449, May 4, 1998; 65 FR 8279, Feb. 18, 2000; 66 FR 5181, Jan. 18, 2001]

§ 86.1320–90 Gas meter or flow instrumentation calibration; particulate, methanol, and formaldehyde measurement.

(a) Sampling for particulate, methanol and formaldehyde emissions requires the use of gas meters or flow instrumentation to determine flow through the particulate filters, methanol impingers and formaldehyde impingers. These instruments shall receive initial and periodic calibrations as follows:

(1)(i) Install a calibration device in series with the instrument. A critical flow orifice, a bellmouth nozzle, or a laminar flow element or an NBS traceable flow calibration device is required as the standard device.

(ii) The flow system should be checked for leaks between the calibration and sampling meters, including any pumps that may be part of the system, using good engineering practice.

(2) Flow air through the calibration system at the sample flow rate used for particulate, methanol, and formaldehyde testing and at the backpressure which occurs during the sample test.

(3) When the temperature and pressure in the system have stabilized, measure the indicated gas volume over a time period of at least five minutes or until a gas volume of at least ±1 percent accuracy can be determined by the standard device. Record the stabilized air temperature and pressure